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NOTATIONS IN THIS JOURNAL are the following:

* Indicates who will present the paper at the meeting.

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PAPERS PRESENTED AT MEETINGS

THIS CALENDAR lists meetings of the Society which have been approved by the Council at which papers may be presented. Programs of Annual Meetings appear in the *Notices* and on the AMS website; programs for sectional meetings appear on the AMS Web pages in the Meetings & Conferences section, and are electronically archived in the *Notices* section on the AMS website.

MEETING #	DATE	PLACE	ABSTRACT DEADLINE	ABSTRACT ISSUE
1117	March 5–6, 2016	Athens, GA	January 19	Vol 37, No. 2
1118	March 19–20, 2016	Stony Brook, NY	February 2	Vol 37, No. 2
1119	April 9–10, 2016	Salt Lake City, UT	February 16	Vol 37, No. 2
1120	April 16–17, 2016	Fargo, ND	February 23	Vol 37, No. 2
1121	September 24–25, 2016	Brunswick, ME	July 19	Vol 37, No. 3
1122	October 8–9, 2016	Denver, CO	August 16	Vol 37, No. 3
1123	October 28–30, 2016	Minneapolis, MN	August 30	Vol 37, No. 4
1124	November 12–13, 2016	Raleigh, NC	September 13	Vol 37, No. 4
1125	January 4–7, 2017	Atlanta, GA	TBA	Vol 38, No. 1
1126	March 10–12, 2017	Charleston, SC	TBA	TBA
1127	April 1–2, 2017	Bloomington, IN	TBA	TBA
1128	April 22–23, 2017	Pullman, WA	TBA	TBA
1129	May 6–7, 2017	New York, NY	March 21	TBA
1130	July 24–28, 2017	Montréal, Canada	TBA	TBA

SEATTLE, WA, January 6–9, 2016

Abstracts of the 1116th Meeting.

00 ► General

1116-00-46 **Jennifer Chayes***, Microsoft Research, Cambridge, MA. *Network Science: From the Online World to Cancer Genomics.*

Everywhere we turn these days, we find that networks can be used to describe relevant interactions. In the high tech world, we see the Internet, the World Wide Web, mobile phone networks, and a variety of online social networks. In economics, we are increasingly experiencing both the positive and negative effects of a global networked economy. In epidemiology, we find disease spreading over our ever-growing social networks, complicated by mutation of the disease agents. In biomedical research, we are beginning to understand the structure of gene regulatory networks, with the prospect of using this understanding to manage many human diseases. In this talk, I look quite generally at some of the models we are using to describe these networks, processes we are studying on the networks, algorithms we have devised for the networks, and finally, methods we are developing to indirectly infer network structure from measured data. I'll discuss in some detail particular applications to cancer genomics, applying network algorithms to suggest possible drug targets for certain kinds of cancer. (Received September 23, 2015)

1116-00-68 **Natasha Dobrinen*** (`natasha.dobrinen@du.edu`), Department of Mathematics, University of Denver. *Inner topological Ramsey spaces.*

Topological Ramsey spaces are spaces which satisfy an abstract version of the Ellentuck theorem: Every subset with the property of Baire in the abstract Ellentuck topology is Ramsey. The inherent structure of a topological Ramsey spaceprovides strong machinery for use in investigations of its forcing properties, and partition properties and initial Rudin-Keisler and Tukey structures of its associated ultrafilter. This talk will include a selection of forcings which wehave shown actually contain dense subsets which form topological Ramsey spaces, including some creature forcings, and their applications. The proofs that these form topological Ramsey spaces involve proving some new pigeonhole prinicples.

(Received July 10, 2015)

1116-00-209 **Rachel Kuske***, rachel@math.ubc.ca. *Stochastic facilitation and sensitivities in discontinuous dynamics.*

While there have been recent advances for analyzing the complex deterministic behavior of systems with discontinuous dynamics, there are many open questions around understanding and predicting noise-driven and noise-sensitive phenomena in the non-smooth context. Familiar concepts from smooth systems such as escapes, resonances, and bifurcations appear in unexpected forms for non-smooth systems, so that effective analyses typically depend on the creative combination of multiple scales techniques, probabilistic models, and nonlinear methods. The appropriate strategy is often not immediately obvious from the area of application or model type, yet we gain intuition from seemingly unrelated canonical models of biophysics, mechanics, and chemical dynamics. Combining the geometrical perspective with asymptotic approaches in physical and phase space is critical for characterizing the stochastic dynamics, robustness, and sensitivity to noisy fluctuations. Models in biology, engineering, and the environment are discussed. (Received August 14, 2015)

1116-00-298 **Jeremy Tillay*** (jrt5493@gmail.com), **Adela Yang**, **Yilun Chen** and **Xiudi Li**. *Text-Mining and Topic Modeling the Wall Street Journal to Find Market Inefficiencies.*

In this project, we aim to find semi-strong form inefficiencies in the market and delays in stock price changes following the release of publicly available information online. Specifically, we analyze all publicly available articles on the online archives of *The Wall Street Journal*. We make predictions about stock behavior following a day by assuming it will be similar to days when similar news are published online.

In order to analyze text, we implement Natural Language Processing (NLP) to refine our text documents and Latent Semantic Indexing (LSI) to group words into topics and analyze the frequency these topics appear in a given day. Then, we make predictions about the behavior of the stock market under the assumption that its behavior will mimic days when there is a similar frequency distribution of these topics. (Received August 23, 2015)

1116-00-406 **Frank Morgan*** (frank.morgan@williams.edu). *Notices of the American Mathematical Society.*

As incoming Editor of Notices of the AMS, I invite comments, suggestions, and submissions as we plan for:

(1) deep but universally readable and enjoyable articles on the latest mathematics and everything related,

(2) a new place for comments, discussion, and more on our webpage,

(3) a new Graduate Student Section,

(4) an entertaining but pointed new Back Page, including comics and a cartoon caption contest. (Received August 31, 2015)

1116-00-446 **Skip Garibaldi*** (skip@garibaldibros.com). *Opportunities for academics with the Department of Defense.*

There are many opportunities for professors to contribute to the Department of Defense by lending their expertise and judgment on science & technology issues. I will talk about my experiences with two such venues — the Defense Science Study Group and the Air Force Scientific Advisory Board — as well as how you can get involved yourself, what to expect if you do, and what kind of impact you could have. (Received September 02, 2015)

1116-00-818 **Hiromi Yasuda*** (hiromy@uw.edu), 107 Guggenheim hall, University of Washington, Seattle, WA 98195, and **Jinkyu Yang** (jkyang@aa.washington.edu), 311B Guggenheim hall, University of Washington, Seattle, WA 98195. *Nonlinear wave dynamics in origami-based mechanical metamaterials.*

We investigate unique wave propagation in two different types of origami-based mechanical metamaterials; the Tachi-Miura Polyhedron (TMP) and the Kresling pattern. The TMP is a bellows-like origami structure which can be made of rigid panels and hinges. We design a 1D system composed of multiple TMP unit cells whose crease lines are modeled as rotational springs. On the other hand, the Kresling pattern is a cylindrical origami which supports both axial and rotational motions. By replacing all crease lines by truss members, we model the Kresling pattern as a truss structure and design the Kresling-based mechanical metamaterials in the form of vertically stacked architectures. We conduct dynamic analysis on both types of mechanical metamaterials by applying compressive impact to the end of the systems. Our analysis shows that the TMP-based metamateirials are capable of generating rarefaction waves, which are characterized by a leading tensile wave front despite the application of compressive impact. Also, the Kresling-based system shows wave mixing behavior due to the coupling mechanism between axial and rotational motions. These origami structures have great potentials in impact mitigation and energy transportation by leveraging these unique wave propagation properties. (Received September 13, 2015)

1116-00-957 **Genetha Gray***, Talent Intelligence & Analytics, Intel Corporation, Folsom, CA. *What makes a mathematician a data scientist?*

In 2012, the Harvard Business Review named Data Scientist the sexiest job of the 21st century. The article and subsequent studies have called out a shortage of data scientists that will increase over the next 20-30 years. In this talk, I will explore what exactly is meant by the term "data scientist" and describe the aspects of mathematical training that can transform a mathematician into a data scientist in the eyes of corporate employers. I will also note some of the surprising places that mathematicians are currently working as data scientists. Using my own career transition from a mathematician in a High Performance Computing Group to a data scientist in Human Resources, I will cite examples of problems that data scientists study including energy usage and renewables integration, environmental monitoring, market intelligence, and recruiting,hiring and retention practices. (Received September 15, 2015)

1116-00-1049 **Piotr Hajlasz** (hajlasz@pitt.edu), 301 Thackeray Hall, Pittsburgh, PA 15213, and **Xiaodan Zhou*** (xiz78@pitt.edu), 301 Thackeray Hall, Pittsburgh, PA 15213. *Sobolev Homeomorphism on a Sphere Containing An Arbitrary Cantor Set in the image.*

We construct a large class of pathological n-dimensional spheres in $\mathbb{R}^{n+1}$ by showing that for any Cantor set $C \subset \mathbb{R}^{n+1}$ there is a topological embedding $f : \mathbb{S}^n \to \mathbb{R}^{n+1}$ of the Sobolev class $W^{1,n}$ whose image contains the Cantor set C. (Received September 16, 2015)

1116-00-1070 **Jon Fassett*** (fassett@cwu.edu), Department of mathematics, Central Washington University, 400 E. University Way, Ellensburg, WA 98926-7424. *A Forerunner of Fractals in Financial Markets.*

Benoit Mandelbrot introduced multifractal "cartoons" as tool to explain his fractal Brownian motion in multifractal trading time model. These cartoons represent artificial stock price patterns and are generated using an iterative process that is now familiar to a wide audience. In this talk we introduce the work of Ralph Nelson Elliott (1871-1948), a self-described business efficiency expert, who beginning in the 1930's, and while in his 60's, developed a model of financial markets containing many similarities to Mandelbrot's fractal cartoons. (Received September 16, 2015)

1116-00-1080 **Xiaoju Xie*** (sophia.xie@okstate.edu). *Expected number of real zeros of random orthogonal polynomials.*

We study the expected number of real zeros for random linear combinations of orthogonal polynomials. It is well known that Kac polynomials, spanned by monomials with i.i.d. Gaussian coefficients, have only $(2/\pi + o(1)) \log n$ expected real zeros in terms of the degree n. On the other hand, if the basis is given by Legendre (or more generally by Jacobi) polynomials, then random linear combinations have $n/\sqrt{3} + o(n)$ expected real zeros. We prove that the latter asymptotic relation holds universally for a large class of random orthogonal polynomials on the real line, and also give more general local results on the expected number of real zeros. This is a joint work with Doron S. Lubinsky and Igor E. Pritsker. (Received September 16, 2015)

1116-00-1117 **Claude M. Viallet*** (viallet@lpthe.jussieu.fr). *Singularity and algebraic entropy analysis of a delay-differential equation.*

We analyze some algebraic properties of the delay-differential equation $a\ u(t) - b\ \partial_t u(t) = u(t)\ (u(t+1) - u(t-1))$. This equation may be obtained by a symmetry reduction of an integrable lattice equation. It is a slight generalization of the so-called one-dimensional Born-Green-Yvon equation for a hardrod fluid. Even if the original notion of integrability (à la Liouville) is barely applicable to this kind of equations, one would like to call it integrable delay-differential equation. The naming "delay Painlevé equation" was also proposed.

Considering the above equation as an order two recurrence on functional space allows to evaluate its algebraic entropy. Moreover the stabilization of the form of the iterates, in relation to the singularity analysis, gives not only a proof of the validity of the heuristic evaluation of the entropy, but suggests a change of description of the equation, allowing to write a generic form of the solutions in terms of entire functions.

Keywords: Discrete dynamical systems, algebraic entropy. (Received September 17, 2015)

1116-00-1373 **Sharif Ibrahim*** (jmm2016@sharifibrahim.com). *Joint Mathematics: Lessons from a Marijuana License Lottery.*

How do you distribute a limited number of licenses fairly? Washington state faced this question after voters legalized recreational marijuana and decided to assign retail licenses in a lottery. This lottery was performed by the Social & Economic Sciences Research Center at Washington State University with extensive help from the math department. How can you be sure (and, importantly, make others sure) that a lottery is fair, robust, and auditable? When it turns out that some applicants were wrongly disqualified before the original lottery (and you find out after the lottery), can you make it right without advantaging some applicants over others? What if the number of wrongly disqualified applicants is initially unknown and the process might need to be repeated an unspecified number of times? And how did a math grad student end up designing and implementing a marijuana lottery anyway? These questions and more are answered in this study of randomness and procedural issues. (Received September 19, 2015)

1116-00-1518 **Xiyang Luo*** (xylmath@gmail.com), 2143 Midvale Ave., Los Angeles, CA 90025, and **Andrea L Bertozzi**. *Convergence Analysis of the Graph Allen-Cahn Scheme.*

Graph partitioning problems have a wide range of applications in machine learning. This work analyzes convergence conditions for a class of diffuse interface algorithm [A.L. Bertozzi and A. Flenner, *Multiscale Modeling & Simulation*, 10(3):1090[1118, 2012.] for binary and multi-class partitioning. Using techniques from numerical PDE and convex optimization, convergence and and monotonicity is shown for a class of schemes under a graph-independent timestep restriction. We also analyze the effects of spectral truncation, a technique used to save computation cost. Convergence of the scheme with spectral truncation is also proved under a timestep restriction inversely proportional to the size of the graph. Moreover, this restriction is shown to be sharp in the worst case. Various numerical experiments are done to compare theoretical results with practical performance. (Received September 20, 2015)

1116-00-1536 **Keertana Anandraj*** (kanandra@wellesley.edu) and **Laura Brunner**. *Phylogenetic Supertree Reconstruction Using Weighted Quartets.* Preliminary report.

Phylogenetic trees, a tool often used by biologists, are branching diagrams representing the relationships among organisms and their ancestors. Combining multiple phylogenetic trees into one larger supertree has been a challenging, yet intriguing, problem. Quartet based amalgamation methods, which are often used to reconstruct supertrees, create large supertrees in an efficient manner. We have attempted to improve this method by increasing its accuracy. To do this, we have constructed a weighting system which will allow quartets to be considered differently based on the confidence or reliability of the relationships among the organisms. Our improvements involve devising a new weighting system for the quartets developed from gene-species trees as well as branch lengths. (Received September 20, 2015)

1116-00-1554 **James Michael Keane*** (jkeane@uco.edu). *Successfully Managing Distinct Research Projects.* Preliminary report.

The benefits of conducting research as an undergraduate student are clear: experience working on open-ended questions, enhancing communication skills, problem-solving and higher-level thinking skills. I was a part of two research projects, one in pure mathematics (Disjunctive Rado numbers) and the other in applied mathematics (modeling fire management and population dynamics). Working on two distinct projects simultaneously has had its challenges, but has also enhanced my cognitive and personal skills. This presentation will not only address the process of research, but also the differences and similarities of conducting research in two different fields and how to manage multiple research projects simultaneously. (Received September 20, 2015)

1116-00-1571 **Torrey Gallagher**, University of Pittsburgh, **Chris Lennard**, University of Pittsburgh, and **Roxana Popescu***, University of Pittsburgh. *Weak compactness is not equivalent to the fixed point property in c.*

We will discuss recent work of Torrey Gallagher, Chris Lennard and Roxana Popescu where we prove the existence of a non-weakly compact, closed, bounded, convex subset W of the Banach space of convergent sequences $(c, ||\cdot||_\infty)$, such that every mapping $T : W \to W$ with $||Tx - Ty||_\infty \leq ||x - y||_\infty$, $\forall x, y \in W$, has a fixed point. (Received September 20, 2015)

1116-00-1626 **David Ruddy***, Cornell University Library, Ithaca, NY 14850. *Mathematics publishing in an academic library context.*

This presentation will address questions around the involvement of academic libraries in the publication of scientific literature. What is unique and valuable about an academic library's involvement in mathematics publishing? What are the challenges and opportunities in continuing that involvement? Can, should, and how might that involvement be sustained? (Received September 20, 2015)

1116-00-1673 **Michael Shulman*** (shulman@sandiego.edu). *From the nLab to the HoTT Book.*

I will share some thoughts from my experiences communicating and collaborating on mathematics online, including blogging at the n-Category Cafe, writing on the nLab wiki, writing the Homotopy Type Theory book, and developing the Homotopy Type Theory Coq library. In particular, I will discuss the value of group-editable content with stored history, such as offered by a wiki site or a version control system such as git/GitHub. (Received September 21, 2015)

1116-00-1674 **Z. Q. Xu*** (xuzhqmaths@126.com), Department of Mathematics, Shanghai Jiao Tong University, Room 325, PhD office, Shanghai, 200240, Peoples Rep of China, and **D. M. Xiao** (xiaodm@sjtu.edu.cn), Department of Mathematics, Shanghai Jiao Tong University, Room 328, Prof. office, Shanghai, 200240, Peoples Rep of China. *Spreading speeds and uniqueness of traveling waves for a reaction diffusion equation with spatio-temporal delays.* Preliminary report.

This talk is concerned with a class of reaction diffusion equation with spatio-temporal delays. When the reaction function of this equation is nonlinear without monotonicity, it is shown that there exists a spreading speed $c^* > 0$ for this equation such that c^* is linearly determinate and coincides with the minimal wave speed of traveling waves, and that this equation admits a unique traveling wave (up to translation) with speed $c > c^*$ and no traveling wave with $c < c^*$. (Received September 21, 2015)

1116-00-1711 **W Timothy Gowers***, Centre for Mathematical Sciences, Wilberforce Road, Cambridge, CB3 0WB, United Kingdom. *How should mathematical knowledge be organized?*

The internet has changed all our lives in many ways, but it has the potential to change them much more in the future. I shall consider whether the journal article is the ideal "basic unit of discourse" for recording mathematical ideas, and consider the merits and drawbacks of a number of alternatives. (Received September 21, 2015)

1116-00-1713 **Petr Sojka*** (sojka@fi.muni.cz), Faculty of Informatics, Masaryk University, Botanická 68a, 60200 Brno, Czech Rep, and **Michal Růžička** (mruzicka@mail.muni.cz), Faculty of Informatics, Masaryk University, Botanická 68a, 60200 Brno, Czech Rep. *Math-Aware Search Interfaces for Digital Mathematical Libraries (DML).*

Search is an ubiquitous way of access to digital knowledge today and math is no exception. Re-searching using online digital libraries like arXiv.org or the European Digital Mathematics Library (EuDML, http://eudml.org/) needs specific tools allowing math-aware similarity search or formulae search in addition to the widespread textual keyword queries.

We will reflect on the implementation and experience with two search modules that take into account math specifics: (i) advanced search supporting mathematical formulae in addition to text keyword queries and (ii) semantic similarity search. Similarity search allows to find semantically similar papers (using distributional semantics methods such as LDA or word vectors) to a given one to allow math-aware browsing. Experiments taking into account formulae for topic (MSC) representation will be discussed. Both modules have been deployed by the EuDML for more than 2 years now. We will share experience with their use scenarios.

We will also discuss suitable web interfaces to access the DML, and their acceptance by the community. (Received September 21, 2015)

1116-00-1751 **David Mumford*** (dbmumford@gmail.com), 282 Harts Neck Rd, Tenants Harbor, ME 04860. *Embracing the dislocations as well as the gifts of the internet.*

The advent of cheap personal computers and the internet has, in principle, ushered in a golden age for scientific research providing instant availability of results and sharing of ideas. But this cannot be realized without seismic changes in our work habits and our relationships to libraries, publishers and our professional societies – especially our financial relationships. Mathematics is a relatively small player here but it's the one we know and love. I want to describe some of my own experiences, positive and negative, and call for all my colleagues to be pro-active in navigating these uncertain seas. (Received September 21, 2015)

1116-00-1824 **Tyler J Jarvis*** (jarvis@math.byu.edu), Department of Mathematics, 275 TMCB, Provo, UT 84602. *"Yours was the hardest class I've ever taken—I want more".*

When students complained that math is hard, boring, and useless, I used to think they were just lazy. But in the right setting, these same students love to learn, work very hard, and enthusiastically recruit their friends to join them for more math.

I will share some things that seem to help with this wonderful transformation, including surprising successes of an ambitious teaching experiment at BYU. (Received September 21, 2015)

1116-00-1867 **Henry Cohn*** (`cohn@microsoft.com`), One Memorial Drive, Cambridge, MA 02142.
Ensuring access and reproducibility: where do we go from here? Preliminary report.
After a period of exciting developments a few years ago, mathematical publishing seems to have calmed down. This talk will look at how the community can move forwards productively. (Received September 21, 2015)

1116-00-1884 **Timothy W. Cole*** (`t-cole3@illinois.edu`), Mathematics Library, 216 Altgeld Hall, 1409 W. Green Street, Urbana, IL 61801. *Linked Data, Annotations and the Future of Mathematics Libraries.*
This talk anticipates advances to come for mathematics libraries. The information resources libraries collate, link, acquire, license and curate in support of mathematics research and pedagogy continue to grow and diversify, encompassing not only traditional monographs, dissertations and peer-reviewed articles, but also self-published arXiv.org research papers, virtual discussions captured by MathOverflow.net, lecture and meeting session online videos, Websites of functions, sequences and other mathematical objects. At present, these information resources remain poorly integrated, hobbling discovery and use. Traditional library methods for name and subject authority control are evolving, using emerging standards and Linked Data best practices to enhance connectedness. But mathematics literature deals also with objects not well represented in bibliographic metadata – e.g., theorems, lemmas, functions, sequences. Connections between resources that discuss the same or related objects often remain hidden. Automated recognition systems, though limited by the imprecision of natural language, variations in mathematical notation and changes in terminology over time, can help but fail to reveal all linkages. Domain expert involvement, e.g., using annotation tools, is needed as well. (Received September 21, 2015)

1116-00-1947 **Peter Krautzberger***, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294, and **Davide Cervone** and **Volker Sorge**. *Evolving Math Web Standards from a Usability Perspective.*
The Open Web Platform provides a radical new medium for human expression. Efforts to bring mathematical notation to this setting have a long history, but math continues to struggle to find its place within it. The proposed `<math>` element in HTML3 was removed, but led to the creation of MathML, whose success in the XML world drove its re-introduction into HTML5. Despite this, MathML's deployment in browsers remains extremely limited.

Like most areas, mathematics has initially transferred pre-existing idioms, such as print layout and computational notation, to the web. But it has failed to evolve alongside the rapid developments on the web.

With support from the Alfred P. Sloan Foundation, MathJax has developed refined heuristics for semantic enrichment of Presentation MathML. This was driven by practical usability issues to provide responsive rendering of mathematics together with assistive technology for navigation, exploration, and summarization in the context of education and disability support. Enriching the presentation directly instead of separating it out as Content MathML follows modern web-development practices, and we believe our results can inform standards development to help move mathematics towards original forms of expression on the web. (Received September 21, 2015)

1116-00-2050 **Lara El Sherif*** (`laraelsherif@gmail.com`), Alexandria, VA 22302. *The Maximum Genus of planar 2-connected graphs and its generalizations.*
The maximum genus of a connected graph is defined to be the maximum integer g for which the graph has a cellular embedding in an orientable surface of genus g. We study the maximum genus of planar 2-connected graphs using a new class of intersection graphs defined on a given plane embedding. We show that using this tool, building the maximum genus embedding of a planar 2-connected graph follows a simple graph theoretical algorithm. We will also touch on techniques and ideas to generalize this method to the non-planar case and produce locally maximal embeddings. (Received September 21, 2015)

1116-00-2095 **Matthew Leingang***, New York University, 251 Mercer Street, New York, NY 10012.
Streamlining assessment, feedback, and archival with auto-multiple-choice.
Auto-multiple-choice (AMC) is an open-source optical mark recognition software package built with Perl, LaTeX, XML, and sqlite. I use it for all my in-class quizzes and exams. Unique papers are created for each student, fixed-response items are scored automatically, and free-response problems, after manual scoring, have marks recorded in the same process. In the first part of the talk I will discuss AMC's many features and why I feel it's ideal for a mathematics course. My contributions to the AMC workflow include some scripts designed to automate the process of returning scored papers back to students electronically. AMC provides an email gateway, but I have written programs to return graded papers via the DAV protocol to student's dropboxes on our (Sakai)

learning management systems. I will also show how graded papers can be archived, with appropriate metadata tags, into an Evernote notebook. (Received September 21, 2015)

1116-00-2101 **Carina Curto***, Pennsylvania State University, University Park, State College, PA 16801. *What can topology tell us about the neural code?*

Cracking the neural code is one of the central challenges of neuroscience. Neural codes allow the brain to represent, process, and store information about the outside world. Unlike other types of codes, they must also reflect relationships between stimuli, such as proximity between locatoins in an environment. In this talk, I will explain why algebraic topology and commutative alegebra provide natural tools for understanding the structure and function of neural codes. (Received September 21, 2015)

1116-00-2114 **Patrick D. F. Ion*** (ion@ams.org), **Olaf Teschke** and **Stephen M. Watt**. *MIDAS: Mathematical Information in the Digital Age of Science.*

Since the notion of building a World Digital Mathematical Library was endorsed by the International Mathematical Union about a decade ago, the goals of the digitization of mathematics have become much more ambitious than the mere imaging of article pages. Consequently, at the 2014 ICM in Seoul a working group of the IMU Committee on Electronic Information and Communication was established to take the necessary steps to turn the modern vision into a reality.

The MIDAS session organized by that WG will provide the community with information about these possibilities for the further strengthening of access to our mathematical literature and its preservation as a global public good. It provides a forum for discussing the opportunities to help guide or make useful progress to that end. Some of the issues considered and progress made will be indicated, as well as the way in which the special session may speak to them.

Addressing a variety of relevant social, technological and financial issues will help set up a WDML and an International Mathematical Knowledge Trust system. Other ways of using the digital environment to benefit mathematics will also be considered. (Received September 21, 2015)

1116-00-2116 **Yuval Peres***, University of California, Berkeley, Berkeley, CA. *Laplacian growth, sandpiles and scaling limits.*

How can repeating simple local operations lead to an intricate large scale structure? This phenomenon arises in several growth models originating in Physics: Internal diffusion limited aggregation (IDLA) and the Abelian sandpile. The first of these is closely related to free boundary problems for the Laplacian and an algebraic operation introduced by Diaconis and Fulton know as smash sum. These connections allow a precise description of large scale geometry. The abelian sandpile, discovered independently by Statistical Physicists and Combinatorialists is harder to analyze yet has recently yielded many of its secrets. In classical DLA, particles arriving from the outside attach to an existing shape; Characterizing the limit in this case remains open. (Received September 21, 2015)

1116-00-2121 **Amie Wilkinson***, University of Chicago, Chicago, IL 60637. *What are Lyapunov exponents, and why are they interesting?*

In this talk I will introduce the concept of Lyanunov exponents and describe how understanding these elusive exponents underpins much of the recent work of Artur Avila in spectral theory and dynamics. (Received September 21, 2015)

1116-00-2195 **Essouabri**, **Lapidus**, **Scott Roby*** (roby@math.ucr.edu) and **Rock**. *Hypergeometric Multifractal Zeta Functions.* Preliminary report.

The study of self-similar measures arising from weighted iterated function systems has led to the construction of a class of multifractal zeta functions which can be shown to be transformations of generalized hypergeometric series. The analytic continuation of these series allows for the study of the complex dimensions of certain subsets of the support of the self-similar measures. (Received September 22, 2015)

1116-00-2222 **Paul Dreyer*** (dreyer@rand.org). *Mathematics, Public Policy, and High Frequency Trading.*

This talk will introduce the session and discuss the wide variety of ways mathematics can be used to address various issues in public policy, as well as where such work can be done. The second half of the talk will introduce work on one such subject, namely equity markets, high frequency trading, and how to analyze the effects of policy changes in the markets on all of its participants. (Received September 22, 2015)

1116-00-2248 **Fabian Müller*** (fabian.mueller@fiz-karlsruhe.de), FIZ Karlsruhe, Zentralblatt MATH, Franklinstr. 11, 10587 Berlin, Germany. *Creating Mathematical Knowledge Networks.*

One of the core concerns of current and future WDML efforts is the facilitation of access to mathematical research knowledge. While such knowledge historically resided within a network of mathematical literature, navigatable by hand through the following of citation trails, there are nowadays multiple other kinds of repositories in which mathematical knowledge is contained. This includes electronic literature resources like the ubiquitous arXiv or the seminal EuDML project, but also different forms of mathematical research data like, e.g., results of modeling or computer algebra computations, programming code, integer sequences or group representations encoded in machine-readable formats.

In this talk we will review the ongoing efforts at zbMATH to link these and other kinds of mathematical knowledge together. We will describe the heuristic algorithms developed to match citation strings with the articles they reference, enabling computer assisted traversal of citation networks, as well as the ongoing efforts to interlink emerging new types of data, both on an article basis as well as on the more finely grained level of mathematical objects. A secondary focus of the talk will be the design of appropriate user interfaces to support manual aid in curating this data. (Received September 22, 2015)

1116-00-2256 **Mario Aigner*** (mario.aigner@springer.com), Springer International Publishing AG, P.O. Box 133, CH-4010 Basel, Switzerland. *A publishers view on various aspects of handling digital scientific information.*

We will discuss the current standard and ongoing developments of creating, providing and long term archiving of digital scientific data from a publishers point of view.

Special emphases will be placed on topics concerning online databases, new publishing formats and the collaboration between the scientific community and service providers. (Received September 22, 2015)

1116-00-2335 **Edgardo Cheb-Terrab***, ecterrab@maplesoft.com, and **Laurent Bernardin**. *30 Years of Digitizing Mathematical Knowledge with Maple.*

We will talk about lessons learned and progress made over 30 years of encoding mathematical knowledge within the Maple system. A wealth of information is now readily available to query and compute with.

In particular, we will highlight two examples. First, our effort to digitize and encode into Maple, Exact Solutions of Einstein's Field Equations, a book representing knowledge about known solutions of Einstein's field equations. Three main challenges have arisen: 1) how to digitize this monumental piece of information, 2) how to frame this information such that we can take full advantage of it, and 3) how to define metadata to make the encoded knowledge computable.

The second example is about the Maple digital library of mathematical functions, which consists of a repository of knowledge on identities and properties of mathematical functions following the NIST Digital Library of mathematical Functions, again combined with the ability to, on demand, generate additional identities by algorithmic deduction from the available knowledge base. In addition to challenges on digitizing and encoding, query methods to provide effective ways for a mathematician to navigate and utilize this body of digital knowledge, turn out to be crucial. (Received September 22, 2015)

1116-00-2361 **Luke Wolcott*** (luke.wolcott@lawrence.edu). *The User's Guide Project: giving experiential context to research papers.*

A user's guide – at the same time humanistic and technical – is written to accompany a published or soon-to-be-published research article, providing further exposition and context for the results. Enchiridion is a new informal annual journal that brings together five mathematicians from a common subfield to write user's guides on their own papers, then work closely together to collaboratively group-edit and peer-review a compilation. The goal of this online-only journal is to make research mathematics more accessible, to explore unconventional expositional styles, and to augment rigor with humanistic meta-data. My talk with describe and demo the project, which is up at mathusersguides.com. (Received September 22, 2015)

1116-00-2385 **Elena Demidova**, , Germany, and **Peter Löwe**, **Margret Plank** and **Mila Runnwerth*** (mila.runnwerth@tib.uni-hannover.de), Welfengarten 1b, 30167 Hanover, Germany. *Non-textual information infrastructure for mathematics at the German National Library of Science and Technology.* Preliminary report.

The digital publication process enables authors to append research data and tools to articles which summarise the findings. For the unique character of most research data, citation via DOI suffices since a sustainable reuse is often improbable. Software to process experimental data, however, is likely to be reused in order to fullfill further scientific purposes. With the maths-oriented information infrastructure project "FID Mathematik", the German National Library of Science and Technology (TIB) presents a maths software citation framework including metadata and metrics to reflect the citation impact in coordination with the mathematical community by exploitation of participation instruments via the web. This framework can facilitate efficient software reuse and significantly enhance the visibility of the author's contributions within the mathematical community. In addition to its leading role as supplier of textual information concerning, this framework completes the TIB's unique non-textual service portfolio which comprises scientifically valuable audiovisual content with enhanced metadata obtained by video and speech analysis Thus, the TIB offers services matching mathematicians' needs in archiving and disseminating data accompanying the whole research process:. (Received September 22, 2015)

1116-00-2424 **Edward Dunne*** (egd@ams.org), Mathematical Reviews, 416 Fourth St, Ann Arbor, MI 48103. *Enhanced Guides to the Mathematical Literature.*

The mathematical literature has never been more widely available. Digital publishing has enabled great innovations, coming from large, established publishers and from small, new publishers. Navigating the world of online literature is not easy. Various guides to the literature exist, both old and new. Advances in technology allow these guides to be more than just roadmaps. They can also provide information obtained from statistics, from meta-data, or from human input. I will discuss some general developments, using Mathematical Reviews / MathSciNet as a source of examples. (Received September 22, 2015)

1116-00-2437 **Bonnie Gold*** (bgold@monmouth.edu), Mathematics Department, Monmouth University, 400 Cedar Avenue, West Long Branch, NJ 07764-1898. *Is school mathematics "real" mathematics?* Preliminary report.

One objection mathematicians often have to the work of philosophers of mathematics is that they don't ever discuss "real" mathematics. Many philosophers don't know mathematics beyond the school level (arithmetic and geometry); or if they know any advanced mathematics, it's often logic or set theory, which one can argue are somewhat anomalous. I've been interested for many years in trying to answer "what is mathematics?" by looking at topics that are on the boundary – some would say they're mathematics, others would say they're not really mathematics. So I'd like to consider one such topic: is school mathematics "real mathematics" (as in David Corfield's *Towards a Philosophy of Real Mathematics*, or as what each of us means by the term)? (Received September 22, 2015)

1116-00-2606 **Christina G Knox*** (stinasargent@gmail.com). *The Box Zeta Counting Functions and Complex Dimensions of Self-Similar Sets Under Certain Separation Conditions.*

Under certain separation conditions we can determine the properties of the box counting zeta function and box counting complex dimensions of self-similar sets. We will first briefly introduce the theory of box counting fractal strings, zeta functions and complex dimensions as done by Lapidus, Rock, and Zubrinic. We then use results by Lalley and Lapidus to see how the box counting zeta function and complex dimensions of self-similar sets satisfying open set condition and delta disjoint behave, with a closed form for the box counting zeta function give under the second condition. We will then use this to calculate the box counting zeta function and box counting dimensions of some particular self-similar sets. Then we will highlight how these results fit in the lattice/nonlattice dichotomy. (Received September 22, 2015)

1116-00-2620 **ilker Kocyigit*** (ilkerk@umich.edu) and **Liliana Borcea**. *Array Imaging with Sparsity Promoting Optimization Methods.*

In this work we study array imaging problem where the goal is to find the unknown localized sources or scatterers, which are assumed to be sparse, from the measurements of the wave field at the sensors on the array. The inverse problem is addressed by sparsity promoting optimization methods, and first we consider the case where the unknown locations are assumed to be supported on the imaging grid. We discuss and quantify the relation between the unique recoverability and the sparsity. Secondly, we investigate the general case where the unknown locations can be anywhere and not necessarily on the grid. We show that the resolution and the approximation error of the recovered image depends on the sparsity of the sources (or scatterers) and how well they are separated. The cases where the unique recoverability conditions fail and the unknown locations are not well separated are also considered. We present numerical simulations to support the theoretical results. (Received September 22, 2015)

1116-00-2623 **Austin R Alderete*** (aaldere2@gmu.edu), 4450 Rivanna River Way #1027, Fairfax, VA 22030. *Soft Contact Lens Hydration Modeling.* Preliminary report.

Excessive dehydration in contact lenses can lead to dry eye and general discomfort for the wearer. Previous work in modeling the hydration levels in contact lenses has demonstrated the convergence of the hydration level to an oscillatory steady state whose mean value varies linearly along the spatial domain. In this work, we present a simpler model, based on the heat equation, which reproduces this phenomenon. We also present a means of predicting this steady state. (Received September 22, 2015)

1116-00-2626 **Kathleen A McLane*** (kmclane@masonlive.gmu.edu), **Alexander Baez** (abmincorporated@gmail.com), **Padmanabhan Seshaiyer** (pseshaiy@gmu.edu), **Pradyuta Seshaiyer** (pradyuta@gmail.com), **Carmen Caiseda** (ccaiseda@bayamon.inter.edu), **Byong Kwon** (bkwon1@masonlive.gmu.edu) and **Nithin Ellanki** (nellanki@masonlive.gmu.edu). *Mathematical Modeling, Dynamics, and Simulation of Search and Rescue Operations through UAVs.*

The use of unmanned aerial vehicles (UAVs) to accomplish tasks is a fast growing field in technology today for search and rescue operations. This multidisciplinary area requires precise mathematical modeling, description of associated mechanics, and evolution of probabilistic algorithms. In this project, we consider the development of a unified model for a UAV that incorporates the dynamics along with a decision-making framework using probabilistic search algorithms. The governing differential equations describing the dynamics are solved via numerical algorithms, and its performance compared for our model. Bayes filters are implemented to detect the presence of targets in the search area through calculations of belief functions. The proposed models are validated computationally for benchmark applications including searching a savannah in Africa for poachers to identifying residues of pesticides in crops. The computational results will be compared against experimental results obtained via drones that are built as a part of this research. (Received September 22, 2015)

1116-00-2803 **Tanya A Moore***, tanya.moore@presidio.edu. *Why Mathematicians and Statisticians are Needed to Create Lasting Social Impact.* Preliminary report.

Complex societal problems require impactful and innovative solutions. This talk will discuss why mathematicians and statisticians are vital to the development and implementation of solutions for some of the world's most pressing issues in education, health and sustainability. (Received September 22, 2015)

1116-00-2898 **Ahlam E Tannouri***, Mathematics Department, Morgan State University, 1700 E. Cold Spring, Baltimore, MD 21251, and **Sam Tannouri** (sam.tannouri@morgan.edu). *Big Data Visualization Tools and Algorithms to Build Predictive Models.* Preliminary report.

Prediction models, Recommendation Systems and Advertisements based on big data collection play major roles in all fields impacting our daily life. In order to harness the power of the complex big data coming from sensors used to gather climate information, posts to social media sites, online digital pictures and videos, transaction records of online purchases, tracking the spread of viruses, and cell phone GPS signals, new algorithm are being developed as well as new visualization techniques are being created. In a case study, we will use several mathematical methods, K-means Clustering, dimensionality Reduction, Singular Value Decomposition (SVD) and Principal Component Analysis (PCA) to reduce the complexity of the data, visualize the result in order to discover relevant objects and attributes; and then build predictive models and recommendation systems that satisfy the objective of the study and increase the value of the institution.

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(Received September 22, 2015)

1116-00-2932 **Xin Li*** (xin.li@ucf.edu), 4000 Central Florida Blvd, Orlando, FL 32816. *How to better prepare secondary mathematics teachers for graduate mathematics courses.* Preliminary report.

I would like to share our experience in working together with our college of education and with a state college in offering a graduate mathematics certificate program with desired graduate mathematics courses for secondary mathematics teachers. (Received September 23, 2015)

1116-00-2940 **Syvillia A Averett*** (saverett@centralstate.edu), 1400 Brush Row Road, Wilberforce, OH 45384. *On the Representations of $SL_*(2,\mathcal{A})$.* Preliminary report.

We will explore the representations of $\mathrm{SL}_*(2,\mathcal{A})$ where $\mathcal{A}$ is the direct sum of the upper and lower $n \times n$ block matrices in $M(2n,k)$, where k is a finite field. (Received September 23, 2015)

1116-00-2957 **Chris Jeuell*** (chrisje@microsoft.com). *Techniques For Teaching Problem Solving Using Mathematics Contests.*

This talk highlights some of the common challenges that the author has faced when teaching problem solving to children at the middle school and early high school levels — and various approaches the author has used to address these challenges in order to enrich students' learning experiences. This talk covers some of the presenter's core principles underlying his teaching philosophy and also illustrates some of the classic situations encountered via problems used in teaching mathematics classes. (Received September 23, 2015)

1116-00-2976 **Bin Yu*** (binyu@stat.berkeley.edu), Department of Statistics and EECS, UC Berkeley, 367 Evans Hall #3860, Berkeley, CA 94720. *The multi-facet of a data science project to answer: how are organs formed?*

Genome wide data reveal an intricate landscape where gene actions and interactions in diverse spatial areas are common both during development and in normal and abnormal tissues. Understanding local gene networks is thus key to developing treatments for human diseases. In this talk, I present results from a project co-led by biologist Dr. Frise from LBNL to answer the fundamental systems biology question in the talk title. My group (Wu, Joseph, Kumbier) collaborates with Dr. Erwin and other biologists (Hommands) of Celniker's Lab at LBNL that generate the Drosophila spatial expression embryonic image data. We develop a novel image representation decomposing spatial data into building blocks (or principal patterns). These principal patterns provide an innovative and biologically meaningful approach for the interpretation and analysis of large complex spatial data. They are the basis for constructing local gene networks, and we have been able to reproduced 10 out of the 12 links in the famous (local) gap-gene network. Moreover, we are collaborating with the Celniker Lab to verify possible new members of the gap gene network through knock-out experiments and with Dr. Xu.s group at Hsinghua University for software development based on SPARK. (Received September 28, 2015)

1116-00-2977 **Huaiping Zhu*** (Huaiping@mathstat.yorku.ca<mailto:Huaiping@mathstat.yorku.ca>). *Modeling and the dynamics of the Spread and Control of Dengue with L= imited Public Health Resources*

To study the impact of available resource of the health system on= the spread and control of dengue fever, I will introduce a deterministic m= odel for the transmission dynamics of the disease incorporating a nonlinear= recovery rate reflecting the public health resources. Model results indic= ate the existence of multiple endemic equilibria; and system exhibits the phenomenon of backward bifurcation as a common feat= ure of vector-borne diseases. Additionally, the can undergo a Hopf bifurcat= ion. The results of this study could be helpful for public health plan the = resources essential for control of dengue disease. This is a joint work wi= th Ahmed Abdelrazec, Jacques Belair and Chunhua Shan. (Received September 28, 2015)

1116-00-2987 **Karl H. Schaffer*** (karl_schaffer@yahoo.com), 325 Lucinda St, Scotts Valley, CA 95066. *Dancing with Polyhedra.*

We will briefly explore ways of constructing polyhedra with loops of string, lengths of PVC pipe, fingers, or bodies, and see how these constructions may be incorporated into dances or classroom math and movement activities. Mathematical connections include concepts from graph theory and geometry, and artistic elements include learning to dance with props. The constructions have inspired mathematical problems as well as mathematical dances (Received October 02, 2015)

1116-00-2988 **Mary Leah Karker*** (mkarker@wesleyan.edu<mailto:mkarker@wesleyan.edu>), Wesleyan University, Middletown, CT 06459. *Products of metric structures.*

This talk will focus on analogues, for continuous logic [1], of results of Feferman and Vaught on model-theoretic properties of various kinds of product [2]. For example: a natural continuous-logic version of direct product preserves elementary equivalence and elementary inclusion; and if a sentence θ is true in $\prod_{i=3D0}^{k} \mathcal{M}_i$ for every $k \in \mathbb{N}$, then θ is true in $\prod_{i\in\mathbb{N}} \updownarrow M_i$. (Received October 05, 2015)

1116-00-2989 **Gabriel Conant*** (gconant@nd.edu), University of Notre Dame, Notre Dame, IN 46616. *Unstable theories without the strict order property*

We consider several classes of unstable theories without the strict order property, each of which is motivated by important examples of homogeneous structures. Our main focus will be on theories equipped with an abstract notion of free amalgamation, which reflects the behavior of free amalgamation of relational structures. We give characterizations of simplicity for these theories, and present partial results and questions on the role of forking and thorn-forking in the non-simple case. (Received October 05, 2015)

1116-00-2991 **Caroline Terry*** (cterry3@uic.edu), University of Illinois at Chicago, Chicago, IL 60607. *Some new logical zero-one laws.*

Suppose $\mathcal{L}$ is a finite first-order language and for each integer n, suppose $F(n)$ is a set of $\mathcal{L}$-structures with underlying set $\{1,\ldots,n\}$. We say the family $F=\bigcup_{n\in\mathbb{N}}F(n)$ has a zero-one law if for every first order sentence ϕ, the proportion of elements in $F(n)$ which satisfy ϕ goes to zero or one as $n\to\infty$. In this talk we give a brief overview of the history of zero-one laws, then present some new examples. This is joint work with Dhruv Mubayi. (Received October 08, 2015)

01 ► History and biography

1116-01-49 **Paul R. Bouthellier*** (pbouthe@pitt.edu), 504 East Main Street, University of Pittsburgh-Titusville, Titusville, PA 16354. *Charles Babbage and the Difference Engine 1.*

In this talk we shall discuss Charles Babbage's Difference Engine 1, which was to construct tables of values for functions, such as logarithms, for the British Government. Such tables were indispensable in areas such as navigation. The problem was that at the time, the 1830s, such tables had to be constructed by hand and were hence extremely labor intensive and subject to calculational and printing errors. To allow such tables to be created and printed more accurately, Babbage designed the Difference Engine 1 (DE1), which was to be powered by steam. The architecture of the device was based on its mathematical requirements. To create tables of approximate function values, Babbage approximated the functions by 6th order polynomials and calculated a set of initial values of the functions and their corresponding finite differences. These initial values and finite differences would allow the Difference Engine to compute the remainder of the values in the desired table. The machines ability to compute finite differences gave the machine its name: the Difference Engine. The main point of this talk is that today, almost 200 years later, we still need to first derive the mathematics behind how we compute, then engineer the machine to carry out the mathematical operations. (Received June 22, 2015)

1116-01-80 **Ronald L Merritt*** (ronald.merritt@athens.edu), Athens State University, Dept. of Mathematical, Computer and Nat. Sci., 300 North Beaty Street, Athens, AL 35613. *An investigation of the mathematical texts used by selected eighteenth and nineteenth century United States Presidents.*

President John Quincy Adams, prior to his entrance into Harvard College, studied mathematics primarily from Fenning's Algebra and Ward's Mathematics, under the direction of Adams' tutor. During the early nineteenth century, President James Knox Polk successfully learned about arithmetic, algebra and geometry from Hutton's Mathematics to satisfy his mathematics requirements at the University of North Carolina. A few decades later President James Abram Garfield prepared for transfer into Williams College by practicing the mathematics problems from at least three different mathematics textbooks authored by Elias Loomis. A comparison of these texts used by these three presidents will provide insight regarding the rigor of some of the mathematics problems each likely had to solve. (Received July 15, 2015)

1116-01-223 **Stephan Ramon Garcia*** (stephan.garcia@pomona.edu), Department of Mathematics, Pomona College, Claremont, CA 91711. *Wetzel's problem, Paul Erdős, and the continuum hypothesis: a mathematical mystery.*

In 1963, Paul Erdős provided a stunning solution to Wetzel's Problem in complex variables. But who was Wetzel and how did his problem find its way to Erdős? Tracing the path that this problem took, from its birth to its resolution, was a mathematical mystery. A burnt out car on the streets of Chicago appeared to mark the end of the trail. An enigmatic manuscript, written by unknown hands, prompted even more questions. . . (Joint work with Amy L. Shoemaker). (Received August 15, 2015)

1116-01-228 **Michael J. Barany*** (mbarany@princeton.edu), 129 Dickinson Hall, Princeton, NJ 08544. *Making a Name in Mid-century Mathematics: Individuals, institutions, and the American reaction to Nicolas Bourbaki.*

Nicolas Bourbaki is widely considered one of the most influential mathematicians of the twentieth century, though he is just as widely held to be merely the pen name shared initially by a radical group of French mathematicians from the mid-1930s. His personhood or lack thereof has tended to be treated as a curiosity, illustrative of the distinctive approach to mathematics that came to be associated with his name but in itself presenting little more than a provocation or a challenge of nomenclature. My presentation examines Bourbaki's reception in the 1940s, when the enigmatic mathematician's personhood became a visible and contentious problem in an international mathematical community responding to the Second World War and then rebuilding in its aftermath. Placing in context Bourbaki's two failed attempts to join the American Mathematical Society, I develop an account of the reconfiguration of individuals and institutions in mid-century international mathematics that ties together the effort to revive the International Mathematical Union and International Congresses of Mathematicians, the changing funding landscape for elite mathematics, and the changing role of publications and reviews in establishing and connecting research communities. (Received August 15, 2015)

1116-01-257 **Tom Archibald*** (tarchi@sfu.ca). *Riemann's Model of Nobili's Rings.*

In 1825, Leopoldo Nobili observed coloured rings on a metal plate that had been coated with an electrolyte, a current being passed through the liquid from a point electrode to the plate. The phenomenon attracted the attention of several researchers, among them Emil du Bois-Reymond, Edmond Becquerel, and Bernhard Riemann. In this paper we discuss the differences between the models they employed, their relationship to contemporary mathematico-physical theory, and their relation to experiment. Riemann's work shows one of the ways in which we observe directly the influence of his studies with Dirichlet, and indirectly the influence of Fourier. It also provides an early example of a method for modelling a problem with a partial differential equation that was to become standard, in part via Riemann's lectures. (Received August 18, 2015)

1116-01-264 **Christopher Hollings*** (christopher.hollings@maths.ox.ac.uk), Mathematical Institute, University of Oxford, Andrew Wiles Building, Woodstock Road, Oxford, OX2 6GG, United Kingdom. *Russian participation in the early International Congresses of Mathematicians.*

The picture of Russian/Soviet attendance at the International Congresses of Mathematicians is a very varied one, with strong delegations at some congresses (particularly the ones of the later Soviet era) and conspicuous absences from others (those of 1936 and 1950 most especially). In this talk, I will examine Russian attendance of the early ICMs, namely, those that took place before the October Revolution. We will see that in this period, many Russian mathematicians were active and enthusiastic participants at such international events. (Received August 19, 2015)

1116-01-303 **Ronald E. Mickens*** (rmickens@cau.edu), Clark Atlanta University, Atlanta, GA 30314. *The Effectiveness of Mathematics as Applied to Science.*

We present arguments suggesting that mathematics and science may be "equivalent", and this conclusion can then be used to justify why mathematics is expected to be applicable to science. A brief summary of the history of prior efforts on this issue will be presented [1]. It should be noted that this topic continues earlier work of mine on the relationship between science and mathematics [2].

References

1. Mario Livio, "Is God a Mathematician?" (Simon and Schuster, New York, 2009). In particular, see Chapter 8. 2. Ronald E. Mickens (editor), "Mathematics and Science" (World Scientific, Singapore, 1990).
(Received August 26, 2015)

1116-01-314 **David R Bellhouse*** (bellhouse@stats.uwo.ca), Dept of Statistical and Actuarial Sciences, Western Science Centre, University of Western Ontario, London, Ontario N6A 5B7, Canada, and **Lori L Murray**, Dept of Statistical and Actuarial Sciences, Western Science Centre, University of Western Ontario, London, Ontario N6A 5B7, Canada. *The Construction of Edmond Halley's 1701 Map of Magnetic Declination.*

During two voyages of the HMS Paramore, Edmond Halley collected data on magnetic declination at various points in the Atlantic Ocean. Magnetic declination is the angular difference between magnetic north and geographical or true north for any point on the earth's surface. Following these voyages, in 1701 Halley published a map showing isogones, or lines of equal magnetic declination, over the Atlantic Ocean. Such a map was presented as a possible solution to finding longitude at sea. Halley did not reveal the data analytic techniques that he used in his map construction and they remain unknown to this day. Using some mathematical tools of his day, namely arithmetical averages and Newton's divided difference method to fit a line to data, a plausible method for the map's construction is given. Not enough data was collected that would allow for the construction of all the isogones on the published map. A method is suggested whereby Halley imputed data for his map construction. (Received August 24, 2015)

1116-01-318 **Gregg De Young*** (gdeyoung@aucegypt.edu), Dept of Mathematics and Actuarial Science, The American University in Cairo, PO Box 74, New Cairo, 11835, Egypt. *The Arabic redaction of Euclid's Elements by al-Ṭūsī.*

The Arabic redaction of the *Elements* (completed 1246 AD) by Naṣīr al-Dīn al-Ṭūsī was one of the most influential mathematical treatises in the Islamic world, forming the foundation of mathematics education until the 19th century. The treatise marked a major watershed for Arabic Euclidean studies, a shift from reliance on the Ḥajjāj translation toward that of Isḥāq-Thābit. Moreover, the treatise originated the Persian Euclidean tradition through the translation of al-Shīrāzī. Its mathematical notes (most borrowed from earlier authors) enhance its pedagogical purpose. Despite its historic importance, the treatise is little known to historians. No modern edition, translation, or analysis of the text exists, although it is often confused with an anonymous Arabic redaction printed in Rome (1594). Evidence of its continued importance includes (a) the commentary on book I by Muḥammad Barakāt, printed several times following the 18th century Dars-i-Niẓāmī educational reforms in India, (b) the edition of books I–VI printed by the Calcutta School Book Society (1824) as a geometry textbook for use in British East India schools, and (c) a complete lithograph edition printed in Tehran in 1881. (Received August 25, 2015)

1116-01-349 **Jemma Lorenat*** (`jlorenat@pitzer.edu`), 1050 North Mills Ave, Claremont, CA 91711. *The inner imagination without sensory media: Jakob Steiner and the figure in geometry.*

The transition away from figure-based reasoning during the long nineteenth century is often framed in terms of intuition and rigor. However, the use of the figure could also be attacked from the perspective of intuition, as shown in the geometer Jakob Steiner's injunction that certain geometric considerations could only be properly understood when viewed purely through the inner imagination without any intermediary sensory medium–such as a drawn representation or figure. Steiner reinforced his commitment to the inner imagination by occasionally teaching geometry with the lights out and the curtain drawn, so students would have to see figures internally. Yet in his publications Steiner often used illustrated figures to introduce new definitions, describe constructive procedures, or simplify statements of theorems. This talk will consider Steiner's evolving approach to figures in three comparative contexts: his early articles in the *Journal für die reine und angewandte Mathematik* and the *Annales de mathématiques pures et appliquées* (1826-1832), his famous monograph *Systematische-Entwicklung der Abhängigkeit geometrischer Gestalten von Einander* (1832), and his posthumously published *Vorlesungen über synthetische Geometrie* (1867). (Received August 26, 2015)

1116-01-375 **Nuh Aydin*** (`aydinn@kenyon.edu`) and **Lakhdar Hammoudi** (`hammoudi@ohio.edu`). *The Legacy of Al-Kashi: Why does it matter in the 21st century?*

Ghiyath al-Din Jamshid al-Kashi is one the most important mathematicians of the medieval Islamic civilization. His work and contributions to mathematics have been largely forgotten but there is a growing appreciation of his legacy. Miftah al-Hisab, his major work as a textbook which is a compendium of arithmetic, algebra, and geometry/measurement is yet to be translated to English. In this talk, the authors who are trained mathematicians describe the reasons why they became interested in Al-Kashi's work and why they undertook the task of translating Miftah into English. They will share some of their findings from the translation project so far as well as amazing and disturbing facts related to the legacy of Al-Kashi. (Received August 28, 2015)

1116-01-415 **Nicholas A Scoville*** (`nscoville@ursinus.edu`), Ursinus College, Math and CS, 601 E. Main Street, Collegeville, PA 19426. *The Cantor set before Cantor.* Preliminary report.

The Cantor set is the quintessential counterexample in topology. Defying many of our topological intuitions, this set bearing Georg Cantor's name even has a natural generalization. However, this general Cantor set was first written down and studied in the context of integrable discontinuous functions by Henry J. S. Smith in 1875, eight years before Cantor himself introduced the set. In this talk, we will look at the problem that motivated Smith to define this set, building a bridge between the calculus familiar to students and the less familiar topology. (Received August 31, 2015)

1116-01-510 **Judith R Goodstein*** (`jrg@caltech.edu`). *Recognizing Ricci.* Preliminary report.

The names of the Italian mathematicians Ricci and Levi-Civita have been enshrined in the theory of general relativity since Einstein seized on the absolute differential calculus as the indispensable mathematical tool for expressing his uniquely determined gravitational equations. The physicist's long-standing indifference to mathematics changed abruptly as he struggled with the theory, methods, and notation of the calculus developed and refined by Gregorio Ricci-Curbastro, together with Tullio Levi-Civita at the University of Padua, before the end of the nineteenth century. While mathematicians and physicists are familiar with the Ricci tensor, by and large they know very little about the mathematician for whom this symbol in differential geometry is named. This talk is a brief introduction to the story of his life. (Received September 04, 2015)

1116-01-526 **Margaret A.M. Murray*** (margaret-a-murray@uiowa.edu), 432 English-Philosophy Building, University of Iowa, Iowa City, IA 52242. *American Women Mathematics Doctorates, 1940-1959.* Preliminary report.

In this talk, I'll describe recent research toward a comprehensive picture of the roughly 200 women who earned PhDs in mathematics from American institutions during the years 1940-1959. This work builds significantly on my book Women Becoming Mathematicians (MIT Press 2000), and reveals a more complex picture of the careers of the women mathematicians of this generation. (Received September 05, 2015)

1116-01-599 **Emmylou Haffner*** (emmylou.haffner@gmail.com), Paris, France. *Some remarks on Dedekind and Weber's edition of Riemann's* Gesammelte Werke.

In 1876, the collected works of Bernhard Riemann were published, with additional manuscripts from his *Nachlass*, by Richard Dedekind and Heinrich Weber. The edition of Riemann's works was a long and difficult work, which took Dedekind and Weber more than two years to complete. Indeed, as the letters exchanged by Dedekind and Weber tell us, the state of Riemann's manuscripts made it necessary for them to thoroughly work through the manuscripts, sometimes struggling to understand what Riemann was doing. We will consider some elements of their correspondence and highlight key points to understand the process of edition through which Dedekind and Weber went, such as the steps followed to unfold Riemann's texts until publishable versions could be obtained. We will suggest that it is important, here, to elucidate to what extent Weber and Dedekind's very thorough editing work led to publish adapted or even rewritten versions of Riemann's texts, and to clarify whether Dedekind and Weber's reading of Riemann could have had an influence on our own reading, through their re-appropriation of Riemann's texts that accompanied the edition of the manuscripts. (Received September 08, 2015)

1116-01-609 **Carol Bier*** (bier.carol@gmail.com). *Intersecting Polygons/Exploring Space in Medieval Islamic Architecture.*

Geometric patterns comprise a key component in architecture of the Islamic world. The reasons for this emphasis in the arts are complex; here it is argued that geometric patterns may visually express new mathematical ideas. Between the 9th and 12th centuries major advances involved radical developments in algebra, trigonometry, spherical geometry, optics, number theory, and possibly algebraic geometry. Mathematicians included al-Khwarezmi and his successors, Omar Khayyam, Sharaf al-Din al-Tusi, and Nasir al-Din al-Tusi, among others. My research on monuments in Iran and neighboring regions (Iraq, Afghanistan, Azerbaijan, Syria, Turkey) from an art historical perspective delves into circles and centers, points of intersection, lines and angles, axes and grids, symmetry and tessellations, periodic and quasiperiodic patterns. This paper focuses on the use of intersecting polygons to tile the plane; through visual analysis we may recognize intensive explorations into the nature of two-dimensional space. Such innovations in mathematics and architecture occurred where skill, knowledge, and patronage converged in intellectual centers such as Baghdad, Isfahan, Ghazna, Damascus, Aleppo, and Maragha, with profound implications relating the histories of Islamic art and mathematics. (Received September 08, 2015)

1116-01-611 **Andrzej Lenard*** (andrewlenard@attu.pl). *Polish Math House of the Interwar Period: Stefan Banach.*

After regaining its independence in 1918, Poland experiences an outburst of extraordinary mathematicians. Immediately they create several world-leading mathematical centers at Polish universities in Warszawa, Lvov, Krakow, Poznan and Vilnus, which compete in achievements and significant mathematical publications among themselves. Young, often self-taught mathematicians like Banach, Sierpinski, Ulam, Tarski, Knaster, Steinhaus and many more, practice mathematics in a most unorthodox, original way. Their work result in world-recognition and their minds are desired to help to win the World War II. Some migrate to the USA and contribute to the Manhattan Project; others are used in the Allied army to break the Enigma codes; most, however, stay in Poland and face the slaughter of intellectual class by Germans and Soviets. This presentation is fully dedicated to Stefan Banach. Besides his life and achievements, I also focus on education curricula he learned as student and taught as teacher. (Received September 08, 2015)

1116-01-688 **Daniel S Silver*** (silver@southalabama.edu), Department of Mathematics and Statistics, ILB, University of South Alabama, Mobile, AL 36688. *75 Years of Apology: G.H. Hardy's A Mathematician's Apology.*

The year 2015 was the 75th anniversary of the appearance of G.H. Hardy's *A Mathematician's Apology.* When its second edition appeared in 1967, one well-known critic predicted that "it won't make a nickel for anyone." We explore the history of the book as well as the controversy that continues to surround it. (Received September 10, 2015)

1116-01-720 **Jenny Boucard*** (jenny.boucard@univ-nantes.fr), Centre François Viète, UFR Sciences et Techniques, 2 rue de la Houssinière - BP92208, 44322 Nantes cedex 3, France. *Quadratic forms, Fermat's Last Theorem and Bernoulli numbers from Cauchy to Kummer (1830-1850).*

In 1847 Kummer announced a proof of Fermat's Last Theorem (FLT). The proof was part of Kummer's work on reciprocity laws and was applied to a class of numbers which he called *regular numbers*. To achieve these results, Kummer used the earlier works of Gauss, Jacobi and Dirichlet among others. 1847 was also a year in which were held several discussions on FLT in the Parisian *milieu*. Lamé and Cauchy are for example regularly cited in historical accounts, usually for their failed attempts to make progess on FLT. Through the *Journal of Pure and Applied Mathematics*, Liouville provides communication between these two groups of scholars whose research would appear *a priori* isolated.

In this paper, we will focus on the preceding period, when many results were obtained about Gauss sums, quadratic forms, indeterminate equations, and other mathematical objects. It will enable us to put into perspective the exchanges held between these scholars in 1847. We will analyze a corpus of texts published after 1830 by Cauchy, Kummer, Dirichlet or Jacobi. We will emphasize the links between the various actors involved and their results. We will show that several mathematical results were in circulation in these research areas and used from different perspectives. (Received September 11, 2015)

1116-01-779 **Mohammad K. Azarian*** (azarian@evansville.edu), Department of Mathematics, University of Evansville, 1800 Lincoln Avenue, Evansville, IN 47722. *Nizām al-Dīn 'Abd al-'Alī ibn Muhammad ibn Husain al-Bīrjandī, a 16th Century Polymath Genius.* Preliminary report.

Nizām al-Dīn 'Abd al-'Alī ibn Muhammad ibn Husain al-Bīrjandī (known as 'Abd al-'Alī Bīrjandī) a student (and colleague) of both Jamshīd al-Kāshī and his cousin Mu'īn al-Dīn al-Kāshī, was a renowned 16th century Persian astronomer, mathematician, physicist, and logician, who lived in Birjand, the center city of Southern Khorāsān province in Iran. Like most people of that era, there is no record of his date of birth. However, it is believed that he died sometime in 934 A.H.L. (ca. 1528). He is buried in a village on the outskirts of the city of Birjand calld Wujd. From an inspiring list of Bīrjandī's work in diverse areas, without exaggeration, one could label him a polymath. He wrote some of his work in his native Persian language. However, to make his work more accessible to a wider readership he wrote most of his work in Arabic. Although he was known for his numerous contributions in astronomy, he also wrote impressive treatises, commentaries, and books on mathematics, astrology, logic, cosmology, and agriculture. The most well known of his work in the West is his Sharh-i Zaīj-i Ulugh Beg. (Received September 12, 2015)

1116-01-781 **Glen R Van Brummelen*** (gvb@questu.ca), 3200 University Boulevard, Squamish, BC V0N 1T0, Canada, and **James Byrne**, 3200 University Boulevard, Squamish, BC V0N 1T0, Canada. *Rheticus, Maurolico, and the Birth of the Secant Function.*

In 1551 Georg Rheticus published a small but remarkable set of trigonometric tables introducing all at once the secant, cosecant, and cotangent functions. His approach and terminology, later partly adopted by Viete, varies substantially from the common parlance of the time. Seven years later Francesco Maurolico published his own secant table, following a different tradition established by Regiomontanus. Later in the century, within the context of the emergence of trigonometry textbooks, this led to accusations of plagiarism. We examine the content and setting of both works, including an analysis of the tables themselves that leads to a resolution of the dispute four centuries later. (Received September 12, 2015)

1116-01-782 **Glen R Van Brummelen*** (gvb@questu.ca), 3200 University Boulevard, Squamish, BC V0N 1T0, Canada. *Al-Kashi's Two Methods for Finding* $\sin 1^\circ$.

Jamshīd al-Kāshī, a mathematical astronomer in Ulugh Beg's court at Samarqand in the early 15th century, devised a well-known method for computing $\sin 1^\circ$ — the fundamental quantity for constructing trigonometric tables — that has been compared to fixed-point iteration. Less known is another method found in his great astronomical handbook of a decade earlier, the *Khāqānī Zīj*. The dramatic differences between the two methods highlight falling disciplinary boundaries within mathematics, leading to a mathematical landscape much more familiar to modern readers. (Received September 12, 2015)

1116-01-831 **Maria Zack*** (mzack@pointloma.edu), Mathematical, Information & Computer Sciences, Point Loma Nazarene University, 3900 Lomaland Drive, San Diego, CA 92106. *Some Aspects of the History of the Cycloid.* Preliminary report.

The cycloid is a simple curve with an interesting history. Many well-known mathematicians of the seventeenth and eighteenth centuries studied the cycloid. These include Roberval, Descartes, Pascal, Wallis, Huygens,

Newton and Leibniz and a few Bernoullis. This talk will consider the work done on the cycloid by a few of these individuals and examine how their work connects to the development of some of the fundamental ideas of calculus. (Received September 13, 2015)

1116-01-1100 **Lawrence A. D'Antonio*** (ldant@ramapo.edu), 505 Ramapo Valley Rd., Mahwah, NJ 07430. *The* Vis Viva *Controversy: a Tercentenary Celebration.* Preliminary report.

What is the nature of force? What is the proper measure of force and is force conserved? These questions found traction in the late 17th and early 18th centuries. The controversy begins in 1686 with Leibniz proposing *vis viva* as an alternative measure of force to the Cartesian law of the quantity of motion. In this talk we will follow the dispute through the work of Wallis, Huygens, Boscovich, and ending with d'Alembert who asserted that the previous controversy was simply "*une dispute de mots.*" This talk celebrates two tercentenaries, the death of Leibniz in 1716 and the birth of d'Alembert in 1717 (Received September 16, 2015)

1116-01-1128 **Fernando Q Gouvêa*** (fqgouvea@colby.edu) and **Jonathan Webster**. *Determining the Discriminant.* Preliminary report.

Both number fields and polynomials have invariants called "discriminant". We will discuss the history of this concept from before it had a name to the work of Dedekind, who established its importance. If time allows, we will also discuss the problem of the "inessential divisors", discovered by Dedekind and finally solved by Hensel. (Received September 17, 2015)

1116-01-1145 **Craig Fraser*** (craig.fraser@utoronto.ca), Inst. Hist. Phil. Sci. Tech, University of Toronto, Victoria College, 91 Charles Street West, Toronto, Ontario M4K3A4, Canada. *Cauchy's Work on Complex Analysis in the 1820s.* Preliminary report.

In 1814 August-Louis Cauchy commenced the serious study of problems in analysis involving complex variables. The subject would engage him for the next forty years. During the 1820s a theory of functions of a complex variable began to come together in his extensive work on analysis. The paper examines Cauchy's evolving understanding of complex analysis during this period, paying particular attention to how he presented the subject material in his didactic treatises of 1821, 1823 and 1829. Topics to be explored include the identity of the theory of complex variables as a distinct part of analysis, and the role that geometric conceptions played in Cauchy's investigation. (Received September 17, 2015)

1116-01-1223 **Raymond Tennant*** (raymond.tennant@psuad.ac.ae), Paris Sorbonne University Abu Dhabi, PO Box 38044, Al Reem Island, Abu Dhabi, United Arab Emirates. *Geometric Techniques in Medieval Islamic Art and Architecture: From Strapwork Ornamentation to Quasicrystal Constructions.* Preliminary report.

The Islamic world has a rich artistic tradition of creating highly geometric and symmetric art and architecture. Throughout the Middle Ages, artisans in collaboration with mathematicians developed geometric techniques for producing periodic tilings from the Middle East and Central Asia to North Africa and Andalusia in Spain. Other historic architecture from the same period contains more intriguing non-periodic patterns that possess pentagonal quasicrystal symmetry similar to that of Penrose tiles. Early 10th Century writings like the Subtlety of Geometric Figures by philosopher Abu Nasr al-Farabi and Geometry Needed by Craftsmen by Khorasan mathematician Abu l-Wafa describe some construction methods of these medieval artisans. Later historic manuscripts like the 15th Century Topkapi Scroll provide insight into how other intricate designs might have been produced. In addition to historic writings, this paper looks at evidence from surviving medieval architecture to understand the symmetry of these patterns. Straightedge and compass constructions of regular shapes as well as approximations of non-constructible figures like regular 7-sided and 9-sided stars are investigated to further understand how the artisans achieved their aesthetic results. (Received September 18, 2015)

1116-01-1326 **Victor J. Katz*** (vkatz@udc.edu). *Medieval Mathematics in Three Languages.* Preliminary report.

When one thinks of medieval mathematics in Europe, the first ideas that come to mind are the introduction of the Hindu-Arabic number system with its algorithms as well as the first beginnings of algebra based on Latin translations from the Arabic. But there was far more mathematics developed and discussed in the European Middle Ages, not only in Latin but also in Arabic and Hebrew. In this talk we will particularly consider Hebrew and Arabic writings that involved sophisticated geometric and combinatorial ideas. The geometry often had its origins in Greek work, some of which had nearly been lost to Europe, while the combinatorial ideas, based on some fundamental religious concepts, were original to Muslim and Jewish authors. (Received September 18, 2015)

1116-01-1327 **Victor J. Katz*** (vkatz@udc.edu). *Mathematics in the Medieval Islamic West: Its Relationship to Hebrew and Latin Mathematics.* Preliminary report.

There has been much written in recent years about the mathematical contributions of Muslim mathematicians during the medieval period, mostly about contributions of mathematicians in Western Asia. But there was also significant mathematics accomplished by Muslim mathematicians in the Maghreb and Spain, where there were more possibilities of transmission of ideas to and from mathematicians writing in Latin or Hebrew in France, Italy, or Spain itself. This talk will consider some important ideas in advanced geometry, spherical trigonometry, and combinatorics that were discussed in Arabic in that time period and consider how these were related to similar work accomplished in Hebrew and Latin. (Received September 18, 2015)

1116-01-1341 **Jacqueline Feke*** (jfeke@uwaterloo.ca), University of Waterloo, Waterloo, Ontario , Canada. *Geometry's Indisputability: From Hero to Hobbes.*

In the first and second centuries, Hero of Alexandria and Claudius Ptolemy claimed that geometry was indisputable. Although philosophers had prized mathematics highly for centuries, Hero and Ptolemy cast geometrical proofs as superior to the work of philosophers. According to Hero, the statesman must employ geometry in order to distribute land precisely. According to Ptolemy, philosophers may seek knowledge but only mathematics can provide sure and incontrovertible knowledge to its practitioners. Moreover, the mathematical proofs that convey this knowledge are indisputable. After Ptolemy, only ten cases in the Greek corpus echo this claim to geometry's indisputability, but I argue that it had an overlooked and long-lasting effect. Proclus, the fifth-century Neoplatonist, appropriated it, and I argue that he took it one step further. While Hero and Ptolemy used it to position mathematics as superior to philosophers' discourses, Proclus employed it to transform them. He constructed his Elements of Theology and Elements of Physics in the style of a geometrical proof, and early-modern philosophers followed Proclus' lead. In this paper, I trace the influence of Hero and Ptolemy's portrayals of geometry's indisputability to the work of Descartes, Spinoza, and Hobbes. (Received September 18, 2015)

1116-01-1381 **Veronica Gavagna*** (vgavagna@unisa.it), Department of Mathematics, University of Salerno, Via Giovanni Paolo II, 132, I-84084 Fisciano, Italy. *Francesco Maurolico and the problem of filling space with regular polyhedra (1529).*

In 1528, the mathematician Francesco Maurolico (1494-1575) lectured on Euclid's *Elements* on behalf of the Senate of Messina. The unsatisfactory level of the available editions of the *Elements* convinced himself to provide a new edition, based on the known traditions but supplemented by some original contributions. Maurolico's reworking of Books XIII-XV, devoted to regular polyhedra, is particularly interesting for the increased number of new propositions. Maurolico's deep interest in these solids is also testified by *De impletione loci*, a work on the problem of filling space with regular polyhedra written in 1529. The goal of this writing is to confute the Averroes' remark (influenced by Aristotle) on the possibility of filling space with regular tetrahedra. The novelty is that Maurolico's approach to this problem was definitively mathematical and not philosophical: he measured the dihedral angles of the regular polyhedra and tested all the suitable combinations of the solids. Last but not least, in his studies on regular polyhedra Maurolico emphasized the discovery of a relationship among edges, faces and vertices that sounds as a kind of Euler's polyhedron formula. (Received September 19, 2015)

1116-01-1405 **Della Dumbaugh*** (ddumbaugh@richmond.edu), Department of Mathematics, University of Richmond, Richmond, VA 23173. *What makes a student the "best"?* Preliminary report.

Saunders Mac Lane has referred to A. Adrian Albert as Leonard Dickson's "best" student. How did Mac Lane determine this designation of "best"? In this talk, we consider the careers of three students of Leonard Dickson, A. Adrian Albert, Ko-Chuen Yang and Mina Rees, in order to explore how students are classified—or not—as "best" and how we might rethink that designation. (Received September 19, 2015)

1116-01-1491 **June Barrow-Green*** (june.barrow-green@open.ac.uk), Faculty of Mathematics, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom, and **Reinhard Siegmund-Schultze** (reinhard.siegmund-schultze@uia.no), Faculty of Engineering and Science, University of Agder, Serviceboks 422, 4604 Kristiansand, Norway. *"The first man whom you meet on the street": tracing back a well-known quotation by Hilbert.* Preliminary report.

In his famous lecture at the ICM in Paris in 1900, David Hilbert included a quotation on mathematical understanding which he attributed to "an old French mathematician" but with no hint as to whom he meant. This talk will discuss the quotation and describe the journey taken to trace its origin, a journey which starts in Paris and ends up—via Bradford and Brussels—in Montpellier, and passes by some misattributions along the way.
(Received September 20, 2015)

1116-01-1617 **Shigeru Masuda*** (hj9s-msd@asahi-net.or.jpj), 2-18-5, Tama-cho, Fuchu, 183-0002, Japan. *The Historical Derivatives of the Particular Value and the Particular Function in the Wave and Heat Theory.* Preliminary report.

We discuss Historical Development of Classical Heat Analyses, including Prévost 1792, Physico-Mechanical Researches of the Heat, Fourier 1822, Analytic Theory of the Heat, and Poisson 1835, Mathematical Theory of the Heat and finally Poincaré 1895 Analytic Theory of Propagation of Heat.

In the rivalry with Fourier, Poisson puts forth his personality independent of Fourier, the digressions on the mathematics. Poisson traces many historical facts of the origins of the wave equations including the trigonometric series by the trailblazers such as Euler, Lagrange, Laplace, Fourier, etc.

Poincaré puts forth many conceptions of pure analysis to solve the flux of heat from the viewpoint of up-to-date mathematical physics.

We talk about derivative productions of classical heat analyses such as particular value and eigenvalue, trigonometric series and its convergence, linear integral equation, meromorphic function, terrestrial system, or meteorology, etc. from the widely comparative viewpoint in the history of mathematics or mathematical physics. (Received September 20, 2015)

1116-01-1637 **Toke Knudsen*** (toke.knudsen@oneonta.edu), Dept. of Mathematics, Comp. Sci., and Stat., State University of New York at Oneonta, 108 Ravine Parkway, Oneonta, NY 13820. *The Contributions to Mathematics of Piet Hein.*

The Danish polymath Piet Hein (1905–1996) was a poet, author, inventor, scientist, mathematician, and world citizen. He is most famous for his grooks (Danish, *gruk*), short, subtle poems, often accompanied by drawings, of which he wrote over 7000 in Danish and English. His main mathematical preoccupation was combinatorics, and he invented several remarkable games and puzzles, including Hex and the Soma cube. His name is also associated with the superellipse and the superegg. Even though Piet Hein did impressive work in mathematics he is better known as a scientist, and a general study of his mathematics is lacking. This presentation will provide an overview of Piet Hein's life and contributions to mathematics. (Received September 21, 2015)

1116-01-1659 **Deborah Kent*** (deborah.kent@drake.edu). *Visualizing a constructive cubic solution: Omar Khayyam meets Oliver Byrne.*

Although a geometric solution to a cubic equation may seem peculiar to modern eyes, the study of cubic equations was initially motivated by geometric problems. Twenty-first century readers tend to lack fluency in reading proofs of this type without rewriting them in familiar algebraic notation. This presentation employs Oliver Byrne's application of colour and space to showcase one of Omar Khayyam's geometric constructions of a solution to a cubic. This graphical approach removes the modern reliance on algebraic notation and focuses instead on a visualization that emphasizes ratios, conic sections, and dimensional reasoning. (Received September 21, 2015)

1116-01-1677 **Peter J Lu*** (plu@fas.harvard.edu), 17 Oxford Street, Cambriidge, MA 02138. *Modern math in medieval islamic architectural tilings.*

The conventional view holds that girih (geometric star-and-polygon) patterns in medieval Islamic architecture were conceived by their designers as a network of zigzagging lines, and drafted directly with a straightedge and a compass. I will describe recent findings that, by 1200 C.E., a conceptual breakthrough occurred in which girih patterns were reconceived as tessellations of a special set of equilateral polygons (girih tiles) decorated with lines. These girih tiles enabled the creation of increasingly complex periodic girih patterns, and by the 15th century, the tessellation approach was combined with self-similar transformations to construct nearly-perfect quasicrystalline patterns. Quasicrystal patterns have remarkable properties: they do not repeat periodically, and have special symmetry—and were not understood in the West until the 1970s. I will discuss some of the properties of Islamic quasicrystalline tilings, and their relation to the Penrose tiling, perhaps the best known quasicrystal pattern. (Received September 21, 2015)

1116-01-1688 **Thomas Drucker*** (druckert@uww.edu), Department of Mathematics, University of Wisconsin–Whitewater, 800 West Main Street, Whitewater, WI 53190. *Programming Before Computers.* Preliminary report.

The importance of a mathematician's contributions to the development of the subject is not always appropriately measured by the number of theorems proved. Instead, a program can involve a wider vision, and many of the details are left to others to carry out. Frege's program for the logicization of arithmetic has continued to have an influence, even when there were flaws in his own attempt to carry it out. Leibniz's program for the mechanization of reason did not get nearly so far as Frege's, but it has also retained its importance, especially with regard to motivation. This talk will look at these two programs and their continuing influence, while comparing them with other research programs that were more conspicuously successful in detail. (Received September 21, 2015)

1116-01-1845 **John H Conway*** (conway@math.princeton.edu), Department of Mathematics, Fine Hall, Washington Road, Princeton, NJ 08544-1000. *The History of the Surreal Numbers.*

I shall describe the way I came to find the surreal numbers. In 1970, the British Go champion was a graduate student in the Cambridge mathematics department. This revived the idea I had for quite some time of adding the Sprague-Grundy theory of impartial games to the non-partial case. Nothing surprised me more than the fact that the resulting group of games contained the group of real numbers and many more! (Received September 21, 2015)

1116-01-1919 **Walter J. Meyer*** (meyer1@adelphi.edu). *The Long Birth of Modern Algebra for Undergraduates.*

Modern Algebra is usually thought to begin with Galois in the early 19th century – although it is reasonable to say it was not yet very modern back then. However one might quibble on that matter, plenty was known about groups and rings, and some things about fields as well, by the beginning of the 20th century, quite enough for undergraduate courses. But we have assembled data from the Cajori Two Project to show that undergraduate courses did not appear in appreciable numbers till after World War II. (Our data confirms a personal impression noted by G. D. Birkhoff.) This may seem like a long time, but another interpretation is possible. However you view it, it is natural to wonder what made these courses appear when they did. This paper is a data-based investigation, resting on work by historians of mathematical research, on the Cajori Two curriculum survey, and on consideration of the external factors impinging on mathematics in the 20th century. (Received September 21, 2015)

1116-01-1993 **B Lynn Bodner*** (bodner@monmouth.edu), Mathematics Department, Cedar Avenue, West Long Branch, NJ 07764. *Creating Medieval Islamic Ornamentation.* Preliminary report.

Islamic Art reached its apex during medieval times & the use of repetition to cover surfaces quickly became a main feature. How did medieval craftsmen create these elaborate patterns? There are few written records, but it most likely involved practical geometry & the use of a compass & straightedge. Meetings were held between theoretical mathematicians & craftsmen, & basic geometry instructions were given to artians. Architectural scrolls also show that polygonal grids may have been used by artisans - the Topkapi & Tashkent Scrolls contain just such repeat unit design sketches. Lastly, a 2007 article proposed that decagonal geometric patterns were reconceived as tessellations of a special set of 5 contiguous tile shapes, each with a unique decorative line pattern. Its authors contend that, "These tiles enabled the creation of increasingly complex periodic patterns, and by the 15th century, the tessellation approach was combined with self-similar transformations to construct nearly perfect quasi-crystalline Penrose patterns, 5 centuries before their discovery in the West." This presentation will provide illustrative examples of all of these approaches for creating geometric Islamic art & then discuss the pros, cons and limitations of each. (Received September 21, 2015)

1116-01-1999 **James Evans*** (jcevans@pugetsound.edu), Program in Science, Technology and Society, University of Puget Sound, 1500 North Warner Street, Tacoma, WA 98416. *The Antikythera Mechanism: A Masterpiece of Ancient Astronomy, Mechanics, and Mathematical Modeling.*

The Antikythera mechanism is a gear-work astronomical model and computing machine that was recovered in 1901 from an ancient shipwreck near the Mediterranean island of Antikythera. A wave of new research in the last two decades has clarified most of its functions. This machine, probably built around 200 BCE, recorded time in two calendars (the Egyptian solar calendar and a Greek luni-solar calendar). It displayed the changing positions of the sun and moon in the zodiac as well as the moon's phases. And it predicted the months and times of day of solar and lunar eclipses. Most likely, it also included displays of planetary phenomena. Gear trains provided a natural means of representing astronomical period relations. While the mechanism represents a Greek view of the universe, the underlying mathematics is largely Babylonian. This talk will give an overview of our present understanding of the Antikythera mechanism, with emphasis on the ancient mathematics that made it possible. (Received September 21, 2015)

1116-01-2038 **Laura E Turner*** (turnerl@newpaltz.edu). *The "patriotic duty not to nationalize science": aspects of the internationalization of mathematics in the late 19th and early 20th centuries.*

The development of mathematics during the late 19th and early 20th centuries is marked by a newfound drive and commitment to so-called "international" activity, be it through publishing in international journals, participating in international congresses, or less formal forms of communication and cooperation between representatives of different nations. In this talk, we focus on the roots of these behaviours, the reasons for which they were considered important and beneficial, and even the notion of international itself. In particular, we link these themes to broader discourses of civilization and nation-building, to the idea of the "peaceful competition" between peoples and nations and the power this engendered, and the deeply nationalistic, almost warlike character of some international exchanges themselves, undergone in the effort to cultivate and project a particular identity of mathematics to foreign contemporaries. (Received September 21, 2015)

1116-01-2104 **Colin B. P. McKinney***, 301 W Wabash Ave, Crawfordsville, IN 47933. *Four Curves of Alexis Clairaut.* Preliminary report.

In this talk, I will present some details of four families of curves presented by Alexis Clairaut when he was 12 years old. The curves all have applications in finding a number of means proportional between two given straight lines; one type is identical to the curves generated by Descartes' mesolabe compass. Clairaut also concerns himself with tangents to all four families of curves. (Received September 21, 2015)

1116-01-2431 **Janet L. Beery*** (janet_beery@redlands.edu). *The Mathematics of Thomas Harriot.*

Englishman Thomas Harriot (c. 1560-1621) may be best known today for having spent the winter of 1585-86 working to establish the Virginia Colony in America. However, in his own time he was known as an innovative mathematician and scientist, albeit one who never quite seemed to get around to publishing his work. The publication of Harriot's manuscript work on mathematics and science has been a dream of his friends and followers for over 400 years. Modern digitization and the efforts of Matthias Schemmel and Jacqueline Stedall have finally made that dream a reality. We review Harriot's publication history, assess the current state of Harriot scholarship, and suggest directions for the future. (Received September 22, 2015)

1116-01-2691 **Marsha H Cardenas*** (marshacardenas@yahoo.com), 8100 Turquoise St., El Paso, TX 79904. *Are You Smarter Than a Babylonian?* Preliminary report.

Mesopotamia is the land between two rivers, often called the Cradle of Civilization, "Old Babylon", Chaldea, and the Fertile Crescent. It is located in what is today, modern Iraq. Situated between the Tigris and Euphrates Rivers, Mesopotamia became the site for the remarkable birth of civilization, cities, technological sophistication, literary works, and mathematics. The "Old Babylonian" Period (1800 -1600 BC) has produced the majority of knowledge we know as "Mesopotamian mathematics". Mesopotamia was located on a common trade route with extensive business in merchandise, money exchange, taxes, harvest commodities, and real estate. These economic necessities gave rise to a wealth of mathematical invention. Babylonians were able to produce remarkable advances in mathematics by combining the use of the Sexagesimal numbering system and insightful systematic procedures with trial and error. Resources will be explored to introduce students to the high level of mathematical development in an effort to gain an understanding and appreciation for ancient Babylonian mathematics. (Received September 22, 2015)

03 ► Mathematical logic and foundations

1116-03-41 **Joel David Hamkins*** (jhamkins@gc.cuny.edu), Mathematics, CUNY Graduate Center, 365 Fifth Avenue, New York, NY 10016. *The hypnagogic digraph, with applications to embeddings of the set-theoretic universe.*

The hypnagogic digraph, a proper-class analogue of the countable random $\mathbb{Q}$-graded digraph, is a surreal-numbers-graded acyclic digraph exhibiting the set-pattern property (a form of existential-closure), making it set-homogeneous and universal for all class acyclic digraphs. A natural copy of this canonical structure arises during the course of the usual construction of the surreal number line, using as vertices the surreal-number numerals $\{\, A \mid B \,\}$. I shall explain the construction and elementary theory of the hypnagogic digraph and describe recent uses of this digraph in connection with embeddings of the set-theoretic universe, such as in the proof that the countable models of set theory are linearly pre-ordered by embeddability. Questions and commentary concerning this talk can be posted on my blog at http://jdh.hamkins.org/the-hypnagogic-digraph-jmm-2016/.
(Received June 15, 2015)

1116-03-66 **Carl Jockusch*** (jockusch@math.uiuc.edu), Department of Mathematics, University of Illinois at Urbana-Champaign. *Imperfect algorithms, asymptotic density, and Turing degrees.*

I will consider partial algorithms for subsets of ω which answer correctly on a set of (asymptotic) density 1. A set $A \subseteq \omega$ is said to be *generically computable* if there is a partial computable function φ which agrees with A on its domain and has a domain of density 1. A set $A \subseteq \omega$ is said to be *coarsely computable* if there is a (total) computable function f which agrees with A on a set of density 1. I will consider the Turing degrees of sets which have various Boolean combinations of these properties. I will also discuss the corresponding weaker notions where "density 1" is weakened to "lower density at least r" for a given real number r in the unit interval. This leads to two natural assignments of real numbers in the unit interval to subsets of ω and to Turing degrees, corresponding to the weakened versions of generic and coarse computability. I will look at the relationship between these two assignments and their respective ranges. This is joint work with a number of people, including Uri Andrews, Mingzhong Cai, David Diamondstone, Rod Downey, Denis Hirschfeldt, Steffen Lempp, Tim McNicholl, and Paul Schupp. (Received September 10, 2015)

1116-03-67 **James Freitag*** (freitagj@gmail.com), UCLA Mathematics Department, Box 951555, Los Angeles, CA 90095-1555. *Differential algebra and special points conjectures.*

Special points conjectures are a general class of problems in arithmetic geometry. One is given a set of special points, $\mathcal{S}$, usually with some arithmetic significance, inside of some variety V. The general problem is to understand how this set $\mathcal{S}$ intersects subvarieties of V. For instance, in which subvarieties $W \subset V$ is the set $\mathcal{S}$ dense? Examples of conjectures (and theorems) which fit this template are the Manin-Mumford conjecture, the André-Oort conjecture, the Pila-Wilkie theorem.

We will describe a special points conjecture in which $\mathcal{S}$ consists of an isogeny class of a product of elliptic curves. Though far from being definable sets in any tame structure, isogeny classes satisfy a differential equation which is closely related to the j-function. Analyzing the properties this differential equation allows us to prove results regarding the intersections of $\mathcal{S}$ with varieties. Model theory can be used to make these results effective. The structure of the differential equation satisfied by the j-function also allows us to answer a question of Hrushovski about strongly minimal sets in differentially closed fields. We will also explain some extensions of the these ideas to other automorphic functions. (Received September 10, 2015)

1116-03-69 **Dana Bartosova***, Instituto de Matematica e Estatistica, Universidade de Sao Paulo, Sao Paulo, Brazil. *Ramsey properties in topological dynamics.*

We will explain how Ramsey-type properties of (discrete or metric) Fraïssé classes (amalgamation classes of finitely-generated structures with the joint embedding property) can be expressed in terms of automorphism groups of their limit structures. We were motivated by work of Kechris, Pestov and Todorčević who discovered an equivalence between the Ramsey property for classes of finite structures and extreme amenability of automorphism groups of their limits, and provided powerful tools to compute universal minimal flows. A topological group is *extremely amenable* if it has a fixed point under every continuous action on a compact Hausdorff space. For a topological group G, a continuous action (or a *flow*) on a compact Hausdorff space is *minimal* if it contains no proper closed G-invariant subset. A minimal flow is the universal minimal flow of G if every other minimal flow is its quotient.

We will mention our recent Ramsey-type results (with A. Kwiatkowska and J. Lopez-Abad and B.R. Mbombo) and their applications in dynamics and discuss a couple of future directions. For instance, it is not know what the universal minimal flows of the homeomorphism groups of the two-dimensional Euclidean sphere, the Hilbert cube or the pseudo-arc are. (Received September 23, 2015)

1116-03-160 **Radhakrishnan Balu*** (radhakrishnan.balu.civ@mail.mil), radhakrishnan.balu.civ@mail.mil. *Open quantum walk based bias removal algorithms.* Preliminary report.

We consider structured maps to build quantum stochastic flows that capture the evolution of discrete time and discrete state Markov chains. These constructions are interpreted as open quantum walks on a connected graph. Within this framework we discuss algorithms that remove bias, if there is any, in finite outcome probabilistic experiments. We comment on the fixed points of the flows, complexity of the algorithms, and possible applications. (Received September 12, 2015)

1116-03-239 **Jindrich Zapletal***, Department of Mathematics, University of Florida, Gainesville, FL 32611. *Interpretations of topological spaces.*

There is a natural covariant interpretation functor which makes it possible to interpret topological spaces from a wellfounded model of ZFC in a larger wellfounded model of ZFC. There is a wide topological category (the interpretable spaces) on which the interpretation functor commutes with many natural operations, and preserves many properties of popular topological structures. This places the folkloric forcing calculus regarding Polish spaces on a firm foundation and extends it to the non-separable context. The subject resonates with basic concerns of functional analysis and general topology. (Received August 17, 2015)

1116-03-260 **Paula Rangel*** (paularangell@gmail.com), Avenida José Luiz Ferraz, 550 Apt. 1505, Recreio dos Bandeirantes, Rio de Janeiro, Rio de Jan 22790587, Brazil. *The Influence of Language in the Students' Reasoning.* Preliminary report.

The presence of mathematics in the lives of humans is undeniable. It has accompanied the history of mankind throughout the ages. Math is a universal language that goes beyond the barriers of time and space. However,the poor performance of many students is observed on issues related to mathematics, there is an increasing difficulty in this discipline. Many people believe that these difficulties are due to the fact that mathematics involves logical reasoning. Others attribute these difficulties to the language used in mathematics, arguing that it is difficult to understand. The main objective of this work is to verify the influence of language on the performance of a group of students. To achieve this goal, an empirical analysis of the performance of students of a municipal school located in the city of Rio de Janeiro, Brazil, was made in two issues resolution: one involving only logical reasoning and Portuguese and another involving only logical reasoning and mathematics language. The objective was not to test "content", but the influence of language on students' thinking. Thus, the questions were designed so that the fact that the student remember or not the "content" should not influence the resolution of the issues. In the end, the answers were analyzed and compared. (Received August 18, 2015)

1116-03-311 **Ashvin Anand Swaminathan*** (aaswaminathan@college.harvard.edu), 388 Eliot Mail Center, Harvard College, 101 Dunster Street, Cambridge, MA 02138, and **Simon Rubinstein-Salzedo** (complexzeta@gmail.com). *Analysis on Surreal Numbers: Functions and Integration.*

The class **No** of surreal numbers possesses a rich numerical structure and shares many arithmetic and algebraic properties with the real numbers, and some work has also been done to develop analysis on **No**. In this talk, we propose surreal definitions of the arctangent and logarithm functions using truncations of Maclaurin series. Moreover, by defining a new topology on **No**, we obtain the Intermediate Value Theorem even though **No** is not Cauchy complete, and we prove that the Fundamental Theorem of Calculus would hold for surreals if a consistent definition of integration exists. (Received September 18, 2015)

1116-03-409 **Tobias Kaiser*** (tobias.kaiser@uni-passau.de), Faculty of Computer Science and Mathematics, University of Passau, 94030 Passau, Germany. *Lebesgue measure and integration theory on arbitrary real closed fields.*

We have established for the category of semialgebraic sets and functions on arbitrary real closed fields a full Lebesgue measure and integration theory such that the main results from the classical setting hold. The construction involves methods from model theory, o-minimal geometry, valuation theory and the theory of ordered abelian groups. It is set up in such a way that it is uniquely determined by data that can be formulated completely in terms of the given real closed field. We present the construction for the field of real Puiseux series. (Received August 31, 2015)

1116-03-464 **Bakh Khoussainov*** (bmk@cs.auckland.ac.nz). *Algorithmically random infinite structures.*

Over the last two decades a significant progress has been made in the study of algorithmic random infinite strings. The main concepts of algorithmic randomness on infinite strings are based on the natural measure on the Cantor space. In spite of much work, research on algorithmic randomness has excluded the investigation of randomness for infinite structures such as graph, trees, algebras. The reason is that it was unclear how one introduces a meaningful measures into these classes of structures that would be pivotal in defining algorithmic randomness. We provide a solution to this problem. We present an axiomatic approach that introduces measure, and hence algorithmic randomness into various classes of structures. We prove the existence of algorithmically random structures with various computability-theoretic properties. We show that any nontrivial variety of algebras has an effective measure 0. This, for instance, implies that no finitely presented algebra in a variety is algorithmically random. We also prove a counter-intuitive result that there are algorithmically random yet computable structures. This establishes a connection between algorithmic randomness and computable model theory. (Received September 02, 2015)

1116-03-467 **Elliot Alexander Kaplan*** (eakapla2@illinois.edu) and **Philip Ehrlich**. *Number systems with simplicity hierarchies: a generalization of Conway's theory of surreal numbers II.*

In 2001, the second author brought to the fore the algebraico-tree-theoretic simplicity hierarchical structure of J. H. Conway's ordered field **No** of surreal numbers and employed it to provide, among other things, necessary and sufficient conditions for an ordered field to be isomorphic to an initial subfield of **No**, i.e. a subfield of **No** that is an initial subtree of **No**. In this presentation, analogous results for ordered groups and ordered domains are established which in turn are employed to characterize the convex subgroups and convex subdomains of initial subfields of **No** that are themselves initial. It is further shown that an initial subdomain of **No** is discrete if and only if it is an initial subdomain of **No**'s canonical integer part **Oz** of omnific integers. (Received September 18, 2015)

1116-03-469 **Erwin - Engeler*** (engeler@math.ethz.ch). *Neural Algebra and Modelling.*

The mathematical model introduced in this paper attempts to explain how complex scripts of behavior and conceptual contents can reside in, combine and interact on large networks of interconnected basic actors. The approach derives from modeling the neural structure and dynamics of the connectome of a brain. The neurological hypothesis attributes functions of the brain to sets of firing neurons, dynamically as sets of cascades of such firings, typically visualized by imaging technologies. Such sets are represented as the elements of what we call a neural algebra, and their interaction as its basic operation. In particular we analyze the representation of perception and of control in its various forms, distributed, hierarchical, recursive and especially reflexive control, the latter modeling the concept of self-reflecting control. The main thrust of this paper develops from the fact that characteristic properties of these suggestive notions can be cast in the form of equations of the neural algebra. Analyzing the solutions leads to a complete description of the necessary structure of their neural correlates. (Received September 03, 2015)

1116-03-691 **Lou van den Dries*** (vddries@illinois.edu), IL. *Transseries: algebra and model theory.*

The field of Laurent series (with real coefficients, say) has a natural derivation but is too small to be closed under integration and other natural operations such as taking logarithms of positive elements. The field has a natural extension to a field of generalized series, the ordered differential field of transseries, where these defects are remedied in a radical way. I will sketch this field of transseries. Recently it was established (Aschenbrenner, Van der Hoeven, vdD) that the differential field of transseries also has very good model theoretic properties. I will discuss this in the later part of my talk.

Here is a link to our book on the subject: http://arxiv.org/abs/1509.02588 (Received September 10, 2015)

1116-03-696 **Lou van den Dries*** (vddries@illinois.edu). *The surreals as a differential field.*

Berarducci and Mantova have recently equipped the field of surreal numbers with a natural derivation. In joint work with Aschenbrenner and Van der Hoeven we have shown that the resulting differential field of surreals is elementarily equivalent to the differential field of transseries. The model theory of the latter is the subject of our book

"Asymptotic Differential Algebra and Model Theory of Transseries"

Here is a link to it: http://arxiv.org/abs/1509.02588 (Received September 10, 2015)

1116-03-791 **Jouko A Vaananen*** (jouko.vaananen@helsinki.fi), Department of Mathematics and Statistics, PL 68, 00014 Helsinki, Finland. *Dependence logic and biology.*

An essential part of science is detecting variation in data. I will give an introduction to dependence logic (1), an approach to logic emphasising the detection of variation and dependences between variables. I will discuss algorithmic and model theoretic properties of dependence logic, and its relation to other notions of dependence e.g. dependence in biology, model theory, computer science, quantum physics, and economics.

In science it is natural to consider probabilities of formulas rather than just the truth values true/false. Suppose we have a set of assignments of fixed variables into the domain of a first order structure. We call such sets teams. Semantics based on teams is the underlying concept of dependence logic. We may ask, what is the probability that a randomly chosen assignment in a team satisfies a given first-order formula in the structure? The Hardy-Weinberg Theorem is an example of such a first order property of probabilities in teams. In (2) we give axioms for making inferences about first-order properties of probabilities, and prove the completeness of our axioms.

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1116-03-1031 **Vince Guingona*** (vguingona@wesleyan.edu), Department of Mathematics and C.S., Wesleyan University, Exley 655, 265 Church Street, Middletown, CT 06459-0128. *A local characterization of VC-minimality.*

This work is joint with Uri Andrews. This talk combines elements of computable model theory and neostability theory. I discuss VC-minimality, a model-theoretic notion of complexity for theories. Unlike other similar notions (e.g., dp-minimality, stability, NIP), it is difficult to determine whether or not a given theory is VC-minimal. In terms of computability, the usual definition of VC-minimality is Σ^1_1. However, my coauthor and I show that there is a local characterization of VC-minimality (for countable languages). As a corollary, VC-minimality is actually Π^0_4-complete. This leads to a list of examples of theories whose VC-minimality is determined. (Received September 16, 2015)

1116-03-1039 **Mark Furtney*** (mfurtney@alum.mit.edu). *Talking Quantum: Prattle –> Chatter –> Ask –> Solve.*

This talk describes some of the trials, tribulations, triumphs, and features involved in the early development of a language for communication with the only commercially-available Quantum Computing System (from D-Wave Systems). ToQ (pronounced "To Q") is a simple, C-like language which translates user programs into a series of Quantum Machine Instructions for execution on a D-Wave System, and delivers the results back to the user.

By many measures, Quantum Computing is still in its "Pre Vacuum Tube Era." And so it is with quantum computing language development. ToQ is still in its infancy, and has escaped neither controversy, nor false paths, nor criticism, but it has also received very positive feedback from early users - mostly because they are able to focus on their problem domains and not worry about the quantum details of the run-time system. In particular, users have noticed that often, building a ToQ program is in fact the solution. ToQ programming requires a fundamentally different way of thinking.

The evolution of the language and its features will be described, along with its strengths, weaknesses, successes, warts, and paths for future development. The audience may be challenged with a few simple problems, and ToQ solutions will be discussed. (Received September 16, 2015)

1116-03-1068 **Ronald G. Fuller*** (ronald.fuller@wipro.com). *Logic is the missing link in information management.*

People who manage information have known since the 1970's that logic can be used to query information in databases, but the use of logic to *organize* information is not well understood by modern practitioners. Frike [1] states "A greatly underappreciated and unused theoretical background to the organization of information is that of symbolic logic. (The monumental and authoritative Encyclopedia of Library and Information Sciences, Third Edition, 2009, does not have an entry for logic in its 6,856 pages ...)" (p 121). Yet logic has been used, informally but effectively, to organize information for more than 700 years. This session will discuss the following: (a) how the system of interconnected books used in double-entry bookkeeping since the 13th century is precisely consistent with the relational model and, therefore, first-order logic; (b) how cultural and historical factors have undermined modern recognition of important principles and the effective use of logic in organizations; and (c) how logic education and practical application can help enterprise organizations overcome their most difficult and costly challenges in information management.

[1] Martin Fricke, *Logic and the Organization of Information* (Springer, 2012). (Received September 16, 2015)

1116-03-1076 **Ronald G. Fuller** (ronald.fuller@wipro.com) and **Peter Cardon*** (cardon@marshall.usc.edu). *Sophotaxis.*

Sophotaxis (Greek *wisdom* + *order*) combines the notion of entailment with that of intent. If a relational signature can be used to express an intended set of statements and their antecedents, then it is *sophotaxically complete*; if it cannot, then it is *sophotaxically deranged* or incomplete. This concept has important application in the field of enterprise information management. Organizations are frequently unable to produce desired outputs even when their systems are known to contain all necessary inputs. Important meaning and context is lost when those inputs are sophotaxically deranged. New information sources can be created by almost any individual at any level of an organization, so education in fundamental logic and logic-aware management are necessary if enterprise organizations wish to create information systems capable of meeting their expectations. (Received September 16, 2015)

1116-03-1193 **Maarten McKubre-Jordens*** (maarten.jordens@canterbury.ac.nz), School of Mathematics & Statistics, University of Canterbury, Private Bag 4800, Christchurch, Canterbury 8140, New Zealand. *Non-Classical Mathematics, Forward and In Reverse.*

Non-classical mathematics is mathematics done with non-classical logics. Examples include constructive mathematics, relevant mathematics, and paraconsistent mathematics. This talk concerns the interaction of classical mathematics with non-classical mathematics, and is a presentation with two aspects: Forward, and In Reverse.

In the Forward aspect, we investigate formalizations of various paradoxes, such as Russell's, in which individual parts of the paradoxical conclusion are provable, but where the formal theory itself is non-trivial. Formal theories in which such statements are provable in the literature almost invariably explicitly use a paraconsistent logic, and often lack motivation. But here, by suggesting extra criteria on what is admissible as a proof, we provide an alternative motivation wherein less violence is done to the notion of provability and some long-held intuitions concerning paradoxes are explicitly incorporated.

In the Reverse aspect, we study various versions of logical principles sometimes known as "paradoxes of material implication" over minimal logic, and find a clean set of groups into which these principles can be distinguished, which is indiscernible within classical (or even constructive) contexts. (Received September 17, 2015)

1116-03-1208 **Philip Ehrlich*** (ehrlich@ohio.edu), Ohio University, Department of Philosophy, Ellis Hall 202, Athens, OH 45701, and **Ovidiu Costin** and **Harvey M Friedman**. *Integration on the Surreals: A Conjecture of Conway, Kruskal and Norton.*

A longstanding aim has been to develop analysis on the system **No** of *surreal numbers* as a powerful extension of ordinary analysis on $\mathbb{R}$. This entails finding a natural way of extending important functions $f : \mathbb{R} \to \mathbb{R}$ to functions $f^* : \mathbf{No} \to \mathbf{No}$, and naturally defining integration on the f^*. In this work the authors address this and related unresolved issues with positive and negative results. In the positive direction, we show that semi-algebraic, semi-analytic, analytic, meromorphic, Borel summable or more generally Écalle-Borel transseriable functions at $+\infty$ extend naturally, and an integral with good properties exists on them. In the negative direction, we show there is a fundamental set-theoretic obstruction to naturally extending (a fortiori integrating) many larger families of functions including entire ones with rapid decay at $+\infty$. (Received September 21, 2015)

1116-03-1247 **Chris Lambie-Hanson*** (clambiehanson@math.huji.ac.il). *Robust reflection principles.*

It is a common motif in set theory that, if κ is a large cardinal (Mahlo, weakly compact, measurable, supercompact, etc.), then κ satisfies certain interesting reflection principles. In addition, because most large cardinal notions are preserved under small forcing extensions, i.e. forcing extensions by posets with cardinality less than κ, these reflection principles, when they hold at large cardinals, are also robust under small forcing. It has been a fruitful line of research to consider the extent to which these reflection principles can hold at smaller cardinals. However, these principles can in general fail to be preserved by small forcing when they hold at small cardinals. Focusing on stationary reflection and the tree property, we discuss situations in which reflection principles can fail to be robust under small forcing, introduce natural strengthenings which are implied by large cardinals and which are in all cases robust under small forcing, and consider the extent to which these strenthenings can hold at small cardinals. (Received September 18, 2015)

1116-03-1281 **Ovidiu Costin*** (costin.9@osu.edu), Math Tower, 231 W 18th Ave, Columbus, OH 43210, and **Philip Ehrlich** and **Harvey M Friedman**. *Integration on the Surreals: A Conjecture of Conway, Kruskal and Norton.*

A longstanding aim has been to develop analysis on the system **No** of *surreal numbers* as a powerful extension of ordinary analysis on $\mathbb{R}$. This entails finding a natural way of extending important functions $f : \mathbb{R} \to \mathbb{R}$ to functions $f^* : \mathbf{No} \to \mathbf{No}$, and naturally defining integration on the f^*. In this work the authors address this and related unresolved issues with positive and negative results. In the positive direction, we show that semi-algebraic, semi-analytic, analytic, meromorphic, Borel summable or more generally Écalle-Borel transseriable functions at $+\infty$ extend naturally, and an integral with good properties exists on them. In the negative direction, we show there is a fundamental set-theoretic obstruction to naturally extending (a fortiori integrating) many larger families of functions including entire ones with rapid decay at $+\infty$. (Received September 18, 2015)

1116-03-1521 **Alessandro Berarducci*** (berardu@dm.unipi.it), Dipartimento di Matematica, Largo Bruno Pontecorvo 5, 56127 Pisa, PI, Italy, and **Vincenzo Mantova** (vincenzo.mantova@sns.it), Piazza dei Cavalieri 7, 56126 Pisa, PI, Italy. *Transserial derivations on surreal numbers.*

We shall present our recent work on ordered differential fields and Conway's surreal numbers, leading to a solution of the conjecture that Conway's surreal numbers admit the structure of a field of transseries and a compatible derivation. We shall also investigate a notion of composition of surreal numbers and its compatibility with a surreal derivation, leading to partial results and intriguing conjectures. (Received September 20, 2015)

1116-03-1522 **Alessandro Berarducci** (berardu@dm.unipi.it), Dipartimento di Matematica, Largo Bruno Pontecorvo 5, 56127 Pisa, PI, Italy, and **Vincenzo Mantova*** (vincenzo.mantova@sns.it), Piazza dei Cavalieri 7, 56126 Pisa, PI, Italy. *Transserial derivations on surreal numbers.*

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1116-03-1649 **Joachim Mueller-Theys*** (mueller-theys@gmx.de). *Does the Consistency Sentence Really State Consistency?*

The *Second Incompleteness Theorem* actually makes 2 assertions:
(1) Con_Σ states that Σ is consistent;
(2) $\Sigma \nvdash \mathrm{Con}_\Sigma$ if $\Sigma \supseteq \Sigma_{\mathrm{PA}}$ is consistent.

(1) had no explicit definiens.

If (1) is—as the definiendum, lacking another statement of place, suggests—related to (the theory of) Σ, then, as we will show, (2) implies *non* (1), whence (1) & (2) becomes a *contradiction in terms.* In addition, the generalisation: κ states consistency, cannot be fulfilled at all.

If Σ is decidable, (1) becomes true *in* $\mathrm{Th}\,(\mathcal{N})$, the deductively inaccessible theory of arithmetics.

More innately, κ states that Σ is consistent :iff $\Sigma \nvdash \kappa$. Consequently, if Σ is consistent, all of the then existing κ, unprovable from Σ, state this, and, if Σ is inconsistent, *no* κ states that Σ is consistent. If (1) is interpreted in this way, (1) follows from (2), but Con_Σ *is not distinguished from any other* $\Sigma \nvdash \kappa$.

Compare the ASL abstract. Joint work with Wilfried Buchholz. (Received September 23, 2015)

1116-03-1664 **Solomon Feferman*** (feferman@stanford.edu), Department of Mathematics, Stanford University, Stanford, CA 94305. *Many-sorted first-order model theory as a conceptual framework for complex dynamical systems.* Preliminary report.

When complex biological systems (among others) are conceived reductively, they are modeled in set-theoretical hierarchical terms from the bottom up. But the point of view of Systems Biology (SB) is to deal with such systems from the top down. So in this talk I will suggest the use of many-sorted first-order structures with downward nested sorts as an alternative conceptual framework for modeling them. In particular, the notion of a nested substructure allows one to study parts of a structure in isolation from the rest, while the notion of restriction allows one to study a structure relative to some of its parts treated as black boxes. The temporal dimension can be incorporated both as an additional sort and in the indexing of sorts, allowing for both static and dynamic views of a system. Furthermore, one may make use of a quite general theory of recursion on many-sorted first-order structures that includes both discrete and continuous computation. Some possible applications of this model-theoretic approach to SB include excision or substitution of a part as operations on structures, similarity of biological systems via similarity notions for structures, and homeostasis via fixed point recursion.
(Received September 21, 2015)

1116-03-1667 **Katalin Bimbó*** (bimbo@ualberta.ca), University of Alberta, Department of Philosophy, 2–40 Assiniboia Hall, Edmonton, Alberta T6G2E7, Canada. *Connections between relational semantics for $E_{\to}$ and E.*

$E_{\to}$ can be seen (and has been claimed) to capture the core features of entailment. There is a well-known relational semantics for E (the logic of entailment) and E_+ (the positive fragment of E). There are many variations on these semantics. (See e.g., Bimbó, K. and J. M. Dunn, *Generalized Galois Logics: Relational Semantics of Nonclassical Logical Calculi*, vol. 188 of CSLI Lecture Notes, Stanford, CA, 2008.) We show that the straightforward *restriction* of the relational semantics for E to a semantics for $E_{\to}$ is sound, but not complete with several naturally emerging notions that could replace prime filters in the completeness proof for E (or E_+). The addition of extensional conjunction or of intensional conjunction and truth alleviates the previous difficulties

in the semantics, which led to the idea of a modification in the definition of the canonical accessibility relation. We prove that $E_{\rightarrow}$ is complete for this semantics when prime filters are replaced by cones. We also show that this semantics *extends* to the usual relational semantics for E, because the stronger definition of the accessibility relation simplifies in the presence of all the connectives of E. (Received September 21, 2015)

1116-03-1720 **Francis Adams*** (fsadams@ufl.edu). *Extending Anticliques in Borel Graphs.* Preliminary report.

Following a theorem of Zapletal, I will be investigating the question of when an anticlique in a Borel graph on a Polish space can be extended to a Borel anticlique. This includes the case of extending a partial selector for a Borel equivalence relation to a Borel partial selector. This question produces a cardinal characteristic for each Borel graph, that is, the least cardinality of an anticlique that doesn't extend to a Borel one. I will look at some properties of these characteristics and compare them to more standard characteristics such as $\mathfrak{p}$, $non(null)$, and $\mathfrak{b}$. (Received September 21, 2015)

1116-03-1869 **Atila Prates Correia*** (atila.correia@usp.br), Rua Dr. Tito Roberto Liberato 63, Apartment 904, Aquarius, Sao Jose dos Campos, Sao Paulo 12246150, Brazil.
N-dimensional De Morgan Algebras and Further Applications.

This article exhibits specific cases of two and three dimensional De Morgan algebras, their relative generalizations to any higher dimension (which are not De Morgan), their properties and some applications. An attentive reader shall realize its theorems are quite similar to those of the Boolean algebra. Indeed, the resulting sets and its operations presented in the first and third sections came out from a personal struggling to generalize the Godel's algebra, which is already an enlargement of the Boolean. In fact, if we set $n = 1$ in the addition and product definitions given below, they are exactly reduced to their suchlike Godel's versions. Nonetheless, the n-dimensional negation, when restricted to $n = 1$, is closer in meaning to the corresponding Fuzzy algebra version, that is to say, $\neg\, x = 1 - x$. In the second section, it is presented an application to a page rank algorithm based on the previous theoretical development. Although it does not work as a search tool, it can be used by all of them. At last, within the same application, it must be emphasized there is given a function which allows us to determine the efficiency of the Internet sharing behavior, either locally and globally. (Received September 21, 2015)

1116-03-1936 **Oscar Levin** and **Taylor McMillan*** (mcmi9872@bears.unco.edu), 1229 12th St., Greeley, CO 80631. *Embeddings of Computable Planar Graphs.*

Planar graphs are those which have embeddings in the plane without edges crossing. Extending to infinite graphs, we can ask how difficult it is to produce a planar embedding for a given planar graph. To make sense of this question, we consider *computable* graphs and ask whether there is a computable function which describes the planar embedding. We give three potential definitions for a computable graph to be computably planar and show that in each case there are computable graphs which are planar but not computably planar. (Received September 21, 2015)

1116-03-2048 **Julia F. Knight** and **Karen M. Lange*** (karen.lange@wellesley.edu). *Lengths of developments in $K((G))$.*

In [2], Mourgues and Ressayre showed that any real closed field R can be mapped isomorphically onto a truncation-closed subfield of the Hahn field $K((G))$, where G is the natural value group of R and K is the residue field. If we fix a section of the residue field and a well ordering $\prec$ of R, then the procedure of Mourgues and Ressayre yields a canonical value group section, and a unique embedding $d : R \rightarrow K((G))$ such that $d(R)$ is truncation closed.

In [1], we conjectured that if $\gamma = \omega$, then all elements of $d(R)$ have length less than $\omega^{\omega^{\omega}}$. We can now prove the conjecture. We also generalize the conjecture to well orderings γ of arbitrary countable type, provided that the value group G is *Archimedean*. Here we provide an overview of the background, results, and proofs. Knight will provide more details in a later talk.

[1] J. F. Knight and K. Lange, "Complexity of structures associated with real closed fields", *Proc. of London Math. Society*, 107(2013), 177-197.

[2] M. H. Mourgues and J. P. Ressayre, "Every real closed field has an integer part", *J. Symb. Logic*, 58(1993), 641-647. (Received September 21, 2015)

1116-03-2057 **Scott S Cramer*** (cramer@math.rutgers.edu), 110 Frelinghuysen Rd., Piscataway, NJ 08854. *Tree representations from very large cardinals.*

We will discuss the propagation of certain tree representations in the presence of very large cardinals. These tree representations give generic absoluteness results and have structural consequences in the area of generalized descriptive set theory. In fact these representations will give us a method for producing models of strong determinacy axioms. (Received September 21, 2015)

1116-03-2068 **Lynn Scow*** (lyscow@vassar.edu). *Transfer of the Ramsey Property between Classes.* Preliminary report.

A class of finite structures is *Ramsey* if it satisfies a certain partition property: for all $A, B \in \mathcal{K}$ there is some big enough $C \in \mathcal{K}$ so that for any coloring of copies of A in C there is a copy of B in C all of whose copies of A are colored the same color under this coloring. We look at some category-theoretic and model-theoretic approaches to transfering the Ramsey property from one class to another. (Received September 21, 2015)

1116-03-2264 **Matthew Jura** and **Oscar Levin*** (oscar.levin@unco.edu), School of Mathematical Sciences, University of Northern Colorado, Greeley, CO 80639, and **Tyler Markkanen**. *Graphs between computable and highly computable.*

There are features of countable graphs whose behavior, in terms of computability theory, depends on the complexity of the neighborhood relation. Specifically, the behavior changes when we move from computable graphs to highly computable graphs. It is natural, therefore, to ask what happens between these two extremes. An A-computable graph is a computable, locally finite graph for which A can compute the neighbors of a given vertex. Gasarch and Lee first investigated these graphs and proved that for any noncomputable c.e. set A, the A-computable graphs behave just like computable graphs when it comes to chromatic number. In this talk we consider a similar result for Euler paths. We then take up the question of what happens in the case when A is merely noncomputable Δ^0_2. We show the theorems which hold of noncomputable c.e. sets do not extend to all $A \in \Delta^0_2$ and classify those sets for which they do. (Received September 22, 2015)

1116-03-2373 **Thomas C Hales***, Mathematics Department, Thackeray Hall, University of Pittsburgh, Pittsburgh, PA 15260. *Formal Proof.*

A theorem is formally verified if every step of the proof has been checked at the level of the primitive inference rules of logic and the foundational axioms of mathematics. Because of the number of steps involved, formal proofs are generally carried out by computer.

This presentation will describe some of the major theorems that have been formally verified in recent years. Looking forward, we might imagine the day when formal verification is in widespread use by mathematicians and software systems. (Received September 22, 2015)

1116-03-2429 **Luke Stephen Serafin*** (lserafin@alumni.cmu.edu). *Cardinal Characteristics Above the Continuum.* Preliminary report.

Cardinal characteristics of the continuum provide an efficient means of summarizing combinatorial facts about ${}^{\omega}\omega$ and similar structures, and the relationships between these structures provide a rich theory and collection of open problems. It is natural to ask how this theory generalizes above the continuum, say by replacing ${}^{\omega}\omega$ by ${}^{\kappa}\kappa$. We explore such a generalization and prove that various inequalities between characteristics of the continuum generalize upward, some of these results being original. (Received September 22, 2015)

1116-03-2515 **Justin Brody***, justin.brody@goucher.edu. *Amalgamation Classes with ∃-Closures and a Conjecture of Moss'.*

The Hrushovski construction amalgamates members of a class of finite structures $(\mathbf{K}, \leq)$ together in a canonical way to produce a *generic* structure of the class, where $\leq$ is strong-substructure relation on elements of $\mathbf{K}$. Most examples satisfy the property that for $A, B, C \in \mathbf{K}$ if $A \leq B$ then $A \cap C \leq B \cap C$. This property guarantees the uniqueness of a closure operation in the generic. In this talk we will examine properties of classes which do not have this property but are well-behaved in other ways, which we call having ∃-closures. In particular, we will examine the class $(\mathbf{K}_d, \leq_d)$ of all finite graphs with the understanding that $A \leq_d B$ whenever A is an *isometric* substructure of B (that is, the distance between vertices in A does not go down when A is considered as a subgraph of B). This class has ∃-closures, and we will use this fact to shed some light on a conjecture of Larry Moss' about the class $(\mathbf{K}_d \leq_d)$. (Received September 22, 2015)

1116-03-2676 **James Dustin Chandler** (chandlerj@goldmail.etsu.edu), **Cecilia Ashlie Dorado*** (dorado@goldmail.etsu.edu) and **Teresa W Haynes** (haynes@etsu.edu).
Neighborhood-restricted [≥ 3]*-Chromatic Colorings.*

A (closed) neighborhood-restricted [≥ 3]-coloring of a graph G is an assignment of colors to the vertices of G such that at least three colors are assigned in any closed neighborhood, that is, for every vertex v in G, the vertex v and its neighbors are in at least three different color classes. The [≥ 3]-*chromatic number* is defined as the minimum number of colors in any [≥ 3]-coloring of G. We study the [≥ 3]-chromatic number for several classes of graphs and establish bounds for certain families of graphs.
(Received September 22, 2015)

1116-03-2900 **Mojtaba Moniri*** (m-moniri@wiu.edu). *Additive vs. Multiplicative Near-linearity in Open Induction.*

For a function $f : M \to M$ over a model of some fragment of arithmetic, consider two homogeneous near-linearity properties

$$(\forall x, y)[f(x+y) = f(x) + f(y) \vee f(x+y) = f(x) + f(y) + 1] \quad \text{(ANL)},$$

$$(\forall x, y)[yf(x) < xf(y) + x] \quad \text{(MNL)},$$

and two inhomogeneous (meaning not necessarily homogeneous) such:

$$(\forall x, y, z)[f(x+y) + f(z) = f(x) + f(y+z) \vee f(x+y) + f(z) = f(x) + f(y+z) \pm 1] \quad \text{(IANL)},$$

$$(\forall x, y, u, v)[v(f(x+y) - f(x) - 1) < y(f(u+v) - f(u) + 1)] \quad \text{(IMNL)}.$$

Theorem. For a function f over a model of Open Induction, MNL is stronger than ANL, and IMNL is stronger than IANL. (Received September 22, 2015)

05 ► Combinatorics

1116-05-45 **Bruce Reed***, breed@cs.mcgill.ca. *The Structure and Chromatic Number of H-free Graphs.*

We present a conjecture about the structure of typical graphs without a specified graph H as an induced subgraph. We show that almost every H-free graph does indeed have the conjectured structure when H is a cycle or a tree. We deduce that for such graphs, the chromatic number is assymptotically the clique number. This is joint work with Lema Yuditsky and Alex Scott. (Received June 19, 2015)

1116-05-78 **Aaron M. Montgomery*** (amontgom@bw.edu), Department of Mathematics and Computer Sci, Baldwin Wallace University, Berea, OH 44130. *Asymptotic enumeration of difference matrices over cyclic groups.* Preliminary report.

We identify a relationship between a family of random walks on lattices and difference matrices over cyclic groups. By estimating the probabilities that these walks will return to their origins, we are able to exploit the aforementioned relationship to obtain the asymptotic number of difference matrices over cyclic groups as the number of columns increases but all other possible parameters remain fixed. Further, these return probability estimates are sufficiently sharp to provide proof of the existence of some previously-unknown difference matrices with certain parameter configurations. (Received July 14, 2015)

1116-05-111 **Alexander Diaz-Lopez** and **Pamela Estephania Harris*** (pamela.harris@usma.edu), 646 Swift Road, West Point, NY 10996, and **Erik Insko** and **Darleen Perez-Lavin**. *Peak Sets of Classical Coxeter Groups.*

We say a permutation $\pi = \pi_1\pi_2\cdots\pi_n$ in the symmetric group $\mathfrak{S}_n$ has a peak at index i if $\pi_{i-1} < \pi_i > \pi_{i+1}$ and we let $P(\pi) = \{i \in \{1, 2, \ldots, n\} | i \text{ is a peak of } \pi\}$. Given a set S of positive integers, we let $P(S; n)$ denote the subset of $\mathfrak{S}_n$ consisting of all permutations π, where $P(\pi) = S$. Billey, Burdzy, and Sagan proved $|P(S; n)| = p(n)2^{n-|S|-1}$, where $p(n)$ is a polynomial of degree $max(S) - 1$ and Castro-Velez *et al.* considered the Coxeter group of type B_n as the group of signed permutations on n letters and showed that $|P_B(S; n)| = p(n)2^{2n-|S|-1}$ where $p(n)$ is the same polynomial of degree $max(S) - 1$. In this talk, we embed the Coxeter groups of Lie type C_n and D_n into $\mathfrak{S}_{2n}$ and partition these groups into bundles of permutations $\pi_1\pi_2\cdots\pi_n|\pi_{n+1}\cdots\pi_{2n}$ such that $\pi_1\pi_2\cdots\pi_n$ has the same relative order as some permutation $\sigma_1\sigma_2\cdots\sigma_n \in \mathfrak{S}_n$. This allows us to count the number of permutations in types C_n and D_n with peak set S by reducing the enumeration to calculations in the symmetric group and sums across rows of Pascal's triangle. (Received July 28, 2015)

1116-05-133 **Roger Vargas*** (rv2@williams.edu), Department of Mathematics and Statistics, Williams College, Williamstown, MA 01267, **Abigail Waldron**, Mathematics Department, Presbyterian College, Clinton, SC 29325, and **Anika Sharma**, Department of Mathematics, 244 Mathematics Building, Buffalo, NY 14260-2900. *Centrality Properties of Graphs with an Application of Functional Connectivity of the Brain.* Preliminary report.

We investigate the leverage centrality of a vertex which is a comparison of the degree of a vertex with the degrees of its neighbors. This property was introduced by Joyce et al. (doi:10.1371/journal.pone.0012200) for the analysis of functional Magnetic Resonance Imaging data of the brain. We explore this property from a mathematical perspective and determine the leverage centrality for several families of graphs. In particular we show the number of distinct leverage centralities in the Cartesian product of path powers ($P_n^k \times \cdots \times P_n^k$) has a surprising link to the triangular and figurate numbers.

In addition, we also apply degree centrality to data from a functional magnetic resonance imaging (fMRI) study at the University of Rochester. To accurately and precisely model dynamic functional connectivity of the brain it is not sufficient to use a single static network, but rather a time varying aggregate of hundreds of networks. (Received August 05, 2015)

1116-05-134 **Kelsey Quigley*** (kquigle6@mail.naz.edu), Mathematics Department, Nazareth College, Rochester, NY 14618, and **Sarah Renfro**, Department of Mathematics and Statistics, Sam Houston State University, Huntsville, TX 77341. *Rankings of Cartesian Product* $(K_s - e)\Box P_n$. Preliminary report.

A ranking of a graph is a vertex labeling such that every path between vertices with the same label contains a vertex with a larger label. The rank number of a graph is the smallest possible number of labels in a ranking. Rankings were first introduced in 1995 by Bodlaender et al. for the purpose of studying algorithms. For a given graph G and a positive integer t, the question whether the rank number is less than or equal to t is NP-complete for many classes of graphs. Interest in rankings of graphs was sparked by their many applications to other fields including designs of very large scale integration layouts (VLSI), Cholesky factorizations of matrices in parallel, and scheduling problems of assembly steps in manufacturing systems. While rank numbers for some families of graphs are established, there exist numerous families of graphs, for which the rank numbers remain unknown. Lately, families of Cartesian products are being investigated for their rank numbers.

In 2010 Alpert established rank numbers for the Cartesian product of complete graphs and paths. We studied the rankings of $(K_s - e)\Box P_n$. (Received August 05, 2015)

1116-05-135 **Alexander Neal Riasanovsky*** (alexneal@math.upenn.edu), Department of Mathematics, University of Pennsylvania, Philadelphia, PA 19104-6395, and **John Wallace**, Department of Mathematics, Trinity College, Hartford, CT 06016. *Zarankiewicz and Bipartite Ramsey Numbers.* Preliminary report.

The Zarankiewicz number $z(b;s)$ is the maximum size of a subgraph of $K_{b,b}$ which does not contain $K_{s,s}$ as a subgraph. The two-color bipartite Ramsey number $b(s,t)$ is the smallest integer b such that any coloring of the edges of $K_{b,b}$ with two colors contains a $K_{s,s}$ in the first color or a $K_{t,t}$ in the second color.

In this work, we design and exploit a computational method for bounding and computing Zarankiewicz numbers. Using it, we obtain several new values and bounds on $z(b;s)$ for $3 \leq s \leq 5$. Our approach and more knowledge about $z(b;s)$ permit us to improve some of the results on bipartite Ramsey numbers obtained by Goddard, Henning and Oellermann in 2000. In particular, we compute the smallest previously unknown bipartite Ramsey number, $b(2,5) = 17$. Moreover, we prove that up to isomorphism there exists a unique 2-coloring which witnesses the lower bound $16 < b(2,5)$. We also find tight bounds on $b(2,2,3)$, $17 \leq b(2,2,3) \leq 18$, which currently is the smallest open case for multicolor bipartite Ramsey numbers. (Received August 05, 2015)

1116-05-150 **Elizabeth Niese*** (niese@marshall.edu), One John Marshall Dr, Huntington, WV 25755, and **Sarah K Mason**. *The combinatorics of quasisymmetric (k,l)-hook Schur functions.*

In this talk we introduce a refinement of Berele and Regev's (k,l)-hook Schur functions using quasisymmetric Schur functions and row-strict quasisymmetric Schur functions. The quasisymmetric (k,l)-hook Schur functions can be defined as the generating function for a certain set of composition tableaux on two alphabets. We will present combinatorial properties of the quasisymmetric (k,l)-hook Schur functions, including a decomposition into super-fundamental quasisymmetric functions, an analogue of the RSK algorithm, and a generalized Cauchy identity. (Received August 07, 2015)

1116-05-151 **Sonica Saraf***, Department of Mathematical Sciences, Carnegie Mellon University, Pittsburgh, PA 15213, and **Natalie Wellen**, Department of Mathematical Sciences, Worcester Polytechnic Institute, Worcester, MA 01609. *The Resolution Limit for Detecting Communities in Benchmark Graphs.* Preliminary report.

Detecting community structure within networks is important in a variety of practical applications including social networks, biological networks, technological networks, and many more. Modularity optimization is a popular method for detecting communities of nodes within networks. It was shown by Fortunato and Barthelemy that modularity optimization is subject to a resolution limit wherein communities smaller than a certain size cannot be detected. In this talk, we will examine the resolution limit for certain classes of benchmark graphs, and discuss how the inclusion of a multi-resolution parameter affects the ability to detect communities. (Received August 07, 2015)

1116-05-156 **Liz Lane-Harvard*** (elaneharvard@uco.edu), 100 North University Drive - Box 129, Edmond, OK 73034. *Constructing Strongly Regular Graphs Using Finite Geometry.*

There are many open problems concerning strongly regular graphs: proving non-existence for parameters where none are known; proving existence for parameters where none are known; constructing more for parameters where examples are already known. The work surveyed in this talk will fall under the last two categories. In particular, one of the results overlaps with Paley graph parameters. The methods used to construct these graphs involve symmetry and geometry, with the aid of computer algebra packages to gain insight. (Received August 09, 2015)

1116-05-179 **Ranjan Rohatgi*** (rrohatgi@indiana.edu). *Lozenge tilings of halved hexagons with defects.*

MacMahon's boxed plane partition formula from over a century ago enumerates the lozenge tilings of a hexagon with side-lengths a, b, c, a, b, c in cyclic order on the triangular lattice. More recently several authors have enumerated the number of tilings for hexagons with different types of defects. Proctor treated the case where a "maximal staircase" is removed, and several others have found formulas for hexagons with triangles removed from the boundary. Potential lozenges used in the tiling of a region can be given weights. For a given tiling μ, define $\mathrm{wt}(\mu)$ to be the product of the weights of all lozenges used in μ. Rather than counting the number of tilings of a weighted region R, one tries to determine its *tiling generating function*, $M(R)$ defined by $M(R) = \sum_{\mu\in\mathcal{M}} \mathrm{wt}(\mu)$ where $\mathcal{M}$ is the set of all tilings of R. Evidently, if all weights are 1, $M(R)$ is precisely the number of tilings of R. We present results for both unweighted and certain weighted hexagonal regions with both a maximal staircase and boundary triangles removed. Treating these regions as halved hexagons allows us, with the help of Ciucu's factorization theorem, to recover known results in a new way. (Received August 11, 2015)

1116-05-211 **Ruth Davidson**, **Augustine O'Keefe*** (aokeefe@conncoll.edu) and **Daniel Parry**. *A new shellability proof of an old identity of Dixon.*

We give a new proof of an old identity of Alfred Cardew Dixon (1865-1936). The new proof uses tools from topological combinatorics. Dixon's identity is re-established by constructing a family of non-pure shellable simplicial complexes $\Delta(n)$, whose structure is a function of any positive integer n. The alternating sum of the numbers of faces of $\Delta(n)$ of each dimension is the left-hand side of the the identity, and we show that the alternating sum of the Betti numbers of the complex is equal to the right-hand side of the identity. In other words, Dixon's identity is re-established by using the Euler-Poincaré relation for $\Delta(n)$. The Betti numbers are calculated by showing that for any n, $\Delta(n)$ is shellable. Then, using the well-known fact that a (possibly non-pure) shellable simplicial is homotopy equivalent to a wedge of spheres, we count the number of faces of $\Delta(n)$ of each dimension that attach along their entire boundary-also known as homology facets-in the shelling order, thereby computing the Betti numbers of $\Delta(n)$. This is joint work with Ruth Davidson and Daniel Parry. (Received August 14, 2015)

1116-05-221 **Rekha Biswal**, **Vyjayanthi Chari**, **Lisa Schneider*** (schneiderl@susqu.edu) and **Sankaran Viswanath**. *Demazure Flags, Chebyshev Polynomials, Mock and Partial Theta Functions.*

In this talk, I will present recent joint work with Rekha Biswal, Vyjayanthi Chari, and Sankaran Viswanath concerning the multiplicities associated to Demazure flags of Demazure modules for the current algebra $\mathfrak{sl}_2[t]$. I will first introduce the notion of a Demazure flag and the associated q-multiplicities. Then I will define generating series which encode these q-multiplicities. Using previous results in representation theory, I will present recursive formulae for these series. Then I will discuss the interesting combinatorics that arise from special cases and the specialization to $q = 1$. In particular, I will relate these series to Chebyshev polynomials, partial theta functions, and fifth order mock theta functions of Ramanujan. (Received August 14, 2015)

1116-05-244 **Zeev Dvir*** (zdvir@princeton.edu). *Sets of points with many collinear triples: a theorem and variations.*

The Sylvester-Gallai theorem states that in any set of points in the real plane, not all on the same line, there exists a line passing through only two of the points. In this talk I will describe several natural variants of this theorem and the techniques used to prove them. These include the complex and finite field versions, quantitative variants and variants in which points are replaced with k dimensional subspaces. If time permits, I will also discuss applications of these theorems to the theory of error correcting codes. (Received August 17, 2015)

1116-05-261 **Dr. Meenakshi Rana*** (mrana@thapar.edu), House No. 40, Type-III, New, Thapar University, Patiala, 147004, India. *Rogers–Ramanujan Type Identities and Restricted k–Color F–Partitions.*

It is seen how F–partitions are helpful in providing the combinatorial meaning to q–series and Rogers–Ramanujan type identities. Andrews studied extensively the two classes of generalized F–partitions. We also can observe that for many q–series identities and Rogers–Ramanujan type identities, there is a bijection between F–partitions and $(n+t)$–color partitions. Recently $(n+t)$–color partitions have been extended to split $(n+t)$–color partitions. So the natural question arises about the bijection of split $(n+t)$–color partitions to certain class of F–partitions. The purpose of this paper is to establish a bijection between the split $(n+t)$–color partitions and restricted k–color F–partitions for some generalized basic q–series. They further give rise Rogers-Ramanujan type identities for some particular cases. (Received August 19, 2015)

1116-05-266 **Wasin So*** (wasin.so@sjsu.edu), Department of Mathematics and Statistics, San Jose State University, San Jose, CA 95192. *Automorphisms and Eigenvalues of Knodel graphs.* Preliminary report.

In this talk, we first define Knodel graphs and explain their role in the study of interconnection networks. Then we describe the automorphisms and eigenvalues of Knodel graphs, and deduce some interesting consequences. In particular, we show that Knodel graphs and hypercubes are not isomorphic even though both are regular bipartite graphs of same order. (Received August 19, 2015)

1116-05-270 **Mitchell M Lee***, mitchlee@mit.edu. *Sets with few differences in abelian groups.*

Let $(G, +)$ be an abelian group. In 2004, Eliahou and Kervaire found an explicit formula for the smallest possible cardinality of the sumset $A + A$, where $A \subseteq G$ has fixed cardinality r. We consider instead the smallest possible cardinality of the difference set $A - A$, which is always greater than or equal to the smallest possible cardinality of $A + A$ and can be strictly greater. We conjecture a formula for this quantity, and prove the conjecture in the case that G is a cyclic group or a vector space over a finite field. This resolves a conjecture of Bajnok and Matzke on signed sumsets. (Received August 19, 2015)

1116-05-277 **Nathaniel Karst**, **Jessica Oehrlein*** (jessoehrlein@gmail.com), **Denise Sakai Troxell** and **Junjie Zhu**. *The minimum span of $L(2,1)$-labelings of generalized flowers.*

Given a positive integer d, an $L(d,1)$-labeling of a graph G is an assignment of nonnegative integers to its vertices such that adjacent vertices must receive integers at least d apart, and vertices at distance two must receive integers at least one apart. The λ_d-number of G is the minimum k so that G has an $L(d,1)$-labeling using labels in $\{0, 1, \dots, k\}$. Informally, an amalgamation of two disjoint graphs G_1 and G_2 along a fixed graph G_0 is the simple graph obtained by identifying the vertices of two induced subgraphs isomorphic to G_0, one in G_1 and the other in G_2. A flower is an amalgamation of two or more cycles along a single vertex. We provide the exact λ_2-number of a generalized flower, which is the Cartesian product of a path P_n and a flower, or equivalently, an amalgamation of cylindrical rectangular grids along a certain P_n. In the process, we provide general upper bounds for the λ_d-number of the Cartesian product of P_n and any graph G, using circular $L(d+1,1)$-labelings of G where the labels $\{0, 1, \dots, k\}$ are arranged sequentially in a circle and the distance between two labels is the shortest distance on the circle. (Received August 20, 2015)

1116-05-288 **Poppy Immel***, School of Mathematical Sciences, Rochester Institute of Technnology, Rochester, NY 14623. *Distinguishing Numbers of 2-Trees.* Preliminary report.

Given a graph G, a k-coloring is a function from the vertex set to the subset of integers 1,2,..,k. A k-coloring of G is distinguishing every nontrivial automorphism of G maps some vertex to a vertex with a different color; that is, no nontrivial automorphisms of G are color-preserving. The distinguishing number of a graph G, denoted $D(G)$, is the minimum k such that G has a distinguishing k-coloring. We adapt a recursive and enumerative approach developed independently by Cheng, and Arvind and Devanur, to prove that distinguishing numbers can be computed in polynomial time on the family of 2-trees. (Received August 22, 2015)

1116-05-324 **Jonathan L. Gross*** (gross@cs.columbia.edu), 458 Computer Science, New York, NY 10027, **Toufik Mansour**, , Israel, **Thomas W. Tucker**, NY , and **David G.L. Wang**, , Peoples Rep of China. *Combinatorial Conjectures that Imply Local Log-Connectivity of Graph Genus Polynomials.*

The 25-year old *LCGD Conjecture* is that the genus distribution of every graph is log-concave. We present a new topological conjecture, called the *Local Log-Concavity Conjecture*. We also present a purely combinatorial conjecture, which we prove to be equivalent to the Local Log-Concavity Conjecture. We use the equivalence to prove the Local Log-Concavity Conjecture for graphs of maximum degree four. We then show how a formula of David Jackson could be used to prove log-concavity for the genus distributions of various partial rotation systems, with straight-forward application to proving the *local log-concavity* of additional classes of graphs. We close with an additional conjecture, whose proof, along with proof of the Local Log-Concavity Conjecture, would affirm the LCGD Conjecture. (Received September 03, 2015)

1116-05-336 **Joseph Kung*** (kung@unt.edu). *Syzygies on Tutte polynomials of freedom matroids.*

It follows from work of Derksen and Derksen and Fink that the Tutte polynomial of a matroid is "naturally" a linear combination of Tutte polynomials of freedom matroids. However, Tutte polynomials of freedom matroids are not a basis; rather, they are a "spark-6 frame". We find a generating set for all linear relations on Tutte polynomials of freedom matroids. Linear relations in this generating set are indexed by two intervals, one of height 1 and the other of height 2, in the weak order on freedom matroids. The weak order is isomorphic to an interval of Young's partition lattice. We will also discuss the relation between the CATenary data of a matroid and its $\mathcal{G}$-invariant. (Received August 26, 2015)

1116-05-342 **Boris Bukh*** (bbukh@math.cmu.edu), Department of Mathematical Sciences, Carnegie Mellon University, Pittsburgh, PA 15213. *Algebraic constructions of Turán graphs.*

Pick a bipartite graph H. What is the graph with the largest number of edges and no copy of H? Evidence hints at an algebraic answer to this question. In this talk, I will present the available evidence, and explain the current obstacles. (Received August 26, 2015)

1116-05-343 **Boris Bukh*** (bbukh@math.cmu.edu), Department of Mathematical Sciences, Carnegie Mellon University, Pittsburgh, PA 15213. *Ranks of matrices with few distinct entries.*

Given a number lambda, what is the maximum multiplicity of lambda as an eigenvalue of an adjacency matrix of an n-vertex digraph? I will present a solution to this question, and describe general results of ranks of matrices with few distinct entries. The connection to the "linear algebra method in combinatorics" will also be explained. In particular, I will mention applications to spherical codes and L-intersecting families. (Received August 26, 2015)

1116-05-344 **Mark S. MacLean*** (macleanm@seattleu.edu), Dept. of Mathematics, Seattle University, Seattle, WA 98122, and **Stefko Miklavic**. *Bipartite distance-regular graphs with exactly two irreducible T-modules with endpoint 2.*

The *Terwilliger algebra* has been used to classify certain types of distance-regular graphs, such as the bipartite Q-polynomial distance-regular graphs of large diameter. Let Γ denote a bipartite distance-regular graph with vertex set X, diameter $D \geq 4$ and valency $k \geq 3$. For $x \in X$ let $T(x)$ denote the Terwilliger algebra of Γ with respect to x. In 2000, B. Curtin showed that Γ has exactly one irreducible module for $T(x)$ of endpoint 2, and this module is thin, precisely when Γ satisfies a certain combinatorial condition. We extend Curtin's result by proving that Γ has exactly *two* irreducible modules for $T(x)$ of endpoint 2, and both are thin, precisely when Γ satisfies a related combinatorial condition. (Received August 26, 2015)

1116-05-378 **Richard P. Stanley***, Department of Mathematics, University of Miami, Coral Gables, FL 33124. *Combinatorics and Smith normal form.* Preliminary report.

Let A be an $n \times n$ matrix over a commutative ring R with identity. If there exist $n \times n$ matrices P and Q invertible over R such that $B = PAQ$ is a diagonal matrix $\operatorname{diag}(\alpha_1, \ldots, \alpha_n)$, where $\alpha_i | \alpha_{i+1}$ in R for $1 \leq i \leq n-1$ (where $\alpha | 0$ for all $\alpha \in R$), then we call B a *Smith normal form* (SNF) of A. Over a PID an SNF always exists and is unique up to multiplication by units. We will give a survey of some combinatorial aspects of SNF. The two main topics are (1) the distribution of the SNF of a random integer matrix, and (2) interesting examples of the SNF of combinatorially defined matrices. (Received August 28, 2015)

1116-05-386 **Melody Chan**, **Shahrzad Haddadan**, **Sam Hopkins*** (shopkins@mit.edu) and **Luca Moci**. *The expected jaggedness of order ideals.*

The jaggedness of an order ideal I in a poset P is the number of maximal elements in I plus the number of minimal elements of P not in I. A probability distribution on the set of order ideals of P is toggle-symmetric if for every p in P, the probability that p is maximal in I equals the probability that p is minimal not in I. In this paper, we prove a formula for the expected jaggedness of an order ideal of P under any toggle-symmetric probability distribution when P is the poset of boxes in a skew Young diagram. Our result extends the main combinatorial theorem of Chan-López-Pflueger-Teixidor, who used an expected jaggedness computation as a key ingredient to prove an algebro-geometric formula for the genus of the Brill-Noether curve; and it has unexpected applications to homomesies, in the sense of Propp-Roby, of the antichain cardinality statistic for order ideals in posets under rowmotion and gyration. (Received August 29, 2015)

1116-05-393 **Maria Monks Gillespie*** (monks@math.berkeley.edu). *Combinatorics of the q,t-symmetry relation in Macdonald polynomials.*

The Macdonald polynomials $\widetilde{H}_\mu(X;q,t)$ are certain symmetric functions in the variables $X = \{x_1, x_2, \ldots\}$ with coefficients in $\mathbb{Q}(q,t)$. Arising naturally in the context of the geometry of the Hilbert scheme of points in the plane, these polynomials also exhibit a beautiful symmetry relation in the variables q and t. We investigate the combinatorics of this symmetry relation in light of the combinatorial formula for the Macdonald polynomials discovered by Haglund, Haiman, and Loehr in 2004. The relation is a strict generalization of the well-known equidistribution of the Mahonian statistics inv and maj on permutations. (Received August 30, 2015)

1116-05-399 **Peter E. Dillery*** (ped7pc@virginia.edu), 700 Evergreen Avenue, Charlottesville, VA 22902, **Emily E. Cormier** (ecormier@bowdoin.edu), p.o. box 412, Deer Isle, ME 04627, and **John H. Whelan** (jowhelan@vassar.edu), 185 Hunter Avenue, North Babylon, NY 11703. *Minimal Length Maximal Green Sequences for Type $\mathbb{A}$ Quivers.*

The study of maximal green sequences (MGS) is motivated by string theory, in particular Donaldson-Thomas invariants and the BPS spectrum. This concept can also be examined through the framework of τ-tilting modules in representation theory. It is known that triangulations of disks with no punctures yield type $\mathbb{A}$ quivers. B.Keller introduced green mutations and the corresponding MGS's. These sequences can be studied both through the combinatorial transformations of directed graphs as well as through triangulations of disks.

Our research focuses on maximal green sequences of minimal length for quivers mutation equivalent to type $\mathbb{A}$ quivers. It is known that each acyclic quiver has at least one minimal length MGS of length n, where n is the number of vertices in the quiver. First, we define an algorithm that produces such a sequence of mutations for any given acyclic type $\mathbb{A}$ quiver. For cyclic type $\mathbb{A}$ quivers, we define an algorithm that produces an MGS of length $n+t$ where n is the number of vertices and t is the number of 3-cycles in a quiver. We then proceed to show that $n+t$ is always the minimal length of MGS's corresponding to any type $\mathbb{A}$ quiver. (Received August 30, 2015)

1116-05-444 **Feryal Alayont*** (alayontf@gvsu.edu), GVSU Math Department, 1 Campus Dr., Allendale, MI 49504. *Combinatorial Interpretations of Generalized Central Factorial and Genocchi Numbers.*

Classical rook theory concerns non-attacking rook placements on two-dimensional chess boards. The motivation for studying such rook placements comes from permutations with restrictions. One way to generalize the classical rook theory to higher dimensions is by letting rooks attack along hyperplanes. With this generalization, families of boards in three and higher dimensions give rise to rook number interpretations of generalized central factorial and Genocchi numbers. Similar to interpreting two-dimensional rook placements as permutations with restrictions, we will provide an interpretation of these higher dimensional rook placements combinatorially, leading to a combinatorial interpretation of the generalized central factorial numbers in terms of ordered tuples of partitions whose minima are equal, and a new combinatorial interpretation of generalized Genocchi numbers as ordered tuples of permutations with conditions. (Received September 01, 2015)

1116-05-461 **Aida Abiad**, **Phil DeOrsey**, **Leslie Hogben**, **Kirsten Hogenson*** (kahogens@iastate.edu), **Franklin Kenter**, **Jephian C.-H. Lin**, **Sarah Loeb**, **Heather Smith** and **Michael Young**. *Zero forcing number on the counterprism of graphs.*

The zero forcing number of a graph, $Z(G)$, is used in combinatorial matrix theory as an upper bound for the maximum nullity of a graph, $M(G)$. The Graph Complement Conjecture for a graph parameter β of a simple graph G concerns the following inequality: $\beta(G) + \beta(\overline{G}) \geq |G| - 2$. This inequality is known to be true for $\beta = Z$, but is still unknown for $\beta = M$. To work toward the Graph Complement Conjecture for M, we define the counterprism of G, denoted $\sqcup G$, to be the graph on $2|G|$ vertices which is the disjoint union of G, $\overline{G}$, and a perfect matching between the corresponding vertices of G and $\overline{G}$. We have found that $Z(\sqcup G) \in \{|G|-1, |G|\}$. In this talk, I will discuss this result, as well as some results characterizing graphs G such that $Z(\sqcup G) = |G|-1$ and $Z(\sqcup G) = |G|$. This research was conducted during the 2015 Rocky Mountain-Great Plains Graduate Research Workshop in Combinatorics in Ames, IA. (Received September 02, 2015)

1116-05-483 **Joel Brewster Lewis*** (jblewis@math.umn.edu). *The Hurwitz action in real reflection groups.* Preliminary report.

In a group W, the set of length-k factorizations $c = t_1 \cdots t_k$ of an element c carries the *Hurwitz action* of the k-strand braid group B_k: the braid generator σ_i maps $(t_1, \ldots, t_i, t_{i+1}, \ldots, t_k)$ to $(t_1, \ldots, t_{i+1}, t_{i+1}^{-1} t_i t_{i+1}, \ldots, t_k)$. When W is a finite real reflection group and c is a Coxeter element of W, it was shown by Bessis that, when restricted to minimum-length factorizations $(t_1, \ldots, t_n)$ of $c = t_1 \cdots t_n$ as a product of reflections, the Hurwitz action is transitive.

In this talk, we consider extending Bessis' result to *longer* factorizations of a Coxeter element into reflections. It is no longer the case that the braid action is necessarily transitive, but we propose a conjecture that implies that it is "as transitive as possible" (up to the multiset of conjugacy classes of the factors). We prove this conjecture for classical types A, B/C, and D, for dihedral groups, and (by brute-force computation) for several small exceptional reflection groups. (Received September 03, 2015)

1116-05-495 **Benjamin Braun*** (benjamin.braun@uky.edu), Department of Mathematics, University of Kentucky, Lexington, KY 40506, **Robert Davis**, Michigan State University, and **Liam Solus**, IST Austria and MIT. *Lattice point enumeration, mutations, and Fano lattice simplices.* Preliminary report.

We investigate Fano lattice simplices from the perspective of lattice point enumeration. Properties such as unimodality of Ehrhart h^*-vectors, the integral decomposition property, and combinatorial mutations will be considered. (Received September 04, 2015)

1116-05-506 **Alexander Halperin*** (adhalperin@salisbury.edu), 1101 Camden Ave., Salisbury, MD 21801, and **Colton Magnant**. *Large Hamiltonian Balanced Bipartite Graphs with Arbitrary Partitions.*

When can we determine the structure of a hamiltonian cycle within a bipartite graph? We know that a balanced bipartite graph G with $\delta(G) \geq \frac{n}{4}$ is hamiltonian, but we want to travel a specific distance between each ordered pair of k chosen vertices on our hamiltonian cycle. We use the Regularity and Blow-Up Lemmas to show that a sufficiently large balanced bipartite graph G of order n with the sharp condition $\delta(G) \geq \frac{n+4k}{4}$ contains a hamiltonian cycle that visits any choice of k vertices in order and has prescribed path lengths (summing to n and obeying the necessary parity) between each pair of chosen vertices. (Received September 04, 2015)

1116-05-516 **Jozsef Balog*** (jobal@math.uiuc.edu), Mathematics Department, Urbana, IL 61801, and **Hong Liu**, **Maryam Sharifzadeh** and **Andrew Treglown**. *On problems of Cameron and Erdos.*

In 1990 and 1999, Cameron and Erdos proposed several problems in additive combinatorics. They asked about the number of sum-free sets, number of maximal sum-free sets, number of Sidon sets in [n]. Additionally they asked the number of sets in [n] without k-term arithmetic progression. In the talk we survey the recent progress on these questions. (Received September 05, 2015)

1116-05-523 **Hamed Hatami*** (hatami@cs.mcgill.ca), **Pooya Hatami** and **Yaqiao Li**. *A characterization of functions with vanishing averages over products of disjoint sets.*

We characterize all integrable functions $f : [0,1]^m \to \mathbb{R}$ satisfying $\int_{A_1 \times \ldots \times A_m} f = 0$, for any collection of disjoint sets $A_1, \ldots, A_m \subseteq [0,1]$ with prescribed measures. We use this characterization to settle some conjectures of Janson and Sös on pseudo-random graph properties. (Received September 05, 2015)

1116-05-529 **Steven Simon*** (ssimon2@wellesley.edu). *Topological Combinatorics via Finite Fourier Analysis.*

Methods of equivariant topology have been successfully applied in recent years to a variety of problems in geometric combinatorics, especially to those concerning measure equipartitions (generalizations of the ham sandwich-theorem: any d masses in $\mathbb{R}^d$ can be bisected by a single hyperplane) and point partitions of a Tverberg-type (generalizations of Radon's theorem: any $d+2$ points in $\mathbb{R}^d$ can be partitioned into two sets with overlapping convex hulls). Reformulating these problems and their topological reductions in terms of harmonic analysis on finite groups, we will show how a variety of both classical and new partition theorems can be obtained as the annihilation of prescribed Fourier transforms. (Received September 05, 2015)

1116-05-573 **George E Andrews***, Department of Mathematics, Pennsylvania State University, 306 McAllister Bldg., University Park, PA 16802. *A Refinement of the Alladi-Schur Theorem.*

In 1926, I. Schur proved that if A(n) equals the number of partitions of n into parts congruent to 1 or 5 modulo 6, and B(n) equals the number of partitions of n in which any two parts differ by at least 3 and multiples of 3 differ by more than 3, then A(n)=B(n). In the 1990's K. Alladi noted that if C(n) equals the number of partitions of n into odd parts none repeated more than twice, then also C(n)=B(n). We shall consider the following refinement of the Alladi-Schur theorem and its implications: THEOREM. Let C(m,n) denote the number of partitions among those enumerated by C(n) that have exactly m parts. Let B(m,n) denote the number of partitions among those enumerated by B(n) where the number of odd parts plus twice the number of even parts equals m. The B(m,n)=C(m,n). (Received September 07, 2015)

1116-05-603 **J. Laison**, **Y. Li**, **J. Schreiner-McGraw** and **C. Starr*** (cstarr@willamette.edu), Willamette University, 900 State St, Salem, OR 97301. *Prime Power Graphs and Prime Product Graphs.* Preliminary report.

Let $L : V(G) \to \mathbb{Z}$ be a one-to-one integer labeling of the vertices of a simple graph G.

(1) We call L a **prime distance labeling** of G if for any two adjacent vertices u and v, the integer $|L(u)-L(v)|$ is prime; in this case, we say G is a **prime distance graph**.

(2) We call L a **k-prime product distance labeling** of G if for any two adjacent vertices u, v, the integer $|L(u) - L(v)|$ is a product of at most k (not necessarily distinct) primes; in this case, we say G is a **k-prime power distance graph**. If G has a k-prime product distance labeling and not a $(k-1)$-prime product distance labeling, then we set $\pi(G) = k$.

(3) We call L a **prime power distance labeling** of G if for any two adjacent vertices u and v, the integer $|L(u) - L(v)|$ is a positive power of a prime; in this case, we say G is a **prime power distance graph**.

In this paper, we characterize some families of prime distance graphs, prime power distance graphs, and k-prime product distance graphs; provide bounds for $\pi(G)$; and make connections between graphs of these kinds and several important theorems and conjectures from Number Theory (including the Green-Tao Theorem and Fermat's Last Theorem). (Received September 09, 2015)

1116-05-607 **Tatchai Titichetrakun*** (tatchai@math.ubc.ca), Room 121, 1984 Mathematics Road, Vancouver, BC V6T 1Z2, Canada. *Corners in dense subsets of primes via transference principle.*

We will discuss some aspects of the proof of existence of corner configurations in dense subset of prime tuples using transference principle. By transferring hypergraph removal lemma from the unweighted setting to the weighted setting. (Received September 08, 2015)

1116-05-638 **Keivan Hassani Monfared*** (k1monfared@gmail.com), **Paul Horn**, **Franklin Kenter**, **Kathleen Nowak**, **John Sinkovic** and **Josh Tobin**. *On the Principal Permanent Rank Characteristic Sequences of Graphs.*

The principal permanent rank characteristic sequence (ppr) is a binary sequence $r_0 r_1 \ldots r_n$ where $r_k = 1$ if there exists a principal square submatrix of size k with nonzero permanent and $r_k = 0$ otherwise, and $r_0 = 1$ if there is a zero diagonal entry.

The ppr sequence of a nonnegative matrix reveals a lot of information about the cycle covers of all sizes of the underlying graph. In this talk a characterization is provided for all principal permanent rank sequences obtainable by the family of nonnegative matrices as well as the family of nonnegative symmetric matrices. (Received September 09, 2015)

1116-05-652 **Yoshihisa Matsukawa** and **Jun Mitani*** (mitani@cs.tsukuba.ac.jp). *Verification of flat-foldability of crease patterns on the 45 degree grid system.* Preliminary report.

Crease patterns of several well-known fundamental shapes used in origami design are within 45 degrees origami grid system. The gird system is easily creased on a square, and has flexibility for making variety of shapes. Therefore it is commonly used for origami framework. We enumerated all possible formal crease patterns and their folded shapes in 4x4 girds by using a computer, and found 259,659,330 and 13,451 cases respectively. Further, we verified all 13,451 shapes are able to be folded into flat without any self-intersections. Some formal crease patterns which are not flat-foldable due to self-intersections were also found. (Received September 10, 2015)

1116-05-667 **Iztok Peterin**, **Douglas Rall*** (doug.rall@furman.edu), **Tadeja Kraner Šumenjak** and **Aleksandra Tepeh**. *Partitioning the vertex set of G to make $G\Box H$ an efficient open domination graph.*

A graph is an **efficient open domination graph** if there exists a subset of its vertices whose open neighborhoods partition the vertex set of the graph. For a fixed graph H we would like a characterization of those graphs G such that the Cartesian product $G\,\Box\,H$ is an efficient open domination graph. In case H is a complete graph of order at least 3 or a complete bipartite graph we exhibit a certain type of weak partition of $V(G)$ whose existence is equivalent to $G\,\Box\,H$ being an efficient open domination graph. If $n \geq 3$, then this weak partition property allows us to give a constructive characterization of the trees T such that $T\,\Box\,K_n$ is an efficient open domination graph. (Received September 10, 2015)

1116-05-686 **Annie Raymond*** (raymonda@uw.edu), **Mohit Singh** and **Rekha Thomas**. *Symmetry and Turán Sums of Squares.*

Given a graph H, the Turán graph problem asks to find the maximum number of edges in a n-vertex graph that does not contain any subgraph isomorphic to H. In recent years, Razborov's flag algebra methods have been applied to Turán hypergraph problems with great success. We show that these techniques embed naturally in standard symmetry-reduction methods for sum of squares representations of invariant polynomials. This connection gives an alternate computational framework for Turán problems with the potential to go further. Our results expose the rich combinatorics coming from the representation theory of the symmetric group present in flag algebra methods. (Received September 10, 2015)

1116-05-701 **Xiaorui Sun** and **John Wilmes*** (wilmesj@math.uchicago.edu). *Structure and automorphisms of primitive coherent configurations.*

Coherent configurations (CCs) are highly regular vertex- and edge-colorings of the complete digraph. CCs generalize association schemes; their history goes back to Schur in the 1930s. A CC is primitive (PCC) if the digraph in each edge-color is connected.

We address the problem of classifying PCCs with large automorphism groups. This project was started in Babai's 1981 paper in which he showed that only the trivial PCC admits more than $\exp(\widetilde{O}(n^{1/2}))$ automorphisms. (Here, n is the number of vertices and the $\widetilde{O}$ hides polylogarithmic factors.)

We classify all PCCs with more than $\exp(\widetilde{O}(n^{1/3}))$ automorphisms, making the first progress on Babai's conjectured classification of all PCCs with more than $\exp(n^{\epsilon})$ automorphisms.

A corollary to Babai's 1981 result solved a then 100-year-old problem on uniprimitive permutation groups, giving an $\exp(\widetilde{O}(n^{1/2}))$ bound on their order. Similarly, our result implies an $\exp(\widetilde{O}(n^{1/3}))$ upper bound on the order of such groups, with known exceptions. This improvement of Babai's result was previously known only through the Classification of Finite Simple Groups (Cameron, 1981), while our proof, like Babai's, is elementary and almost purely combinatorial. (Received September 10, 2015)

1116-05-705 **Timothee William Bryan*** (twbryan@ncsu.edu) and **Naihuan Jing** (jing@ncsu.edu). *An Algebraic Formula for the Kostka-Foulkes Polynomials.* Preliminary report.

The familiar Hall-Littlewood polynomials, $H_\mu[X;t]$ form a basis for symmetric functions and are related to the Schur function, $s_\mu[X]$, basis via

$$H_\mu[X;t] = \sum_{\lambda\vdash|\mu|} K_{\lambda\mu}(t)s_\lambda[X]$$

where $K_{\lambda\mu}$ is the Kostka-Foulkes Polynomial. Lascoux and Schützenberger proved that for semi-standard Young tableaux

$$H_\mu[X;t] = \sum_{T\in SST^\mu} t^{charge(T)} s_{shape(T)}[X]$$

where the charge of a tableau T is a value obtained by weighting the entries of a reading word corresponding to a filling using content μ in a particular fashion. We define an algebraic formula for the Kostka-Foulkes polynomials using Hall-Littlewood vertex operators and Jing's Hall-Littlewood inner product which does not utilize Lascoux and Schüteznberger's result. We will also discuss combinatorial symmetries which arise during the calculations and proof of our result. (Received September 10, 2015)

1116-05-725 **John Asplund***, Dalton State College, 650 College Drive, Sequoya 153, Dalton, GA 30720. *λ-fold 5-cycle systems and the FUTURE!* Preliminary report.

A k-cycle system of a multigraph G is an ordered pair (V,C) where V is the vertex set of G and C is a set of k-cycles, the edges of which partition the edges of G. A k-cycle system of λK_v (a K_v with each edge repeated λ times) is known as a λ-fold k-cycle system. Various methods have been used throughout recent decades in the pursuit of showing which necessary conditions for the existence of a k-cycle system of λK_v are sufficient. In this talk we will look at the methods that went into finding 5-cycle systems of $(\lambda+\mu)K_{v+u} - \lambda K_v$ (a $(\lambda+\mu)K_{v+u}$ with the edges of a subgraph of λK_v removed) and what will happen next. (Received September 11, 2015)

1116-05-730 **Megan M Bernstein*** (bernstein@math.gatech.edu). *A Random Walk on S_n generated by Random Involutions.*

The involution walk is a random walk on the symmetric group generated by random involutions with 2-cycles distributed binomially with parameter p. Using spectral analysis, the involution walk is shown in this paper to mix for $p \geq \frac{1}{2}$ fixed, n sufficiently large in between $\log_{1/p}(n)$ steps and $\log_{2/(1+p)}(n)$ steps. The paper introduces a new technique for finding eigenvalues of random walks generated by many conjugacy classes using the character polynomial for the characters of the representations of the symmetric group. This is especially efficient at calculating the large eigenvalues of walks with generators with pattered cycle decompositions. The smaller eigenvalues are handled by developing monotonicity relations. These relations also give after sufficient time the likelihood order, the order from most likely to least likely state in the walk. The walk was introduced to study a conjecture about a random walk on the unitary group from the information theory of back holes. (Received September 11, 2015)

1116-05-740 **Shannon Talbott*** (talbotts@moravian.edu). *A Game of Crowns: Layered Generalized Crowns and Chromatic Number.*

Given a map of the United States, what is the smallest number of distinct colors needed to color the map in such a way that no two border states have the same color? Mathematically, this is the infamous graph coloring problem, which is listed as one of Karp's twenty-one NP complete problems in his 1972 paper. For $\mathbb{P}$ a finite partially ordered set (poset), we can associate with this poset a hypergraph $\mathbf{H}_{\mathbb{P}}^{c}$ as well as a graph $\mathbf{G}_{\mathbb{P}}^{c}$, whose chromatic number is bounded above by the order dimension of $\mathbb{P}$. A well known result of Trotter and Felsner proves that $\dim(\mathbb{P}) = \chi(\mathbf{H}_{\mathbb{P}}^{c}) \geq \chi(\mathbf{G}_{\mathbb{P}}^{c})$. We discuss extensions to the infinite family of graphs which arise from posets called layered generalized crowns, whose chromatic number has a known upper bound. (Received September 11, 2015)

1116-05-741 **N Bradley Fox*** (foxb@apsu.edu). *A Lattice Path Interpretation of the Diamond Product.*

The diamond product is a poset operation that corresponds to the Cartesian product of polytopes. Through the use of coproducts, recursive formulas have been developed to study the resulting *cd*-index, a polynomial which contains data on chains within posets, of the diamond product of two Eulerian posets. This talk introduces a combinatorial interpretation for the diamond product of two *cd*-monomials that involves a weighted sum of lattice paths. (Received September 11, 2015)

1116-05-755 **Laura Escobar*** (lescobar@illinois.edu), Department of Mathematics, University of Illinois at Urbana-Champaign, 1409 W. Green Street, Urbana, IL 61801, and **Karola Meszaros**. *Toric matrix Schubert varieties.*

Given a matrix Schubert variety X_π, it can be written as $X_\pi = Y_\pi \times \mathbb{C}^q$ (where q is maximal possible). We characterize when Y_π is toric (with respect to a $(\mathbb{C}^*)^{2n-1}$-action) and study the associated polytope of its projectivization. We construct regular triangulations of this polytope which we show are geometric realizations of a family of subword complexes. Subword complexes were introduced by Knutson and Miller, who also showed that they are homeomorphic to balls or spheres and raised the question of their polytopal realizations. Based on joint work with Karola Meszaros. (Received September 11, 2015)

1116-05-760 **Moa Apagodu*** (mapagodu@vcu.edu), 1707 Bramsford Court, Henrico, VA 23238, and **Doron Zeilberger** and **Tewodros Amdeberhan**. *Wilf's "Snake Oil" Method Proves an Identity in the Motzkin Triangle.*

We give yet-another illustration of using Herb Wilf's Snake Oil Method, by proving a certain identity between the entries of the so-called Motzkin Triangle, that arose in a recent study of enumeration of certain classes of integer partitions. We also briefly illustrate how this method can be applied to general 'triangles'. (Received September 11, 2015)

1116-05-808 **Alex Fink*** (a.fink@qmul.ac.uk). *Ladder ideals and tropical hyperplane arrangements with infinities.*

Much of the combinatorics of tropical hyperplane arrangements, that relate them to triangulations of products of two simplices and other well-known objects, has previously been exhibited only when each hyperplane is normal to the full simplex, but remains valid if faces of that simplex are allowed. Several of these appear in joint work with Rincon, *Stiefel tropical linear spaces.* Another, featured in ongoing work with Dochtermann and Sanyal, is that they yield cellular resolutions of ladder determinantal ideals. We discuss both, along with extensions in progress to broader classes of ideals related to generalised permutahedra. (Received September 13, 2015)

1116-05-827 **Stephanie van Willigenburg*** (steph@math.ubc.ca). *Littlewood-Richardson rules for symmetric skew quasisymmetric Schur functions.*

Symmetric skew quasisymmetric Schur functions are a generalization of skew Schur functions and contain skew Schur functions as a special case. One way of expanding skew Schur functions in terms of Schur functions is to use the famed version of the classical Littlewood-Richardson rule involving Yamanouchi words. This given, a natural question to consider is whether there exists an analogous rule for symmetric skew quasisymmetric Schur functions.

In this talk we will give two Littlewood-Richardson rules for symmetric skew quasisymmetric Schur functions that are analogous to the aforementioned version of the classical Littlewood-Richardson rule. Furthermore, both our rules have the property that they contain the classical version as a special case. We will then apply our rules to classify symmetric skew quasisymmetric Schur functions diagrammatically. This talk is based on joint work with Christine Bessenrodt and Vasu Tewari. (Received September 13, 2015)

1116-05-833 **David Conlon**, **Jacob Fox** and **Yufei Zhao***, Mathematics Institute, University of Oxford, Oxford, OX2 6GG, United Kingdom. *Pseudorandomness in the the Green-Tao theorem.*

The celebrated Green-Tao theorem states that there are arbitrarily long arithmetic progressions in the primes. One of the key steps in its proof is a relative Szemerédi theorem, which roughly says that every relatively dense subset of a pseudorandom set of integers contains long arithmetic progressions. What pseudorandomness hypotheses does one need to prove the Green-Tao theorem? This is the question that I will address in the talk. (Received September 14, 2015)

1116-05-849 **Shaohui Wang***, 115 Northgate Dr PMB2033, University, MS 38677, and **Bing Wei**. *A note on the independent domination number versus domination number.* Preliminary report.

Let $\gamma(G)$ and $i(G)$ be the domination number and the independent domination number of G, respectively. Hedetniemi and Mitchell proved that $i(G)/\gamma(G) = 1$ on line graphs of trees in 1977. Rad and Volkmann posted a conjecture that $i(G)/\gamma(G) \leq \Delta(G)/2$ for any graph G, where $\Delta(G)$ is its maximum degree, see [**?**]. In this note, we verify the conjecture for bipartite graphs. Several graph classes attaining the extremal bound and graphs containing odd cycles with the ratio larger than $\Delta(G)/2$ are provided as well. (Received September 14, 2015)

1116-05-856 **Eric Katz*** (eekatz@uwaterloo.ca), 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada. *Hodge Theory on Matroids.*

The chromatic polynomial of a graph counts its proper colourings. This polynomial's coefficients were conjectured to form a unimodal sequence by Read in 1968. This conjecture was extended by Rota in his 1970 address to assert the log-concavity of the characteristic polynomial of matroids which are the common generalizations of graphs and linear subspaces. We discuss the resolution of this conjecture which is joint work with Karim Adiprasito and June Huh. The solution draws on ideas from the theory of algebraic varieties, specifically Hodge theory, showing how a question about graph theory leads to a solution involving Grothendieck's standard conjectures. (Received September 14, 2015)

1116-05-858 **Kathleen O'Hara** (ohara.kathy1@gmail.com) and **Dennis Stanton*** (stanton@math.umn.edu). *Refinements of the Rogers-Ramanujan identities.*

While searching for a Rogers-Ramanujan bijection, refinements were found. Some parts on the mod 5 side may be weighted. Combinatorial versions are given as all of the results are manifestly positive. For example, one can specify what subset of difference two partitions corresponds to partitions with parts congruent to 2 or 3 mod 5 without any 3's. (Received September 14, 2015)

1116-05-870 **James Haglund** (jhaglund@math.upenn.edu), **Jeffrey Remmel** (jremmel@ucsd.edu), **Brendon Rhoades*** (bprhoades@ucsd.edu) and **Andrew Timothy Wilson** (atwilson@ucsd.edu). *Delta Conjectures and ordered set partition statistics.*

A famous result of MacMahon states that the major index and inversion count statistics share the same distribution on the set of permutations in the symmetric group S_n. We present a generalization of MacMahon's result to ordered set partitions. The Delta Conjectures are a family of conjectures due to Haglund, Remmel, and Wilson which generalize the famous Shuffle Conjecture of diagonal harmonics. As an application of our equidistribution results, we will prove a special case of the Delta Conjectures. (Received September 14, 2015)

1116-05-894 **Douglas Rall** and **Kirsti Wash*** (kirsti.wash@trincoll.edu), 300 Summit Street, Mathematics Department, Hartford, CT 06114. *Identifying codes in the Cartesian product of a graph and K_2.*

An identifying code in a graph is a dominating set that also has the property that the closed neighborhood of each vertex in the graph has a distinct intersection with the set. The minimum cardinality of an identifying code in a graph G is denoted $\gamma^{\mathrm{ID}}(G)$. Due to the nature in which this parameter arose, identifying codes in the Cartesian product are studied as early as the very first paper to appear on the topic by Chakrabarty et al. In this talk, we focus on identifying codes in the Cartesian product of a graph G and K_2, known as the *prism of* G. We investigate general bounds for $\gamma^{\mathrm{ID}}(G\Box K_2)$ for any graph G, and we identify a class of graphs for which $\gamma^{\mathrm{ID}}(G\Box K_2)$ is no larger than $\gamma^{\mathrm{ID}}(G)$. (Received September 14, 2015)

1116-05-900 **Angela S Hicks*** (ashicks@stanford.edu). *Parking Functions, Sandpiles, and Gessel's Fundamental Basis.*

The more than decade old shuffle conjecture ties the bi-graded frobenius characteristic of the diagonal harmonics to two classical statistics (area and dinv) on parking functions, each with an associated quasisymmetric function. It has been previously shown that when we look at only single grading (i.e. only considering the simpler of the two statistics, area) the conjecture is true and the action on parking functions in this case has been given explicitly. A separate bijection (the "phi map") gives that these two statistics are equidistributed on the parking functions with pmaj and area, but the associated quasisymmetric function is not calculated in the same way as in the first sum. We explain how to calculate it and think about the associated action (in the singly graded case) in the context of a natural statistic on sandpile models. (Received September 15, 2015)

1116-05-926 **Ethan Ackelsberg**, **Zachary Brehm**, **Ada Chan**, **Joshua Mundinger** and **Christino Tamon*** (tino@clarkson.edu), Dept. Computer Science, Clarkson University, 8 Clarkson Avenue, Potsdam, NY 13699-5815. *Quantum State Transfer in Corona Products.*

A continuous-time quantum walk on a graph G is given by the time-varying unitary matrix $U(t) = \exp(-itM)$, where M is a Hermitian matrix associated with G. We say such a quantum walk has state transfer between vertices u and v at time τ if the (u, v) entry of $U(\tau)$ has near unit magnitude. This notion was motivated by applications of quantum information transmission in spin networks. We show new constructions of graphs with state transfer using the Frucht-Harary corona product. Our results exploit the spectral properties of the underlying graphs. (Received September 15, 2015)

1116-05-939 **Mikhail I. Ostrovskii*** (ostrovsm@stjohns.edu), Department of Mathematics and Comp.Sci., St. John's University, 8000 Utopia Parkway, Queens, NY 11439. *Low-distortion embeddings of graphs with large girth.*

There exist families of graphs with indefinitely growing girths which admit uniformly bilipschitz embeddings into ℓ_1, and thus do not weakly contain any families of expanders. (Received September 15, 2015)

1116-05-944 **Jeffrey H. Dinitz*** (jeff.dinitz@uvm.edu). *The Construction and Uses of Heffter Arrays.*

A Heffter array $H(m, n; s, t)$ is an $m\times n$ matrix with nonzero entries from $\mathbb{Z}_{2ms+1}$ such that *i*) each row contains s filled cells and each column contains t filled cells, *ii*) every row and column sum to 0 mod$(2ms+1)$, and *iii*) no element from $\{x, -x\}$ appears twice. In this talk we will discuss existence of these arrays in the case where $s = n$ (every cell is filled) and in the case where $m = n$ (square arrays). Heffter arrays are useful in embedding the complete graph K_{2ms+1} on an orientable surface where the embedding has the property that each edge borders exactly one $s-$cycle and one $t-$cycle. We will demonstrate this use by showing that for every n, there exists a biembedding of the complete graph on $6n + 1$ points on an orientable surface such that each edge borders a 3-cycle and a simple n-cycle.

This is joint work with D.S. Archdeacon, D.M. Donovan, E. Ş. Yazıcı, T. Boothby, and A. Mattern. (Received September 15, 2015)

1116-05-963 **Darren A Narayan*** (dansma@rit.edu), School of Mathematical Sciences, 85 Lomb Memorial Drive, Rochester Institute of Technology, Rochester, NY 14623, and **Roger Vargas**, Department of Mathematics and Statistics, Williams College, Williamstown, MA 01267. *Temporal Graph Theory and Functional Connectivity in the Human Brain.* Preliminary report.

The human brain is a dynamic network of firing neurons and continuously changing oxygen levels. To accurately and precisely model this network it is not sufficient to use a single static network, but rather a time varying aggregate of hundreds or thousands of networks. The sequence of networks obtained over the time course of a functional Magnetic Resonance Imaging (fMRI) scan provides valuable information regarding dynamic functional and structural connectivity of the human brain. This research is joint with Bradford Mahon and Frank Garcea at the Rochester Center for Brain Imaging at the University of Rochester. (Received September 15, 2015)

1116-05-975 **Daniel Irving Bernstein** and **Seth Sullivant*** (smsulli2@ncsu.edu). *Combinatorial properties of hierarchical models.*

Hierarchical models are widely used statistical models for analyzing discrete data. To each simplicial complex we associate a vector configuration and corresponding toric variety, whose intersection with the probability simplex is the hierarchical model. We describe combinatorial results on these toric varieties including a classification of which simplicial complexes produce unimodular toric varieties and results on operations on the simplicial compleces that preserve normality of the toric varieties. (Received September 15, 2015)

1116-05-985 **Nevena Francetic*** (nfrancetic@gmail.com), **Sarada Herke** and **Daniel Horsley**. *Non-existence results for symmetric pair coverings with 2-regular excess.*

The famous Bruck-Ryser-Chowla theorem gives necessary conditions for the existence of symmetric block designs. In this talk we present a generalization of the second part of this theorem to symmetric pair coverings which have 2-regular excess.

More precisely, a (v, k, λ)-covering is a pair $(V, \mathcal{B})$, where V is a set of v points, and $\mathcal{B}$ is a collection of k-subsets of V, called blocks, such that every unordered pair of points in V is contained in *at least* λ distinct blocks. It is called symmetric if it has equal number of blocks and points. Its excess is a multigraph on vertex set V such that an edge between two vertices $x, y \in V$ has multiplicity equal to the difference between the replication number, the number of blocks in $\mathcal{B}$ which contain both x and y, and the index λ. We adapt arguments related to the Hasse-Minkowski invariant of the rationally congruent matrices to obtain some necessary conditions for the existence of symmetric coverings with 2-regular excess. (Received September 15, 2015)

1116-05-1003 **Peter Danziger*** (danziger@ryerson.ca), Ryerson University, Toronto, Ontario , Canada. *On the Hamilton-Waterloo Problem.*

Given non-negative integers v, m, n, α, β, the Hamilton-Waterloo problem, asks for a factorization of the complete graph, K_v, into α m-cycle factors and β n-cycle factors. Clearly, $n, m \geq 3$ must be odd, and $m \mid v$, $n \mid v$ and $\alpha + \beta = (v-1)/2$ are necessary conditions. Without loss of generality, we may assume that $n \geq m \geq 3$.

We show that these necessary conditions are sufficient when v is a multiple of nm and $v > mn$, except possibly when $\beta = 1$ or 3, or $(m, n, \beta) = (3, 11, 5)$ or $(3, 13, 5)$. For the case where $v = mn$ we show sufficiency when $\beta > (n+5)/2$, except possibly when $\alpha = 2, 4$, or $(m, n, \alpha, \beta) = (3, 11, 6, 10)$, $(3, 13, 8, 10)$, $(3, 17, 10, 15)$ or $(3, 21, 10, 21)$.

We also show that when $n \geq m \geq 3$ are odd integers, the lexicographic product of C_m with the empty graph of order n has a factorization into α C_m factors and β C_n factors for every $0 \leq \alpha \leq n$, $\beta = n - \alpha$, except possibly when $\alpha = 2, 4$, $\beta = 1, 3$, or $(m, n, \alpha) = (3, 11, 6), (3, 13, 8), (3, 15, 8), (3, 15, 10), (3, 17, 10), (3, 21, 10)$.

This is joint work with Andrea Burgess and Tommaso Traetta. (Received September 15, 2015)

1116-05-1009 **Ian Wanless*** (ian.wanless@monash.edu), School of Mathematical Sciences, Monash University, Clayton, Vic 3800, Australia. *A notion of parity for orthogonal Latin squares.*

Parity is a familiar and important notion in the study of permutations. Latin squares are two dimensional permutations and also have some kind of parity. In fact, they have three basic attributes, each of which can be either even or odd. These obey a relationship which means that any two determine the third. So in information theory terms there are really just two parity bits (i.e. 4 possible parities).

What about MOLS (mutually orthogonal Latin squares)? Do they have a notion of parity? In 2012 Glynn and Byatt showed that they do. We reformulate their notion as a natural generalisation of the parity of a Latin square. We then establish an upper bound on the number of parity bits that a set of k MOLS may have. We show that this bound is achieved in infinitely many cases, but never by complete sets of MOLS. We also study the effect of natural MOLS operations on their parity. This leads to the idea of a switching class, which is a set of parities such that if any one parity in the class is achievable, then they all are. (Received September 16, 2015)

1116-05-1043 **Mark E. Watkins*** (mewatkin@syr.edu), Mathematics Department, 215 Carnegie, Syracuse University, Syracuse, NY 13244-1150. *Infinite Graphical Frobenius Representations.*

A *graphical Frobenius representation (GFR)* of a Frobenius (permutation) group G is a graph Γ whose automorphism group $\mathrm{Aut}(\Gamma)$ acts as a Frobenius permutation group on the vertex set of Γ, that is, $\mathrm{Aut}(\Gamma)$ acts vertex-transitively with the property that all nonidentity automorphisms fix either one or zero vertices and there are some of each kind.

The set K of all fixed-point-free automorphisms together with the identity is called the *kernel* of G. Whenever G is finite, K is a regular normal subgroup of G (F. G. Frobenius, 1901), in which case Γ is a Cayley graph of K. The same holds true for the infinite instances presented here.

Infinite, locally finite, vertex-transitive graphs can be classified with respect to (i) their number of *ends* and (ii) their *growth rate*. We present families of infinite GFRs for all possible combinations of these properties. There exist GFRs with polynomial growth of degree d for every positive integer d, and there are GFRs of exponential growth, both 1-ended and infinitely-ended, that are infinite chiral maps in the hyperbolic plane. (Received September 16, 2015)

1116-05-1057 **David A Pike*** (dapike@mun.ca), Department of Mathematics and Statistics, Memorial University of Newfoundland, Canada. *Block orderings for triple systems.*

A λ-fold triple system of order v consists of a v-set V and a collection of 3-subsets (called blocks or triples) of V such that each 2-subset of V occurs in exactly λ of the system's triples. Given a λ-fold triple system with $\lambda > 1$, we can ask whether its triples can be ordered so that the union of any two consecutive triples consists of four elements of V. We will describe some potential applications, give a review of previous results, and discuss some recent work concerning the existence (or nonexistence) of such orderings, with emphasis on 2-fold triple systems. Recent advances include joint work with Aras Erzurumluoğlu. (Received September 16, 2015)

1116-05-1066 **Thomas Grubb**, **Kyutae Paul Han*** (kyutae.han.16@dartmouth.edu) and **Victoria Horan**. *Overlap cycles of* $\binom{[n]}{k}$.

Universal cycles and Gray codes lists elements of a combinatorial family in a specific manner, and overlap cycles were introduced as a generalization of these in 2010 by Godbole et al. An s-overlap cycle orders a set of strings so that the last s letters of any one string are the first s letters of the next (in order). In this paper, we study s-overlap cycles of $\binom{[n]}{k}$, k-subsets of the set $[n] = \{1, 2, ..., n\}$, and prove that when $k > 3s$, s-overlap cycles of $\binom{[n]}{k}$ do exist. (Received September 16, 2015)

1116-05-1098 **Michael Ferrara*** (michael.ferrara@ucdenver.edu). *The Rocky Mountain - Great Plains Graduate Research Workshop in Combinatorics: An Overview.*

The Rocky Mountain-Great Plains Graduate Research Workshop in Combinatorics (GRWC) is a multi-institutional program of annual research workshops co-organized by faculty from the University of Colorado Denver, Iowa State University, the University of Denver, the University of Nebraska-Lincoln, and the University of Wyoming.

The GRWC aims to (a) provide an intensive collaborative research opportunity for graduate students in combinatorics and related fields, (b) provide high quality mentoring and professional development for participating students and postdocs, and (c) help students build a professional network of peers in their broad research area.

The first GRWC was co-hosted by the University of Colorado Denver and the University of Denver in summer 2014 and the second was hosted by Iowa State University in June 2015. Together, they involved over 70 graduate students and 10 postdocs from 20 institutions and have generated 10 research papers, with several more in preparation.

This talk will discuss the GRWC model, which is centered on students developing and presenting open problems with guidance from faculty and postdocs. We will also give an overview of the GRWC's professional development programs and networking opportunities and summarize participant feedback. (Received September 16, 2015)

1116-05-1099 **J. Han**, **C. Zang*** (czang1@gsu.edu) and **Y. Zhao**. *Minimum vertex degree thresholds for tiling complete* 3*-partite* 3*-uniform hypergraphs.*

Given two r-uniform hypergraphs (in which every edge consists of r vertices) F and H, an F-factor of H is a collection of vertex-disjoint copies of F that covers all vertices of H. The (hyper)graph tiling/packing problems study under which conditions an F-factor exists. The obvious necessary condition is $v(F)|v(H)$, where $v(H)$ denotes the order of H. The $r = 2$ case (i.e., graph tiling) has been intensively studied for decades, e.g., Edmonds shows that there is a polynomial time algorithm finding the maximum matching (where F is an edge), and Kühn and Osthus determines the minimum degree threshold for F-tiling for arbitrary graph F. In contrast, much less is known for hypergraphs. In this talk I will present the minimum vertex degree threshold for K-tiling in 3-uniform hypergraphs, where K is any complete 3-partite 3-uniform hypergraph. This is a joint work with Jie Han and Yi Zhao. (Received September 16, 2015)

1116-05-1118 **Aida Abiad*** (a.abiadmonge@maastrichtuniversity.nl), Maastricht, Netherlands. *On the distance spectra of graphs.*

The distance matrix of a graph G is the matrix containing the pairwise distances between vertices. The distance eigenvalues of G are the eigenvalues of its distance matrix and they form the distance spectrum of G. We determine the distance spectra of halved cubes, double odd graphs, and Doob graphs, completing the determination of distance spectra of distance regular graphs having exactly one positive distance eigenvalue. We characterize strongly regular graphs having more positive than negative distance eigenvalues. We give examples of graphs with few distinct distance eigenvalues but lacking regularity properties. We also determine the determinant and inertia of the distance matrices of lollipop and barbell graphs.

This is joint work with Ghodratollah Aalipour, Zhanar Berikkyzy, Jay Cummings, Jessica De Silva, Wei Gao, Kristin Heysse, Leslie Hogben, Franklin H.J. Kenter, Jephian C.-H. Lin, and Michael Tait. (Received September 17, 2015)

1116-05-1120 **Georgia Benkart*** (benkart@math.wisc.edu), Department of Mathematics, University of Wisconsin-Madison, Madison, WI 53706. *Walking on Representation Graphs and Generalized Hyperbolic Functions.*

A finite group G and a representation of G on a finite-dimensional vector space V determine a certain graph (the so-called representation graph). For example, when G is a product of n copies of the integers modulo 2, V could be taken to be the n-cube. This talk will focus on counting the number of walks from one node to another on such graphs. For any G and V, we give an expression for the number of walks in terms of group characters and show for any abelian group that the exponential generating function for the number of walks can be expressed using generalized hyperbolic functions. The number of walks determines the dimension of the irreducible modules for the centralizer algebra of the action of G on tensor powers of V, so the expressions give those dimensions as well. This is joint work with Dongho Moon. (Received September 17, 2015)

1116-05-1137 **Richard Hammack** and **Wilfried Imrich*** (imrich@unileoben.ac.at). *Products of almost locally finite graphs.*

The Cartesian product of connected infinite graphs is well understood, but other products of infinite graphs are rather intractable in general.

In this talk we consider almost locally finite graphs, that is, graphs where any two vertices have at most finitely many neighbors, and study the strong, the direct and the lexicographic product. Our focus is on prime factorizations, the structure of the automorphism group, vertex- and edge-transitivity and the distinguishing number.

The main tool is the Cartesian skeleton of graphs, which allows to reduce many problems about strong and direct products to the Cartesian product. (Received September 17, 2015)

1116-05-1140 **Levent Alpoge*** (lalpoge@math.princeton.edu). *Square-root cancellation for the signs of Latin squares (i.e., why the Alon-Tarsi conjecture is hard).*

Let $L(n)$ be the number of Latin squares of order n, and let $L^{\text{even}}(n)$ and $L^{\text{odd}}(n)$ be the number of even and odd such squares, so that $L(n) = L^{\text{even}}(n) + L^{\text{odd}}(n)$. The Alon-Tarsi conjecture states that $L^{\text{even}}(n) \neq L^{\text{odd}}(n)$ when n is even (when n is odd the two are equal for very simple reasons). We prove that $|L^{\text{even}}(n) - L^{\text{odd}}(n)| \leq L(n)^{\frac{1}{2}+o(1)}$, thus establishing the conjecture that the number of even and odd Latin squares, while conjecturally not equal in even dimensions, are in fact equal to leading order asymptotically. The proof is actually very short: we apply a differential operator to an exponential integral over $\mathrm{SU}(n)$ and calculate what results in two different ways. The method is inspired by a result of Kumar-Landsberg. (Received September 17, 2015)

1116-05-1144 **Wilfried Imrich*** (imrich@unileoben.ac.at), **Florian Lehner** and **Simon Mark Smith**. *Symmetry breaking in graphs.*

In a graph, a set of vertices that is stabilized setwise by only the trivial automorphism is called a distinguishing set. Tom Tucker conjectured that every connected, infinite locally finite graph G has such a set if each nontrivial automorphism of G moves infinitely many vertices. The conjecture is know as the Infinite Motion Conjecture, which is still open despite the fact that numerous large classes of graphs have been shown to satisfy it.

In finite graphs distinguishing sets, if they exist, can be very small in comparison to the size of the graph, and in infinite graphs such sets can be finite. If they are not finite, their density can be zero. This talk presents classes of graphs that have distinguishing sets of zero density. Moreover, it is shown that the Infinite Motion Conjecture is true for cubic graphs, and that the distinguishing sets can be chosen to have density zero. (Received September 17, 2015)

1116-05-1154 **Christopher Cox**, **Michael Ferrara**, **Ryan R Martin** and **Benjamin Reiniger*** (reiniger@ryerson.ca). *Chvátal-type results for degree sequence Ramsey numbers.*

A sequence of nonnegative integers is called *graphic* if it is the degree sequence of some simple graph; such a graph is called a *realization* of the sequence. For a graph H, a graphic sequence is called *potentially H-graphic* if some realization contains H as a subgraph. We will discuss a degree sequence analogue of the graph Ramsey number: the *potential-Ramsey number* of graphs H_1 and H_2 is the minimum integer N such that for every N-term graphic sequence π, either π is potentially H_1-graphic or the complementary sequence $\overline{\pi}$ is potentially H_2-graphic.

Chvátal found the exact value of the classical Ramsey number of a complete graph vs. a tree. We find the value of the potential-Ramsey number when the tree is large enough compared to the complete graph: if $s \geq 2$ and T is a tree with $|V(T)| \geq 9(s-2)$, then the potential-Ramsey number of K_s and T is equal to $t+s-2$. In order to prove this, we prove a sharp sufficient condition for an arbitrary graph to pack with a forest, following the lead of the classical Sauer-Spencer theorem. (Received September 17, 2015)

1116-05-1157 **Sinan G Aksoy*** (saksoy@ucsd.edu), Department of Mathematics, 9500 Gilman Drive #0112, La Jolla, CA 92093, and **Paul Horn** (paul.horn@du.edu), Department of Mathematics, Aspen Hall, Room 717, 2280 S. Vine Street, Denver, CO 80208. *Graphs with many strong orientations.*

The classic Robbins' theorem provides a simple criterion for determining whether a graphs edges can be oriented to yield a strongly connected directed graph. While determining the existence of a strong orientation is straightforward, it is more difficult to count all strong orientations of a given graph. In this talk, we establish mild conditions under which almost all of a graphs orientations are strongly connected. Unless prohibitively large, a minimum degree requirement alone is insufficient; it neither suffices to only control a graphs "bottleneck" through an isoperimetric condition. However, we prove a mild combination of these properties ensures (almost all) a graphs orientations are strongly connected. We also provide a construction to show these conditions are, up to a small factor, best possible. (Received September 17, 2015)

1116-05-1164 **Sogol Jahanbekam*** (sogol.jahanbekam@ucdenver.edu), 4203, Student Commons Building, Denver, CO 80204. *On the Strong Chromatic Index of Sparse Graphs.*

The strong chromatic index of a graph G, denoted $\chi'_s(G)$ is the least number of colors needed to edge-color G so that edges at distance at most two receive distinct colors. The strong list chromatic index, denoted $\chi'_{l,s}(G)$, is the least integer k such that if arbitrary lists of size k are assigned to each edge then G can be edge-colored from those lists where edges at distance at most two receive distinct colors. We use the discharging method, the Combinatorial Nullstellensatz, and computation to show that if G is a subcubic planar graph with girth(G) ≥ 41 then $\chi'_{l,s}(G) \leq 5$, answering a question of Borodin and Ivanova. We further show that if G is a subcubic planar graph and girth(G) ≥ 30, then $\chi'_s(G) \leq 5$, improving a bound from the same paper. Finally, if G is a planar graph with maximum degree at most four and girth(G) ≥ 28, then $\chi'_s(G) \leq 7$, improving a more general bound of Wang and Zhao. This paper is a product of the Rocky Mountain - Great Plains Graduate Research Workshop in Combinatorics and is joint work with P. DeOrsey, J. Diemunsch, M. Ferrara, N. Graber, S. G. Hartke, B. Lidicky, L. Nelsen, D. Stolee, and E. Sullivan. (Received September 17, 2015)

1116-05-1167 **Federico Castillo***, University of California, One Shields Avenue, Davis, CA 95616, and **Fu Liu**. *A McMullen formula for the number of lattice points of generalized permutohedra.*

Finding the number of integer points of an integral polytope P is a classical problem in polyhedral geometry. One possible approach is through a McMullen formula, a formula of the form:

$$|P \cap \mathbb{Z}^n| = \sum_{F \subset P} \alpha(F,P)\mathrm{nvol}(F),$$

where the sum is over all faces, and $\alpha(F,P)$ are rational numbers depending just on the feasible cone of F in P. The function $\alpha(F,P)$ is not uniquely determined and different constructions have been discovered. We explore a particular one, given by Berline and Vergne, on generalized permutohedra, deformations of regular permutohedra. We conjecture that the resulting α are positive, this relates to the positivity of the coefficients of their Ehrhart polynomials. We established close connections between this α values, mixed Ehrhart theory for hypersimplices, and the Todd class of the permutohedral toric variety. (Received September 17, 2015)

1116-05-1205 **Hailun Zheng*** (hailunz@uw.edu), University of Washington, Department of Mathematics, Box 354350, Seattle, WA 98195. *Minimal balanced triangulations of sphere bundles over the circle.*

Starting from mid eighties, several researchers (the list includes Kühnel; Bagchi, Datta; Chestnut, Sapir and Swartz) worked on and succeeded in determining the minimum number of vertices needed to triangulate S^{d-2}-bundles over S^1. However, the analogous question for the case of balanced triangulations remained open: Klee and Novik gave an explicit construction of a balanced triangulation of a sphere bundle with $3d$ vertices that is orientable or non-orientable depending on the parity of d; they also constructed balanced triangulations of both bundles with an arbitrary number of vertices $N \geq 3d+2$, and asked if their constructions with $3d$ and $3d+2$ vertices are indeed minimal. We provides an affirmative answer to their conjecture: if d is odd and the bundle is orientable, or d is even and the bundle is non-orientable, then the minimum number of vertices is $3d$; otherwise, it is $3d+2$. (Received September 17, 2015)

1116-05-1220 **Ghodratollah Aalipour*** (ghodrat.aalipour@ucdenver.edu), Department of Mathematical and Statistical Sc, University of Colorado Denver, Denver, CO 80217, and **Aida Abiad**, **Zhanar Berikkyzy**, **Leslie Hogben**, **Franklin H. J. Kenter**, **Jephian C.-H. Lin** and **Michael Tait**. *On the unimodality of coefficients of the distance characteristic polynomial of a tree.*

There are several sequences in combinatorics which are known/conjectured to be unimodal. Some families of these sequences consist of the coefficient sequence of a polynomial associated to a combinatorial structure. One instance of such polynomials is the characteristic polynomial of the distance matrix of a tree. For a tree T with distance characteristic polynomial $p_D(x) = x^n + \delta_{n-2}x^{n-2} + \cdots + \delta_1 x + \delta_0$, Graham and Lovász in 1978 conjectured that the sequence $\{(-1)^{n-1}\delta_k/2^{n-k-2}\}_{k=0}^{n-2}$ is unimodal. In this talk we present a proof for this conjecture. This is joint work with A. Abiad, Z. Berikkyzy, L. Hogben, F. H. J. Kenter, J. C.-H. Lin, and M. Tait. (Received September 18, 2015)

1116-05-1230 **Debra L Boutin***, 33 Homestead Rd W, Clinton, NY 13323. *Symmetry Parameters for Lexicographic Graph Products.* Preliminary report.

A *determining set* S is a set of vertices with the property that each automorphism of the graph is uniquely identified by its action on S. The *distinguishing number* is the smallest number of colors necessary to color the vertices so that no nontrivial automorphism preserves the color classes. The *edge istinguishing number* is similarly defined. If a graph can be (edge or vertex) distinguished with two colors, the *distinguishing cost* is the minimum size of a color class in such a coloring. In this talk, we will explore new work on these paramters for the lexicographic product of graphs. (Received September 18, 2015)

1116-05-1252 **Calvin Deng***, 370 Dunster Mail Center, 945 Memorial Drive, Cambridge, MA 02138. *Even $(\bar{s},\bar{t})$-core partitions and self-associate characters of $\tilde{S}_n$.*

A partition is a $\bar{s}$-core if it is the result of removing all of the s-bars from a partition. We extend a method of Olsson and Bessenrodt to determine the number of even partitions that are simultaneously $\bar{s}$-core and $\bar{t}$-core. When p and q are distinct primes, this also determines the number of self-associate characters of $\tilde{S}_n$ that are simultaneosly defect 0 for p and q. (Received September 18, 2015)

1116-05-1257 **Jessica De Silva**, **Theodore Molla**, **Florian Pfender**, **Troy Retter** and **Michael Tait*** (mtait@math.ucsd.edu). *Increasing paths in edge-ordered graphs.*

Given an arbitrary edge-ordering of a fixed graph, how long of an increasing path is one guaranteed to find? Chvátal and Komlós raised this question when the host graph is the complete graph, and several researchers studied this problem on the complete graph and on other host graphs. In this talk, we discuss what happens for the hypercube and for random graphs, and we end with several interesting questions which are still open. (Received September 18, 2015)

1116-05-1311 **Daniel W Cranston**, **Luke Postle**, **Chenxiao Xue*** (chxue@davidson.edu) and **Carl Yerger**. *Class 0 Bounds for Graph Pebbling.*

Given a configuration of pebbles on the vertices of a connected graph G, a *pebbling move* removes two pebbles from some vertex and places one pebble on an adjacent vertex. The *pebbling number* of a graph G is the smallest integer k such that for each vertex v and each configuration of k pebbles on G, there exists a sequence of pebbling moves that places at least one pebble on v. If the pebbling number of a graph G equals the number of vertices in G, we say that the graph is Class 0. In this talk, we investigate the minimum number of edges in a Class 0 graph on n vertices. Via a discharging-based technique, we conclude that any Class 0 graphs with n vertices have at least $5n/3 - 11/3$ edges, and that any diameter 2 Class 0 graphs have at least $2n-5$ edges. We also show that the $2n-5$ bound for diameter 2 Class 0 graphs is best possible and characterize the graphs where this bound holds. (Received September 18, 2015)

1116-05-1313 **Douglas R Stinson*** (dstinson@uwaterloo.ca) and **Maura B Paterson**. *Characterisations of Optimal Algebraic Manipulation Detection Codes.*

Algebraic manipulation detection (AMD) codes are algebraic/combinatorial structures that are closely related to difference sets. They were defined as a generalisation and abstraction of techniques previously used in constructing robust secret sharing schemes, and their use has been proposed for a range of other cryptographic applications. In this talk we consider lower bounds on the success probability of an adversary in attacking an AMD code, as well as combinatorial characterisations of AMD codes meeting these bounds with equality. (Received September 18, 2015)

1116-05-1342 **Amanda L Ruiz*** (alruiz@sandiego.edu), 5430 Linda Vista Rd #32, San Diego, CA 92110. *Realizations of phased matroids.* Preliminary report.

A matroid is a combinatorial abstraction of linear independence in vector spaces.

A phased matroid is a matroid with additional structure which plays the same role for complex vector arrangements that oriented matroids play for real vector arrangements.

The realization space of an oriented (resp., phased) matroid is the space of vector arrangements in $\mathbb{R}^n$ (resp., $\mathbb{C}^n$) that correspond to oriented (resp., phased) matroid, modulo a change of coordinates.

In this talk, we will define, matroids, oriented matroids, and phased matroids, their similarities, and their surprisingly different realization spaces. (Received September 18, 2015)

1116-05-1384 **Selene Chew*** (sec6971@rit.edu), School of Mathematical Sciences, Rochester Institute of Technnology, Rochester, NY 14612. *A graph theoretic approach to the inverse voter preference voter problem.*

In referendum elections, voters are often required to cast simultaneous votes on multiple questions or proposals. The separability problem occurs when a voter's preferences on the outcome of one or more proposals depend on the predicted outcomes of other proposals. The character of a voter's preferences describes the interdependence relationships (for that voter) between the sets of proposals in the election. While it is easy to determine the character of a voter's preferences, the inverse problem—that is, finding a voter whose preferences have a given, pre-determined character—is much more challenging. In this talk, we will describe a graph theoretic approach to character construction, defining the character spectrum of a graph and investigating related theoretical and computational results. This work was completed as part of the Summer Mathematics REU at Grand Valley State University. (Received September 19, 2015)

1116-05-1386 **Patricia Hersh*** (plhersh@ncsu.edu) and **Cristian Lenart** (clenart@albany.edu). *From the weak Bruhat order to crystal graphs as posets.*

Crystal graphs give a combinatorial approach to studying the representation theory of Kac-Moody algebras, and often can be regarded as partially ordered sets. We prove that fundamental properties of the weak Bruhat order transfer to lower intervals in these crystal posets, but that even in type A these properties do not always hold for arbitrary intervals. In particular, for lower intervals we give a crystal theoretic analogue for the statement that any two reduced expressions for the same Coxeter group element are connected by a series of (long and short) braid moves, and we prove that the Moebius function only takes the values 0,1,-1. This Moebius function determination is a consequence of a stronger homotopy theoretic statement. We will also discuss the role of the key of a crystal in this story. (Received September 19, 2015)

1116-05-1400 **Michael W Raney*** (mwr23@georgetown.edu), Department of Mathematics and Statistics, Georgetown University, Washington, DC 20057. *Trilateral matroids induced by n_3-configurations.* Preliminary report.

We define a new class of a rank-3 matroid called a trilateral matroid. The ground set of such a matroid consists of the points of an n_3-configuration, and the bases of the matroid are the point triples corresponding to non-trilaterals within the configuration. We classify which n_3-configurations induce trilateral matroids, and provide several examples of those that do. (Received September 19, 2015)

1116-05-1402 **Sammy Y Luo*** (sammyluo@mit.edu) and **Mark A Sellke** (msellke@gmail.com). *The Saxl Conjecture for Fourth Powers via the Semigroup Property.*

We study the tensor square conjecture, which states that for all n with a few exceptions, there are irreducible representations of the symmetric groups S_n whose tensor squares contain every irreducible representation. Our main result is that tensor 4th powers suffice to contain all these representations for large enough n. We also show that tensor squares of certain representations contain almost all irreducibles with respect to two natural probability distributions. Our main tool is the semigroup property, which allows breaking partitions down into smaller cases that can be analyzed using simpler methods. (Received September 19, 2015)

1116-05-1446 **Alana Huszar**, **Colin Starr**, **Christina Wahl** and **Corrine Yap*** (cyap@gm.slc.edu).
Unipancylic Matroids.

Based on the concept of uniquely pancyclic graphs, a unipancyclic (UPC) matroid of rank r consists of exactly one circuit of lengths 3 through $r+1$. We begin by looking at Markström's results on the existence of UPC graphs before generalizing them to UPC matroids. We then apply the definition of matroid connectivity, given by Tutte, to determine the connectivity for all UPC matroids, regardless of representability. (Received September 19, 2015)

1116-05-1452 **Harrison C Chapman*** (hchapman@uga.edu). *Asymptotic laws for knot diagrams.*

We consider a model of random knots akin to the one proposed by Dunfield et. al.; a random knot diagram is a random immersion of the circle into the sphere with randomly assigned crossings. By studying diagrams as annotated maps, we are able to show that any given tangle diagram almost certainly occurs many times in a random knot diagram with sufficiently many crossings. Thus, in this model, it is exponentially unlikely for a diagram with n crossings to represent an unknot as $n \to \infty$. This asymptotic behavior is similar to that seen in other models of random knots such as random lattice walks and random polygons. (Received September 19, 2015)

1116-05-1459 **Jerrold R Griggs**, **Kevin G Milans** and **David Offner***, offnerde@westminster.edu, and **David Stoner**. *Tiling the hypercube.* Preliminary report.

A graph G *tiles* another graph H if the vertices of H can be partitioned into disjoint sets so that each set induces a copy of G. We investigate which subgraphs tile the n-dimensional hypercube for n suffiently large. All subgraphs of the hypercube with 2^k vertices for some integer k and at most one cycle have this property. (Received September 19, 2015)

1116-05-1463 **Steven Schluchter*** (sschluch@gmu.edu), Department of Mathematical Sciences, George Mason University, 4400 University Drive, MS: 3F2, Fairfax, VA 22312, and **Justin Z Schroeder**. *Self-dual embeddings of $K_{4m,4n}$ in pseudosurfaces.*

A pseudosurface is the result of identifying a finite number of points of a surface. A proper embedding of a graph G in a pseudosurface P is an embedding in which the regions of the complement of G in P are homeomorphic to discs and pinchpoints of P correspond to vertices in G. We say that a proper embedding of a graph G in a pseudosurface P is self dual if there exists an isomorphism from G to its topological dual. We give an explicit construction of a self-dual embedding of the complete bipartite graph $K_{4m,4n}$ in an orientable pseudosurface for all $m,\ n \geq 1$, which maximizes the number of umbrellas of each vertex and has the property that for any vertex v of $K_{4m,4n}$, there is a face of the constructed embedding that intersects all umbrellas of v. Leveraging these properties, and applying a lemma of Bruhn and Diestel, we apply a surgery introduced here and a different known surgery of Edmonds to each of our constructed embeddings for which at least one of $m, n \geq 1$, we show that there exist several distinct orientable and nonorientable pseudusorfaces with the same Euler characteristic that feature a self-dual embedding of $K_{4m,4n}$. (Received September 20, 2015)

1116-05-1473 **Matthew S Brennan*** (brennanm@mit.edu), 450 Memorial Drive, Apt. H416, Cambridge, MA 02139. *Ramsey numbers of trees and unicyclic graphs versus odd cycles and fans.*

The generalized Ramsey number $R(H, K)$ is the smallest positive integer n such that for any graph G with n vertices either G contains H as a subgraph or its complement $\overline{G}$ contains K as a subgraph. Burr, Erdős, Faudree, Rousseau and Schelp initiated the study of Ramsey numbers of trees versus odd cycles, proving that $R(T_n, C_m) = 2n-1$ for all odd $m \geq 3$ and $n \geq 756m^{10}$, where T_n is a tree with n vertices and C_m is an odd cycle of length m. They proposed to study the minimum positive integer $n_0(m)$ such that this result holds for all $n \geq n_0(m)$, as a function of m. We prove that $R(T_n, C_m) = 2n-1$ for all odd $m \geq 3$ and $n \geq 64m$. Combining this with a result of Faudree, Lawrence, Parsons and Schelp yields $n_0(m)$ is bounded between two linear functions, thus identifying $n_0(m)$ up to a constant factor. We also prove a conjecture of Zhang, Broersma and Chen for $m \geq 9$ that $R(T_n, F_m) = 2n-1$ for all $n \geq m^2 - m + 1$ where F_m denotes a fan on $2m+1$ vertices consisting of m triangles sharing a common vertex. We extend this result from trees to unicyclic graphs UC_n, which are connected graphs with n vertices and a single cycle. (Received September 20, 2015)

1116-05-1480 **Zhanar Berikkyzy** (zhanarb@iastate.edu), **Axel Brandt*** (axel.brandt@ucdenver.edu), **Sogol Jahanbekam** (sogol.jahanbekam@ucdenver.edu), **Victor Larsen** (vlarsen@kennesaw.edu) and **Danny Rorabaugh** (dr76@queensu.ca). *Antimagic Labelings of Weighted and Oriented Graphs.*

A graph is *antimagic* if there exists a bijective edge labeling from $E(G)$ to $\{1, 2, \ldots, |E(G)|\}$ such that the vertex sums are pairwise distinct. In 1990, Hartsfield and Ringle conjectured that every simple connected graph other than K_2 is antimagic. In this talk, we discuss a notion of closeness to being antimagic and a variation thereof.

Specifically, we show that every graph on n vertices having no K_1 or K_2 component is $\lfloor 4n/3 \rfloor$-weighted-list-antimagic, which improves upon a result of Wong and Zhu. Toward a conjecture of Hefetz, Mütze, and Schwartz, we also show that every graph on n vertices admits an orientation that is $\lfloor 2n/3 \rfloor$-oriented-antimagic. (Received September 20, 2015)

1116-05-1512 **W Timothy Gowers***, Centre for Mathematical Sciences, Wilberforce Road, Cambridge, CB3 0WB, United Kingdom. *Quasirandom sets, quasirandom graphs, and applications.*

In this lecture I shall discuss a few applications of discrete Fourier analysis on finite Abelian groups. I shall also talk about quasirandom graphs, explaining what they are and why they are useful. The two topics are closely related, and I shall explain why. Finally, as a way of motivating certain generalizations of Fourier analysis to be discussed in the second and third lectures, I shall give examples of problems that do not yield to the basic technique discussed here. (Received September 20, 2015)

1116-05-1515 **W Timothy Gowers***, Centre for Mathematical Sciences, Wilberforce Road, Cambridge, CB3 0WB, United Kingdom. *Arithmetic progressions of length 4, quadratic Fourier analysis, and 3-uniform hypergraphs.*

In this lecture I shall say something about quadratic (and higher-order) Fourier analysis, which relates to notable results such as Szemerédi's theorem and the Green-Tao theorem. I shall also discuss a notion of quasirandomness for hypergraphs and show that it relates to quadratic Fourier analysis in a similar way to the way that quasirandom graphs relate to conventional Fourier analysis.

I shall also discuss the more general question of what one would ideally like from a generalization of Fourier analysis. Quadratic Fourier analysis has enough of the desired properties to be a useful technique, but there are certain properties that it lacks, at least in its current form, and there are therefore interesting challenges for future research.

Some parts of this lecture will be hard to understand by people who have not attended the first lecture, but I will try to recap the most important ideas. This lecture will, however, not be necessary for following the third. (Received September 20, 2015)

1116-05-1520 **W Timothy Gowers***, Centre for Mathematical Sciences, Wilberforce Road, Cambridge, CB3 0WB, United Kingdom. *Fourier analysis on general finite groups.*

The first two lectures in this series will be about Fourier analysis and generalizations that apply to scalar-valued functions on finite Abelian groups. This one will be about how it can be generalized in two further directions: to non-Abelian groups and to matrix-valued functions. An obvious example of a matrix-valued function on a group is a representation, and indeed basic representation theory plays a central part in these generalizations. I shall give examples of how non-Abelian Fourier analysis can be used to solve interesting problems at the intersection of combinatorics and group theory. I shall also mention connections between some of these problems and the notion of quasirandom graphs from the first lecture. (Received September 20, 2015)

1116-05-1544 **Hedvig Mohacsy*** (hmohacsy@asu.edu), Hedvig Mohacsy, School of Mathematical and, Statistical Sciences, Tempe, AZ 85287-1804. *A New Infinite Family of Group Divisible t-Designs with Strength $t \geq 2$ and index λ.*

In this talk, we present a construction which takes a group divisible t-design with large index and yields a group divisible t-design with larger group size and with a fixed index λ. This method generalizes Wilson's, Blanchard's, Mohácsy's and Ray-Chaudhuri's "block spreading" construction for $t \geq 2$ and for general index. As a result of this generalization, we constructed a new infinite family of group divisible t-designs with fixed index λ. This generalization opens a new path to answer existence questions for designs with fixed index λ. (Received September 20, 2015)

1116-05-1548 **Steven Michael Senger***, Cheek Hall 23M, 901 S. National St., Springfield, MO 65897.
On the number of triples of points determining a pair of dot products.

Given a subset, $E \subset R^d$, of a vector space over a field or a module over a ring of integers, we offer bounds on the number of triples of points from E that determine a given pair of dot products, α and β. We obtain different bounds for different settings and restrictions on α and β. (Received September 20, 2015)

1116-05-1563 **Jonathan Tidor*** (jtidor@mit.edu). *Dense binary $PG(t-1,2)$-free matroids have critical number $t-1$ or t.*

The critical threshold of a (simple binary) matroid N is the infimum over all ρ such that any N-free matroid M with $|M| > \rho 2^{r(M)}$ has bounded critical number. In this talk, we study the critical threshold of the projective geometry $PG(t-1,2)$ as a generalization of a classical problem in graph theory. No knowledge of matroid theory will be assumed.

We resolve two conjectures of Geelen and Nelson, showing that the critical threshold of $PG(t-1,2)$ is $1-3\cdot 2^{-t}$. We do so by proving the following statement: if M is $PG(t-1,2)$-free with $|M| > (1-3\cdot 2^{-t})2^{r(M)}$, then the critical number of M is $t-1$ or t. (Received September 20, 2015)

1116-05-1567 **Glenn Hurlbert*** (ghurlbert@vcu.edu). *Graham's Pebbling Conjecture.*

In 1988 Lagarias and Saks had an idea for solving a number theoretic problem of Erdős and Lemke by modeling the problem with the movement of pebbles in a divisor lattice. In 1989 Chung carried out this idea successfully by proving that the so-called *pebbling number* of the d-dimensional cube is equal to the number of its vertices. In 2005 Elledge and Hurlbert extended the application of graph pebbling to zero-sum theory in finite abelian groups.

In light of Chung's result, Graham considered the following generalized statement. Let $\pi(G)$ denote the pebbling number of the graph G, and for two graphs G and H write $G\Box H$ for their Cartesian product. Graham conjectured that $\pi(G\Box H) \le \pi(G)\pi(H)$.

In this talk we'll introduce the pebbling number, discuss results confirming Graham's conjecture, and share new approaches to the problem, including ideas such as the 2-pebbling property, class 0 graphs, and techniques from linear optimization. (Received September 20, 2015)

1116-05-1584 **Oscar Vega*** (ovega@csufresno.edu), Department of Mathematics, California State University, Fresno, 5245 North Backer Avenue M/S PB 108, Fresno, CA 93740-8001, and **Hillary Bese**. *The well-covered dimension of generalized quadrangles.* Preliminary report.

The well-covered dimension of a graph G is the dimension of the vector space of weight functions on $V(G)$ that are constant on the maximal independent sets of G. In this talk, we will present a variety of results about the well-covered dimension of the adjacency graph of classical generalized quadrangles. (Received September 20, 2015)

1116-05-1605 **Brendan W Sullivan*** (sullivanb@emmanuel.edu), Emmanuel College, 400 The Fenway, Boston, MA 02115, and **Nikolas Townsend** and **Mikayla Werzanski**. *Lazy Cops and Robbers on Product Graphs.*

Our research concerns the pursuit-evasion game of Cops and Robbers on graphs. Generally, one seeks the "Cop number" of a graph, denoted $c(G)$, which is the minimum number of Cops required to guarantee catching the Robber. A recently-proposed variant (Offner & Ojakian, 2012), "Lazy Cops and Robbers," modifies the rules to allow *only one cop* to move per turn. In our analysis of the differences between the Ordinary and Lazy versions, we investigated several classes of graphs and their products.

We found exact values for the Lazy Cop numbers of several product graphs, e.g. $c_L(K_n\Box C_m) = c_L(K_n \boxtimes C_m) = 3$. We have also proven (sharp) bounds for generic products, e.g. $c_L(G\Box T) \le \gamma(G)+1$ for any graph G and any tree T. Perhaps most significantly, we improved upon a result by Neufeld & Nowakowski (1998) to prove that $c(G\boxtimes H) = c(G)+c(H)-1$ for *any* graphs G, H. We believe that subsequent study of factorizations of graphs under the Strong product may yield new results in the field of Cops & Robbers and its variants. Finally, we conclude by sharing partial progress on a conjecture of ours, namely that $c(G\Box H) \ge c(G\boxtimes H)$ for any G, H (and similarly for c_L). (Received September 20, 2015)

1116-05-1625 **Richard H. Hammack*** (rhammack@vcu.edu), **Wilfried Imrich** and **Sandi Klavžar**.
Edge-transitive products.

Under what circumstances is a graph product edge-transitive? A strong product $G\boxtimes H$ is edge-transitive if and only if each factor is a complete graph, whereas a Cartesian product $G\Box H$ is edge-transitive if and only if it is the Cartesian power of an edge- and vertex-transitive graph.

This talk focuses on the case of the direct product. We show that if $G \times H$ is not bipartite then it is edge-transitive if and only if both factors are edge-transitive and one is arc-transitive, or if one is edge transitive and the other is a complete graph with loops at each vertex.

We also discuss the bipartite case, which is considerably more subtle. (Received September 20, 2015)

1116-05-1635 **Ghodratollah Aalipour** (ghodrat.aalipour@ucdenver.edu), **Art Duval*** (aduval@utep.edu) and **Jeremy Martin** (jlmartin@ku.edu). *Weighted Tree Enumeration of Cubical Complexes.*

We find the factorization a weighted enumeration of the (higher-dimensional) spanning trees of skeletons of hypercubes. The key tool is a new version of the weighted cellular matrix-tree theorem, which (under a mild technical assumption) enumerates the spanning trees of a cell complex using its Laplacian matrices. (Received September 20, 2015)

1116-05-1655 **Bruno Benedetti*** (bruno@math.miami.edu), Department of Mathematics, 1365 Memorial Drive, Coral Gables, FL 33146, **Barbara Bolognese** (bolognese.b@husky.neu.edu), Boston, MA , and **Matteo Varbaro** (varbaro@dima.unige.it), Dipartimento di Matematica, Via Dodecaneso 35, 16146 Genova, Genova, Italy. *Balinski's theorem and dual graphs of curves.*

The graph of a convex polytope is just its 1-dimensional skeleton. Balinski's theorem states that the graph of every d-polytope is d-connected. The dual graph of an arrangement of n curves is instead the graphs with n vertices, where we put an edge between vertices i and j iff the corresponding curves intersect. I will explain the connection between these two notions, and state a very general algebraic version of Balinski's theorem. (Received September 21, 2015)

1116-05-1662 **William Kuszmaul*** (kuszmaul@stanford.edu), 37 Vaille Ave, Lexington, MA 02421. *30,000 Conjectures on Pattern-Avoidance.*

We introduce the first provably fast algorithm for generating $S_{\leq n}(\Pi)$, the permutations of sizes 1 through n avoiding a given set of patterns $\Pi \subseteq S_k$. Our algorithm runs in time $O(|S_{\leq n-1}(\Pi)| \cdot nk)$. In contrast, the best previous algorithms, based on generate-and-check, take exponential time per permutation analyzed.

Using our algorithm, we generate $|S_5(\Pi)|, \ldots, |S_{16}(\Pi)|$ for each $\Pi \subseteq S_4$, and analyze OEIS matches for $|\Pi| > 4$. This yields thousands of novel pattern-avoidance conjectures, fourteen of which we present.

Surprisingly, our algorithm extends to an $O(n!k)$-time and $O(n^{k+1})$-space algorithm for counting Π-patterns in each permutation in S_n.

Our data and implementations of our algorithms can be found at https://github.com/williamkuszmaul/patternavoidance. (Received September 21, 2015)

1116-05-1669 **Tommaso Traetta*** (tommaso.traetta@ryerson.ca). *Cycle decompositions: resolvable or without parallel classes.*

A set of cycles of a simple graph Γ whose vertex-sets partition the vertex-set of Γ is called a *parallel class*. A set of cycles whose edge-sets partition the edge-set of Γ is a *cycle decomposition* of Γ. Such a decomposition is *resolvable* if the cycle-set can be partitioned into parallel classes. The Oberwolfach Problem and the Hamilton-Waterloo Problem are two well-known open problems on the existence of resolvable cycle decompositions. Both have been the subject of an extensive research activity over the last few years.

A problem opposite to the resolvability concerns the construction of cycle decompositions, with a given structure, free from parallel classes. This problem is still open, for example, for Steiner triple systems.

In this talk I will present some recent results on cycle decompositions which are either resolvable or free from parallel classes. (Received September 21, 2015)

1116-05-1678 **Kai Fong Ernest Chong*** (kc343@cornell.edu), Agency for Science, Technology and Research (A*STAR), Singapore. *Face enumeration and Kruskal-Katona-type theorems.*

The Kruskal-Katona theorem (1960s) is a classic result in combinatorics that characterizes the f-vectors of simplicial complexes. In 1977, Stanley noticed that Macaulay's theorem (1927) characterizes the f-vectors of multicomplexes, or equivalently, the h-vectors of Cohen-Macaulay complexes. Later in 1988, Frankl-Füredi-Kalai found a colored analogue of the Kruskal-Katona theorem, thereby characterizing the f-vectors of colored simplicial complexes. The purpose of this talk is to reconcile these results using the algebraic notion of Macaulay-Lex rings. We will show that they are in fact three special cases of one main theorem. As a consequence, we completely determine all the possible types of generalized colored simplicial complexes and multicomplexes whose f-vectors can be characterized by "reverse-lexicographic" complexes. (Received September 21, 2015)

1116-05-1679 **Fatemeh Mohammadi*** (fatemeh.mohammadi716@gmail.com), TU Berlin, 10623 Berlin, Berlin, Germany. *Combinatorial and geometric view of the system reliability theory.*

Associated to every coherent system there is a canonical ideal whose Hilbert series encodes the reliability of the system. We study various ideals arising in the theory of system reliability. Using ideas from the theory of orientations, and matroids on graphs we associate a polyhedral complex to our system so that the non-cancelling terms in the reliability formula can be read from the labeled faces of this complex. Algebraically, this polyhedron resolves the minimal free resolution of these ideals. In each case, we give an explicit combinatorial description of non-cancelling terms in terms of acyclic orientations of graph and the number of regions in the graphic hyperplane arrangement. This resolves open questions posed by Giglio-Wynn and develops new connections between the theory of oriented matroid, the theory of divisors on graphs, and the theory of system reliability. (Received September 21, 2015)

1116-05-1691 **Uli Wagner*** (uli@ist.ac.at), IST Austria, Am Campus 1, 3400 Klosterneuburg, Austria. *Pseudorandomness & Higher-Dimensional Topological Expansion.* Preliminary report.

We will discuss connections between two topics that are closely related but seem to be studied by mostly disjoint communities:

(1) quasirandomness properties of hypergraphs (in particular, of *sparse hypergraphs*), such as Gowers uniformity norms and cut norms; and

(2) higher-dimensional *topological expansion properties* of simplicial complexes, as introduced in the work of Gromov and of Linial and Meshulam.

We will present some preliminary results, but mostly focus on questions and open problems. (Received September 21, 2015)

1116-05-1695 **Ed Swartz*** (ebs22@cornell.edu). *Recent results on face enumeration of manifolds and or pseudomanifolds.*

As the title suggests, we will present some recent development concerning face enumeration on manifolds or pseudomanifolds. (Received September 21, 2015)

1116-05-1709 **Viorel Nitica*** (vnitica@wcupa.edu), Department of Mathematics, West Chester University, West Chester, PA 19383. *Tilings by ribbon L n-ominoes, n odd.* Preliminary report.

Recently there has been some progress in solving tilings problems by ribbon L n-ominoes, n even. Two papers of interest are M. Chao, D. Levenstein, V. Nitica, R. Sharp, A coloring invariant for ribbon L-tetrominoes, Discrete Mathematics, 313 (2013) 611-621 and V. Nitica, Every tiling of the first quadrant by ribbon L n-ominoes follows the rectangular pattern. Open Journal of Discrete Mathematics, 5, (2015) 11-25. The main observation is that any tiling of the first quadrant reduces to one by rectangles. This property does not hold for n odd.

We will discuss in the talk tiling problems by ribbon L n-ominoes, n odd. New techniques are developed, based on nonlinear algebra. (Received September 21, 2015)

1116-05-1715 **J L Gross** (gross@cs.columbia.edu), **T Mansour** (tmansour@univ.haifa.ac.il), **T W Tucker** (ttucker@colgate.edu) and **Guoliang Wang*** (glw@bit.edu.cn), School of Mathematics and Statistics, Beijing Institute of Technology, Fangshan District, Beijing, Beijing, 102488. *The CLLC conjecture holds for cyclic permutations.*

Recently, Gross et al. posed the LLC conjecture for the locally log-concavity of the genus distribution of every graph, and provided an equivalent combinatorial version, the CLLC conjecture, on the log-concavity of the generating function counting cycles of some permutation compositions. In this paper, we confirm the CLLC conjecture for cyclic permutations, with the aid of Hultman numbers and by applying the Hermite-Biehler theorem on the generating function of Stirling numbers of the first kind. This leads to a further conjecture that every local genus polynomial is real-rooted. (Received September 21, 2015)

1116-05-1717 **James Oxley** and **Simon Pfeil***, spfeil2@math.lsu.edu, and **Charles Semple** and **Geoff Whittle**. *Matroids with many small circuits and many small cocircuits.* Preliminary report.

A consequence of Tutte's Wheels-and-Whirls Theorem is that the only 3-connected matroids in which every element is in both a 3-element circuit and a 3-element cocircuit are the well-known wheels and whirls. Miller showed that a sufficiently large 3-connected matroid in which every pair of elements is contained in a 4-element circuit and a 4-element cocircuit must belong to another well-known family, namely spikes. This follow-up to last year's talk presents the full solution to several variants of these two results. (Received September 21, 2015)

1116-05-1733 **Virgil U Pierce*** (virgil.pierce@utrgv.edu), 1201 W University Drive, Edinburg, TX 78539. *Enumeration of Ribbon and Mobius Graphs.*

The partition function of the Gaussian Unitary Ensembles of random matrices has an expansion in terms of Ribbon graphs: graphs embedded into an oriented Riemann surface in such a way that they give a dissection of the surface into discs. We have exploited this connection by deriving a hierarchy of differential equations that governs the generating functions, and finding solutions of them in some special cases, thus solving explicitly the enumeration problem in those cases. Mobius graphs are graphs embedded into unoriented Riemann surfaces in such a way that they give a dissection of the surface into discs. Generating functions for Mobius graphs can be given in terms of partition functions for the Gaussian Orthogonal and Symplectic Ensembles of random matrices. We will show that in some special cases we can solve the associated enumeration problem, and give some general results about the relationship between the two combinatoric problems. (Received September 21, 2015)

1116-05-1773 **Melody Chan**, **Darren Glass**, **Matthew Macauley**, **David Perkinson*** (davidp@reed.edu), **Caryn Werner** and **Qiaoyu Yang**. *Sandpiles, spanning trees, and plane duality.*

The sandpile or critical group of a graph G is an associated finite group whose order is the number of spanning trees of G. Holroyd et al. used a dynamical process known as rotor-routing to define a simply transitive action of the sandpile group of G on its set of spanning trees.

It is well-known that if G is planar, its set of spanning trees are in canonical bijection with those of its planar dual G^* and furthermore that the sandpile groups of G and G^* are isomorphic. Thus, one can ask: are the two rotor-routing actions, of the sandpile group of G on its spanning trees, and of the sandpile group of G^* on its spanning trees, compatible under plane duality? We give an affirmative answer to this question, which had been conjectured by Matthew Baker. (Received September 21, 2015)

1116-05-1795 **Jay Schweig** and **Russ Woodroofe*** (rwoodroofe@math.msstate.edu). *Order congruence lattices are shellable.*

The lattice of order congruences of a poset P is the subposet $O(P)$ of the lattice of partitions of P, consisting of all partitions that satisfy a certain order-convexity type property. The partition lattice is both semimodular and supersolvable, but Körtesi, Radelecki and Szilágyi gave examples of order congruence lattices that are not semimodular, and we find examples that are not supersolvable.

We show that the order congruence lattices satisfy a recursive condition on the existence of modular elements, and use this modularity condition to show shellability. This result improves a weaker result of Jenča and Sarkoci. We also can recover several other shellability results on subposets of the partition lattice with a similar proof.

This is joint work with Jay Schweig. (Received September 21, 2015)

1116-05-1801 **W Timothy Gowers***, Centre for Mathematical Sciences, Wilberforce Road, Cambridge, CB3 0WB, United Kingdom. *Probabilistic combinatorics and the recent work of Peter Keevash.*

Recently Peter Keevash settled a famous problem that was well over a century old, concerning the existence of designs, which are systems of subsets of a finite set that cover the finite set in a particularly even way. More precisely, a design with parameters (n, r, s, λ) is a collection A of subsets of an n-element set, each of size r, such that every subset of size s is contained in exactly λ sets from A. There are some trivial divisibility conditions that the parameters must satisfy: Keevash showed that if these conditions are satisfied and if n is sufficiently large, then a design with parameters (n, r, s, λ) exists. This was a vastly more general result than anything that had been previously proved, or indeed anything that looked likely to be proved.

The proof is probabilistic. This talk will be about the probabilistic method in general, and about the sophisticated new ideas that Keevash introduced in order to apply it to a problem that does not at first glance look suitable for it. (Received September 21, 2015)

1116-05-1830 **Maria Monks Gillespie** and **Jake Levinson*** (jakelev@umich.edu). *K-theory and Monodromy of Schubert Curves.*

We establish a combinatorial connection between the real geometry and the K-theory of complex *Schubert curves* $S(\lambda_\bullet)$, which are one-dimensional Schubert problems defined with respect to flags osculating the rational normal curve. Recent work by Speyer and by the second author showed that the real geometry of these curves is described by the orbits of a map ω on skew tableaux, defined as the commutator of jeu de taquin rectification and promotion. In particular, the real locus of the Schubert curve is naturally a covering space of $\mathbb{RP}^1$, with ω as the monodromy operator.

We provide a local algorithm for computing ω without rectifying the skew tableau, and show that certain steps in our algorithm are in bijective correspondence with Pechenik and Yong's *genomic tableaux*, which enumerate the K-theory Littlewood-Richardson coefficient of the Schubert curve. We then give purely combinatorial proofs of several numerical results relating the K-theory and the real geometry of $S(\lambda_\bullet)$. (Received September 21, 2015)

1116-05-1895 **William P. Noland*** (wpnoland@noctrl.edu), 2949 Carlsbad Circle, Aurora, IL 60503, and **Ethan Gegner** and **Robert Winslow**. *Covering Sets for Rectangles in the Lattice.*
The famous Turán-type problems study the maximum fraction of a structure one may select without selecting certain forbidden configurations. Stated in terms of complements, our problem is: given a set S of rectangles of specified dimensions, we want to determine the minimum density of a set A of points in $\mathbb{Z}\times\mathbb{Z}$ such that every copy in $\mathbb{Z}\times\mathbb{Z}$ of any rectangle in S has at least one of its four vertices in A; in this case we say that A is a covering set for the rectangles in S. It is trivial that covering all axb rectangles requires precisely 1/4 of the lattice. Our first result is that the covering density for 1x1 and angled $\sqrt{2}$x$\sqrt{2}$ squares is also 1/4. The primary focus of our work was on covering two different sizes of axis-aligned rectangles. Covering both axb and bxa rectangles requires just 1/4 of the lattice (no more than just axb), though the patterns which do so vary with the relative parity of the dimensions. We also have results on covering pairs of squares, which lead to a general conjecture in that regard. Finally, we have determined the exact required covering density required for axc and axd rectangles. (Received September 21, 2015)

1116-05-1896 **Esther R Lamken*** (lamken@caltech.edu). *The asymptotic existence of $DR(v,k,k-1)$-BIBDs.*
A Kirkman square with index λ, latinicity μ, block size k, and v points, $KS_k(v;\mu,\lambda)$, is a $t\times t$ array ($t = \lambda(v-1)/\mu(k-1)$) defined on a v-set V such that (1) every point of V is contained in precisely μ cells of each row and column, (2) each cell of the array is either empty or contains a k-subset of V, and (3) the collection of blocks obtained from the non-empty cells of the array is a (v,k,λ)-BIBD. For $\mu = 1$, the existence of a $KS_k(v;\mu,\lambda)$ is equivalent to the existence of a doubly resolvable (v,k,λ)-BIBD. A few years ago, I established the asymptotic existence of $KS_k(v;1,1)$. In this talk, I will show that the necessary conditions are also sufficient for the asymptotic existence of $KS_k(v;1,k-1)$ or DR$(v,k,k-1)$-BIBDs and discuss some extensions of this work. (Received September 21, 2015)

1116-05-1901 **Guoli Ding**, **Joshua Fallon** and **Emily Marshall*** (emarshall@lsu.edu). *Characterizing Almost-planar Graphs.* Preliminary report.
A non-planar graph G is *almost-planar* if $G\setminus e$ or G/e is planar for all edges $e \in E(G)$. This class of graphs is minor-closed so by the results of Robertson and Seymour in their Graph Minors project, the class can be described by a finite set of forbidden minors. Gubser provides a characterization of the 3-connected graphs in this class (*Combinatorics, Probability, and Computing*, 1996). In this talk, we prove a forbidden minor characterization for all almost-planar graphs. This work is joint with Guoli Ding and Joshua Fallon. (Received September 21, 2015)

1116-05-1908 **Ali Kemal Uncu*** (akuncu@ufl.edu), University of Florida, Department of Mathematics, 1400 Stadium Road 358 Little Hall, Ganesville, FL 32611. *A New Companion to Capparelli's Identities and Some Combinatorial Inequalities.*
We discuss a new companion to Capparelli's identities. Capparelli's identities for $m = 1, 2$ state that the number of partitions of n into distinct parts not congruent to m, $-m$ modulo 6 is equal to the number of partitions of n into distinct parts not equal to m, where the difference between parts is greater than or equal to 4, unless consecutive parts are either both consecutive multiples of 3 or add up to to a multiple of 6. In this paper we show that the set of partitions of n into distinct parts where the odd-indexed parts are not congruent to m modulo 3, the even-indexed parts are not congruent to $-m$ modulo 3, and $3l+1$ and $3l+2$ do not appear together as consecutive parts for any integer l has the same number of elements as the above mentioned Capparelli's partitions of n. In this study we also extend the work of Alladi, Andrews and Gordon by providing a complete set of generating functions for the refined Capparelli partitions, and conjecture some combinatorial inequalities. This work is based on my recent joint work with Alexander Berkovich. (Received September 21, 2015)

1116-05-1914 **Qiuju Bian**, **Ronald J. Gould**, **Paul Horn**, **Susan Janiszewski**, **Steven La Fleur** and **Paul Wrayno*** (paul.wrayno@cnu.edu). *3-connected $\{K_{1,3},P_9\}$-free Graphs are Hamiltonian Connected.*
We show that any graph that is 3-connected and does not contain either the claw, $K_{1,3}$, or a path on 9 vertices, P_9, as an induced subgraph is hamiltonian connected. Additionally, by building on previous restrictions, we are

able to say that this is the penultimate result on forbidden pairs that imply 3-connected graphs are hamiltonian connected. After incorporating our restrictions, the only potential additional pair whose forbidding could imply hamiltonian connectedness is $\{K_{1,3}, Ł_3\}$, the claw and a pair of triangles connected by a single a path of 3 edges. (Received September 21, 2015)

1116-05-1928 **Peter J Dukes*** (dukes@uvic.ca). *Designs and dimension.*

This talk examines dimension in the context of finite geometry and pairwise balanced designs. Specifically, the dimension of a design is the maximum integer d such that any set of d points is contained in a proper subdesign.

We consider in detail the particular case of dimension three where lines have sizes 3, 4 or 5. Results in this case come from collaboration with two students: Joanna Niezen's Master's thesis settles the existence of such designs for all orders (apart from a few small exceptions and unknown values) and Nick Benson's USRA work obtains constructions for all orders with a universal bound (94) on the size of three-point-generated subdesigns. This leads to a construction of latin squares "covered" by bounded subsquares. (Received September 21, 2015)

1116-05-1949 **Alexander Engstrom*** (alexander.engstrom@aalto.fi). *Polytopal resolutions of Stanley-Reisner ideals of polytopes.*

Sometimes a projective resolution of an ideal is inherited from the boundary maps of a cell complex: it's a cellular resolution. For Stanley-Reisner ideals of polytopes one could expect even more structure. We will discuss some cases where the cellular resolutions can be constructed from polytopes with beautiful symmetries. (Received September 21, 2015)

1116-05-1982 **Emily Sergel Leven*** (esergel@ucsd.edu). *Parking Functions and the Square Paths Conjecture.* Preliminary report.

In 2005, Halgund, Haiman, Loehr, Remmel and Ulyanov conjectured a relation between parking functions and the image of the elementary symmetric function e_n under a certain modified Macdonald polynomial eigenoperator, ∇. This conjecture was refined by Haglund, Morse and Zabrocki in 2012 and proven by Carlsson and Mellit in 2015. A similar (open) conjecture from 2007 by Loehr and Warrington relates $\nabla(p_n)$ to preference functions. Here we connect this conjecture to parking functions using tools from symmetric function theory and enumerative combinatorics. (Received September 21, 2015)

1116-05-2003 **Charles Suer*** (suerchaj@gmail.com), 3800 Nicholasville Rd. #9612, Lexington, KY 40503. *Color blind index in graphs of very low degree.*

Let $c : E(G) \to [k]$ be an edge-coloring of a graph G, not necessarily proper. For each vertex v, let $\overline{c}(v) = (a_1, \cdots, a_k)$, where a_i is the number of edges incident to v with color i. Reorder $\overline{c}(v)$ for every v in G in nonincreasing order to obtain $c^*(v)$, the color-blind partition of v. When c^* induces a proper vertex coloring, that is, $c^*(u) \neq c^*(v)$ for every edge uv in G, we say that c is color-blind distinguishing. The minimum k for which there exists a color-blind distinguishing edge coloring $c : E(G) \to [k]$ is the color-blind index of G, denoted $\mathrm{dal}(G)$. We present some previously known results and then demonstrate that determining the color-blind index is more subtle than previously thought. In particular, determining if $\mathrm{dal}(G) \leq 2$ is NP-complete. Time permitting, a connection to 2-colorable regular hypergraphs will be discussed. (Received September 21, 2015)

1116-05-2008 **Bobby C. Shen*** (runbobby@mit.edu). *The Parametric Frobenius Problem.*

The Frobenius number of relatively prime positive integers $a_1, \ldots, a_n$, which we denote by $F(a_1, \ldots, a_n)$, is the largest integer that is not a nonnegative integer combination of the a_i. We extend this to all positive integers: let $F(a_1, \ldots, a_n)$ be the largest multiple of $\gcd(a_1, \ldots, a_n)$ which is not a nonnegative integer combination of the a_i. We consider a parametric version of the Frobenius problem. Let $P_1, \ldots, P_n$ be polynomials from $\mathbb{Z}$ to $\mathbb{Z}$ with positive leading coefficients, and let $Q(t) = F(P_1(t), \ldots, P_n(t))$, which is defined for sufficiently large integers t. We prove that this function is eventually quasi-polynomial; Q is eventually quasi-polynomial if there exists a positive integer d and polynomials $R_0, \ldots, R_{d-1}$ such that for such that for sufficiently large t, $Q(t) = R_{t \pmod d}(t)$. We do so by forming a parametric integer linear program whose optimum value at t equals $Q(t)$ for sufficiently large t. Using these ideas, one can show that if $n > 1$ and p, m are positive integers, then the p^{th} largest multiple of $\gcd(a_1, \ldots, a_n)$ which is a nonnegative integer combination of the a_i in less than m ways is eventually quasi-polynomial in t (not in the presentation). (Received September 22, 2015)

1116-05-2018 **Jay Cummings*** (jjcummings@ucsd.edu). *Graph Builds.* Preliminary report.

Let G be a graph with edge set $E(G)$. A *build* is an ordering $B = (e_1, \ldots, e_m)$ of the edges of G, which we think of as a construction of the graph edge-by-edge. Define $F(G, k)$ to be the number of builds of G that add k isolated edges. The study of $F(G, k)$ grew from the study of so-called "edge-flipping in graphs." In this talk we will discuss new results and future directions in the study of this function. This project is joint work with many coauthors. (Received September 21, 2015)

1116-05-2035 **Sara C. Billey***, University of Washington, Box 354350, Seattle, WA 98105, and **Matjaz Konvalinka** and **Frederick Matsen**. *Enumeration of Double Cosets in Symmetric Groups and Beyond.*

Let G be a group with subgroups H and K. The collection of double cosets $H\backslash G/K = \{HgK|g \in G\}$ partition G. The double cosets are generally more complicated than the one-sided cosets. For example, different double cosets can have different sizes. If G is finite, the size of $H\backslash G/K$ is given by the inner product on the character of the two trivial representations on H and K respectively induced up to G.

We will present recent results enumerating all distinct double cosets for certain types of subgroups of the symmetric groups. The first case was inspired by a problem in mathematical biology related to tanglegrams. This is joint work with Konvalinka and Matsen (see arXiv:1507.04976). The second case is inspired by the geometry/topology of generalized flag varieties related to parabolic subgroups. Some of our results extend to all Coxeter groups. This is joint work in progress with Konvalinka, Petersen, Slofstra and Tenner. (Received September 21, 2015)

1116-05-2060 **Thomas Grubb*** (grubbtho@msu.edu), **Paul Han** and **Bill Kay**. *Probabilistic Thresholds for Combinatorial Structures.*

The process of optimizing the size of a set with a specified property has a long history within combinatorics. In this talk we use standard probabilistic tools to explore a related operation; namely, for positive integers n, we take a ground set G of size $f(n)$, and create a subset A of G by selecting each element in G independently with probability p. Then, with a specific property in mind, we determine an asymptotic threshold function $t(n)$ such that

$$p \ll t(n) \implies P(A \text{ has the desired property}) \to 1 \text{ as } n \to \infty$$
$$p \gg t(n) \implies P(A \text{ has the desired property}) \to 0 \text{ as } n \to \infty.$$

Alternatively, if the chance that A has the desired property increases with the size of A, then the role of 0 and 1 will be interchanged above. Topics studied include set packings, permutation packings, and generalized Sidon properties. (Received September 21, 2015)

1116-05-2062 **Chen Xie*** (chen.xie@uwaterloo.ca). *On the Incidence Coloring Conjecture for Cartesian Graph Products.*

An *incidence* in a graph G is a pair (v, e) such that $v \in V(G), e \in E(G)$, and $v \in e$. An *incidence coloring* of G is a coloring of its incidences such that adjacent incidences receive different colors. The Incidence Coloring Conjecture claims that for all graphs G, its *incidence chromatic number*, denoted $\chi_i(G)$, is bounded above by $\Delta(G) + 2$. Gregor and Luzar conjectured in 2015 that for all graphs G, H such that $\chi_i(G) = \Delta(G) + 1$, and $\chi_i(H) \leq \Delta(H) + 2$, their Cartesian product $G\Box H$ satisfies the Incidence Coloring Conjecture. We prove that the conjecture is false, provide a characterization of Cartesian products of graphs that satisfies the Incidence Coloring Conjecture, and find the explicit values of incidence chromatic numbers of the Cartesian products of complete graphs and paths, and of stars and paths. (Received September 21, 2015)

1116-05-2071 **Jennifer Vandenbussche*** (jvandenb@kennesaw.edu), **Sarah Holliday** (shollid4@kennesaw.edu) and **Erik Westlund** (ewestlun@kennesaw.edu). *Hall precolorings with $\Delta(G)$ colors extend to proper colorings.* Preliminary report.

In the context of list-coloring the vertices of a graph, Hall's condition is a generalization of Hall's Marriage Theorem and is necessary (but not sufficient) for a graph to admit a proper list-coloring. In this talk, we show that any precoloring of a graph G with $\Delta(G)$ colors extends to a proper coloring of G, provided that the natural list assignment associated with the precoloring satisfies Hall's condition. We also discuss other results regarding the extension of precolorings satisfying Hall's condition. (Received September 21, 2015)

1116-05-2072 **Michael A. Jackson*** (majackson@gcc.edu). *Partitioning Polytope Number Sequences into Simplex Number Sequences.*

The polytope number sequence for a given polytope is an integer sequence defined by the combinatorics of the polytope. Polytope number sequences are a type of figurate number sequence and recent work by H. K. Kim and J. Y. Lee has focused on writing polytope number sequences as sums of simplex number sequences. In addition, this work has given a process for writing the polytope number sequence in a recursive fashion by using the interior sequences for the various k-faces of the polytope, each viewed as a k-dimensional polytope. We show that the polytope number sequence for any convex polytope can be written as a linear combination of simplex numbers in the same dimension with non-negative coefficients. This result arises from using a pointed triangulation of the polytope which is partitionable and then realizing the coefficients as the h-vector of the resulting polytopal complex. In addition, we show that the corresponding interior polytope number sequence is the linear combination of interior simplex number sequences with the same coefficients appearing in the opposite order. (Received September 21, 2015)

1116-05-2112 **Thomas W Tucker*** (ttucker@colgate.edu), Math Dept, Colgate University, Hamilton, NY 13346, and **Jonathan L Gross** (gross@cs.columbia.edu) and **Toufik Mansour** (tmansour@univ.haifa.ac.il). *The recursive structure of genus polynomials for linear families.*

The *genus polynomial* for a finite graph G is the generating function $g_G(z) = \Sigma a_i z^i$, where a_i is the number of imbeddings of G in the surface of genus i. A *linear family* G_n of graphs is formed by taking n copies of the same graph G and forming a path of them by adding edges in the same way between one copy of G and the next; Stahl suggested these families as a case study for genus polynomials. For any such linear family there is a *production* or *transfer* matrix $M(z)$ and initial vector $v(z)$ (all entries are polynomials in z with non-negative integer coefficients) such that the genus polynomial for G_n is $M^n(z)v(z)$. These matrices have been computed by hand for a few small cases and by computer for some larger examples. Almost nothing is known about the entries of $M(z)$ or the behavior of $M^n(z)$. We conjecture that for sufficiently large n all entries of $M^n(z)$ are non-zero. This would imply that the Markov chain associated with $M(1)$ is regular, allowing one to infer the long-run distribution of the different types of imbeddings of G_n. (Received September 21, 2015)

1116-05-2127 **Lowell Abrams*** (labrams@gwu.edu) and **Jo Ellis-Monaghan**. *Dualities and Trialities from Ribbon Group Stabilizers.*

The ribbon group acts on cellulary embedded graphs by applying Wilson operations, generated by dualizing and twisting, to individual edges. To account for actions on edge-labeled graphs, we reformulate this action in terms of a semidirect product with the symmetric group on the ribbons. In this context, we show how studying the stabilizers of single-vertex orientable embeddings provides an approach to produce, for example, self-dual and self-trial cellular embeddings that are not necessarily regular. We close with discussion of some results of a computer search for examples. (Received September 21, 2015)

1116-05-2134 **Se-jin Oh*** (sejin092@gmail.com), #108 275 South Garden way, Eugene, OR 97401. *Auslander-Reiten quiver and representation theories related to KLR-type Schur-Weyl duality.*

We introduce new notions on the sequences of positive roots by using Auslander-Reiten quivers. Then we can prove that the new notions provide interesting information on quantum groups of finite types, by using their categorifications via modules over KLR-algebras and quantum affine algebras. (Received September 21, 2015)

1116-05-2146 **William J Keith*** (wjkeith@mtu.edu), 1400 Townsend Drive, Dept. of Mathematical Sciences, Fisher Hall, Houghton, MI 49931. *Partitions simultaneously regular, distinct, and/or flat.*

It is a classical fact in partition theory that three classes of partitions are equinumerous: those in which parts are not divisible by m, those in which parts appear fewer than m times, and those in which parts differ by less than m and the first part is smaller than m. Glaisher's map and conjugation prove the two equivalences, but yield little information about their fixed points, partitions with two or more of the given conditions.

This talk will explore some interesting results concerning these sets and their close cousins; for instance, generating functions for the fixed points of Glaisher's map appear as some of the Thompson-McKay series for the Monster group, and particular classes have additional congruences and symmetries. (Received September 21, 2015)

1116-05-2148 **Charles Tomlinson*** (ctomlinson2@math.unl.edu), 203 Avery Hall, P.O. Box 880130, Lincoln, NE 68588, and **Philip DeOrsey** (pdeorsey@ehc.edu). *Fast percolation on the hexagonal lattice.*

Bootstrap percolation considers the evolution of a cellular automaton of cells arranged in a rectangular array with the update rule that a cell becomes 'infected' if half its neighbors are infected. Cells are included in the initially infected sites, seed, with probability p. Classical interest was in the critical threshold, c, such that if $p > c$ an n-cell lattice becomes infected asymptotically almost always. Variations have been considered, including alternative lattice structures and infection rules. Exact thresholds of alternative lattices have proven elusive, and much work has gone into their estimation.

We approach the model from an extremal perspective, asking how fast a hexagonal lattice can be percolated by a minimum size seed . We provide what we believe is a novel proof of the folklore result that the $n \times n$ square cannot be percolated in less than $n-1$ steps. For the hexagon of side length n, the n-hex, we show percolation with a minimum seed requires $2n+1$ steps. However, the percolated region does not reside entirely in the n-hex, and when so constrained we show the fastest percolation time, t, satisfies $2n+1 \leq t \leq \frac{7}{3}(n-2)+3$. The upper bound is a construction which we are working to show is the unique fastest internal seed. (Received September 21, 2015)

1116-05-2155 **Amol Aggarwal*** (agg_a@mit.edu). *Correlation Functions of Schur Processes.*
Schur processes are measures on sequences of partitions that are weighted by products of skew-Schur functions. They were introduced in 2003 by Okounkov and Reshetikhin as an algebraic framework to understand a vast collection of combinatorial models that had captured the attention of probabilists for decades, including Last Passage Percolation, the Totally Asymmetric Simple Exclusion Process, and the Longest Increasing Subsequence of a Random Permutation. Central to Okounkov-Reshetikhin's analysis is their derivation of the correlation functions of the Schur process; they showed that the Schur process is a determinantal point process and found its correlation kernel matrix explicitly. The original proofs of these results were representation theoretic; they used properties of the fermionic Fock space. In this talk, we will define the Schur process; highlight a few of its many applications; and outline a new, combinatorial way to derive the correlation functions of the Schur process through Macdonald difference operators. (Received September 21, 2015)

1116-05-2160 **Axel Brandt**, **Michael Ferrara**, **Mohit Kumbhat**, **Sarah Loeb*** (sloeb2@illinois.edu), **Derrick Stolee** and **Matthew Yancey**. *I,F-partitions of sparse graphs.*
A *star k-coloring* is a proper k-coloring such that the union of two color classes induces a star forest. While every planar graph is 4-colorable, not every planar graph is star 4-colorable. One method to produce a star 4-coloring is to partition the vertex set into a 2-independent set and a forest, where a 2-independent set is a set of vertices having pairwise distance more than 2. Such a partition is called an *I,F-partition.* We use the discharging method and other techniques to prove that every graph with maximum average degree less than $\frac{5}{2}$ has an I,F-partition, which is sharp and answers a question of Cranston and West. This result implies that planar graphs of girth at least 10 are star 4-colorable, improving upon previous results of Bu, Cranston, Montassier, Raspaud, and Wang. (Received September 21, 2015)

1116-05-2165 **Joshua Cooper** and **Danny Rorabaugh*** (rorabaugh@mast.queensu.ca). *Homomorphism densities in free words.*
Word W is said to *encounter* word V provided there is a homomorphism ϕ mapping letters to non-empty words so that $\phi(V)$ is a substring of W. For example, taking ϕ such that $\phi(J) = Sea$ and $\phi(M) = t$, we see that "Seattle" encounters "JMM" since $Seatt = \phi(JMM)$. The density of V in W, $\delta(V,W)$, is the proportion of substrings of W that are homomorphic images of V. So the density of "JMM" in "Seattle" is $3/\binom{8}{2}$.

This talk features several asymptotic results about the densities of words in random words, beginning with the following dichotomy. Let V be a word, Σ a finite alphabet with at least 2 letters, and $W_n \in \Sigma^n$ chosen uniformly at random. $\lim_{n\to\infty} \mathbb{E}(\delta(V,W_n)) = 0$ if and only if V is doubled (i.e., every letter in V appears at least twice). (Received September 22, 2015)

1116-05-2166 **Hélène Barcelo*** (hbarcelo@msri.org), 17 Gauss Way, Berkeley, CA 94720. *Discrete Homotopy and Homology Groups.*
Discrete homotopy theory is a (refined) discrete analogue of homotopy theory, associating a (bigraded) sequence of groups to a simplicial complex, capturing its combinatorial structure, rather than its topological structure. It can be defined for graphs, resulting in algebraic invariants that differ substantially from the classical homotopy groups. One can also define discrete homology groups in analogy to the continuous case. We will review these notions and discuss a surprising application. (Received September 22, 2015)

1116-05-2198 **Kenneth Barrese*** (kbarrese@ucsd.edu), **Nicholas Loehr**, **Jeffrey Remmel** and **Bruce E. Sagan**. *Bijections on m-level Rook Placements.*
Suppose the rows of a board are partitioned into sets of size m, called levels. An m-level rook placement is a subset of the squares of the board such that no two squares are in the same column or the same level. We can construct explicit bijections between Ferrers boards having the same number of m-level rook placements. One such bijection uses a generalization of transposition to generalize a map by Foata and Schützenberger. This bijection also preserves the m-inversion number statistic of an m-level rook placement, defined by Briggs and Remmel. (Received September 22, 2015)

1116-05-2199 **Brian D Cook** (bcook@math.wisc.edu), **Akos Magyar*** (amagyar@uga.edu) and **Tatchai Titichetrakun** (tatchai@math.ubc.ca). *Configurations in dense subsets of P^d.*

Let A be a subset of the prime lattice P^d of positive relative upper density. We prove that the set A contains infinitely many affine copies of any finite set F of lattice points, that is sets of the form $F' = x + tF$. Our approach is based on the extension of the proof of the hypergraph removal lemma to weighted hypergraphs, with weights possibly attached to any edge. The proof exploits the pesudo-randomness properties of the weights, expressed by the so-called linear forms conditions of Green and Tao.
(Received September 22, 2015)

1116-05-2242 **Po-Shen Loh*** (ploh@cmu.edu), Wean 6113, Dept of Math Sciences, Carnegie Mellon University, Pittsburgh, PA 15213. *Directed paths: from Ramsey to Ruzsa and Szemerédi.*

Starting from an innocent Ramsey-theoretic question regarding directed paths in tournaments, we discover a series of rich and surprising connections that lead into the theory around a fundamental problem in Combinatorics: the Ruzsa-Szemerédi induced matching problem. Using these relationships, we prove that every coloring of the edges of the transitive n-vertex tournament using three colors contains a directed path of length at least $\sqrt{n}e^{\log^* n}$ which entirely avoids some color. We also completely resolve the analogous question for ordinary monochromatic directed paths in general tournaments, as well as natural generalizations of the Ruzsa-Szemerédi problem which we encounter through our investigation. (Received September 22, 2015)

1116-05-2255 **Rebecca F Eastham*** (becky.eastham23@gmail.com), 1120 Chandler St., Apartment 4, Madison, WI 53715, and **Victoria Horan** and **Rose McCarty**. *Creating universal cycles for subsets by expanding the alphabet.*

A **universal cycle** for k-sized subsets of $[n]$ is a cyclic sequence of $\binom{n}{k}$ elements of $[n]$ such that each k-sized subset of $[n]$ appears in the sequence exactly once. Such universal cycles do not always exist: each integer in $[n]$ must appear an equal number of times in the cycle, so it must be the case that n divides $\binom{n}{k}$. Hurlbert constructed universal cyles for $k = 3, 4$, and 6 for large enough n where n and k are relatively prime. For the cases in which k divides n, we consider an alternative approach in which we expand the alphabet by adding a new letter called a 'joker'. These jokers will allow us to represent more than one element of $[n]$ with a single character. (Received September 22, 2015)

1116-05-2282 **Yichao Chen*** (ycchen@hnu.edu.cn), Department of Mathematics, Yue lue shan, ChangSha, Hunan 410082, Peoples Rep of China. *Embedding distributions of the ring-like families of graphs.*

We derive a closed formula for the genus polynomial of any ring-like family of graphs. This presents an unified approach to calculate genus distributions of some known families of graphs. In addition, the explicit formula for the crosscap number polynomial of any ring-like family of graphs is also given. (Received September 22, 2015)

1116-05-2288 **Kelly Yancey** and **Matthew Yancey*** (mpyancey1@gmail.com). *Bipartite Communities.*

A recent trend in data-mining is to find communities in a graph. Generally speaking, a community of a graph is a vertex set such that the number of edges contained entirely inside the set is "significantly more than expected." These communities are then used to describe families of proteins in protein-protein interaction networks, among other applications. Community detection is known to be NP-hard; there are several methods to find an approximate solution with rigorous bounds.

We present a new goal in community detection: to find good bipartite communities. A bipartite community is a pair of disjoint vertex sets S, S' such that the number of edges with one endpoint in S and the other endpoint in S' is "significantly more than expected." We claim that this additional structure is natural to some applications of community detection. In fact, using other terminology, they have already been used to study correlation networks, social networks, and two distinct biological networks. We will show how the spectral methods for classical community detection can be generalized to finding bipartite communities, and we will prove sharp rigorous bounds for their performance. Additionally, we will present how the algorithm performs on public-source data sets. (Received September 22, 2015)

1116-05-2290 **Yoshiharu Kohayakawa*** (yoshi@ime.usp.br), Instituto de Matemática e Estatística, Universidade de São Paulo, São Paulo, SP 05508-090, Brazil. *The regularity method and blow-up lemmas for sparse graphs.*

The combined application of Szemerédi's regularity lemma and an embedding lemma (or a subgraph counting lemma) is now often called the *regularity method*. In its simplest form, the regularity method allows one to investigate the existence of a given fixed graph as a subgraph of a large graph. Komlós, Sárközy and Szemerédi strengthened the regularity method by developing the *blow-up lemma*, which, combined with the regularity lemma, allows one to address problems in which the subgraphs being sought are large, for instance, when they are spanning subgraphs (e.g., the kth power of a Hamilton cycle).

Owing to the work of several researchers, including Balogh, Conlon, Fox, Gowers, Morris, Rödl, Samotij, Saxton, Schacht, Thomason, and Zhao, the regularity method has also been successfully strengthened to handle graphs with a subquadratic number of edges, that is, one now knows well how to apply this method in the sparse setting when one investigates the existence of *small subgraphs*.

In this talk, we shall discuss blow-up lemmas in the sparse setting, currently under development in collaboration with P. Allen, J. Böttcher, H. Hàn and Y. Person. (Received September 22, 2015)

1116-05-2291 **Gregory J Puleo***, puleo@illinois.edu. *Favaron's Theorem, k-dependence, and Tuza's Conjecture.*

A vertex set D in a graph G is *k-dependent* if $G[D]$ has maximum degree at most $k-1$, and *k-dominating* if every vertex outside D has at least k neighbors in D. Favaron proved that if D is a k-dependent set maximizing the quantity $k|D| - |E(G[D])|$, then D is k-dominating. We extend this result, showing that such sets satisfy a stronger structural property, and we find a surprising connection between Favaron's theorem and a conjecture of Tuza regarding packing and covering of triangles. (Received September 22, 2015)

1116-05-2296 **Jason T. Suagee*** (jsuagee@email.gwu.edu). *A generalization of α-orientations to higher genus surfaces.*

Given a graph $G = (V, E)$, and a given function $\alpha : V \to N$, an α-orientation is an orientation of the edges such that the out-degree of each vertex v equals $\alpha(v)$. S. Felsner (TU-Berlin) in 2004 proved that the set of alpha-orientation on an embedded planar graph (a planar map) carries the structure of a distributive lattice, with unique maximal and minimal elements. He uses this result, for example, to construct canonical spanning trees on rooted planar maps as well as several other canonical structures on planar maps.

We obtain a generalization of Felsner's result to higher genus orientable surfaces with possible application to bijective methods in map enumeration and construction. Additionally, by applying this result to pairs of Cayley maps (strongly symmetric embeddings of Cayley graphs) we obtain potential applications to the study of finite group extensions. (Received September 22, 2015)

1116-05-2318 **Tomaz Pisanski*** (tomaz.pisanski@upr.si), Koper, Slovenia. *Operations on oriented maps.* Preliminary report.

In the past we have been using flag graphs and symmetry type graphs for studying certain operations on maps and their symmetries, such as truncation, dual, medial, chamfering, etc. Here we study similar operations on oriented maps. Certain new operations that can only be defined for oriented maps, such as snub, are also considered. In the oriented case the primary tools, ie. flag graphs and symmetry type graphs are substituted by arc graphs and oriented symmetry type graphs. (Received September 22, 2015)

1116-05-2329 **Jose Alejandro Samper*** (samper@math.washington.edu). *Relaxing the exchange axiom and Stanley's conjecture for matroid h-vectors.*

We present a relaxation of the exchange axiom for matroids. This leads to a large class of ordered simplicial complexes that contains all independence complexes of matroids as well as all pure shifted complexes. While the resulting family of simplicial complexes is much larger than that of independence complexes of matroids, the members of this family enjoy a few matroidal properties: for instance, they are vertex decomposable and possess several natural shelling orders. We discuss decompositions of the h-vectors of such a class of complexes and introduce a refinement of Stanley's classical conjecture on the h-vectors of independence complexes of matroids. Finally, we present a solution of this extended conjecture for the class of pure shifted simplicial complexes. (Received September 22, 2015)

1116-05-2362 **Mark Ellingham*** (mark.ellingham@vanderbilt.edu), **Wenzhong Liu**, **Dong Ye** and **Xiaoya Zha**. *Quadrilateral embeddings of cartesian products.*

White, Pisanski and others have proved a number of results on the existence of quadrilateral embeddings of cartesian products of graphs; in some cases these provide minimum genus embeddings. In a 1992 paper Pisanski posed three questions. First, if G and H are connected 1-factorable r-regular graphs with $r \geq 2$, does the cartesian product $G \square H$ have an orientable quadrilateral embedding? Second, if G is r-regular, does the cartesian product of G with sufficiently many even cycles have an orientable quadrilateral embedding? Third, if G is an arbitrary connected graph, does the cartesian product of G with a sufficient large cube $Q_n = \square^n K_2$ have an orientable quadrilateral embedding? We answer all three questions. The answer to the first question is negative, as we show using 3-regular examples. The answers to the second and third questions are positive, as we show using a general theorem that answers both. (Received September 22, 2015)

1116-05-2453 **Richard Anstee*** (anstee@math.ubc.ca), Mathematics Department, #121- 1984 Mathematics Rd, UBC, Vancouver, BC V6T 1Z2, Canada. *Design Theory and Extremal Combinatorics.*

A design can be thought of as a set system where the sets are the blocks and the set system has some strong properties. Translating designs to set systems, one typically would wish to have *simple* designs; namely no repeated blocks. Keevash has proven results about simple designs that settles many existence questions. A condition for 2-designs that the blocks contain a pair $\{i, j\}$ exactly λ times can be reformulated as having a specified number of blocks while for each pair $\{i, j\}$ we do *not* have $\lambda + 1$ blocks that contain $\{i, j\}$. This becomes a *forbidden configuration* problem for sets. A few topics of this interplay between Designs and Extremal Set Theory (Forbidden Configurations) will be explored and includes joint work with Farzin Barekat, Attila Sali. (Received September 22, 2015)

1116-05-2469 **Dewey Taylor*** (dttaylor2@vcu.edu) and **Christopher Whisenant**. *Odd dominating sets in the direct and strong products.*

An odd open dominating set of a graph is a subset of the graph's vertices with the property that the open neighborhood of each vertex in the graph contains an odd number of vertices in the subset. An odd closed r-dominating set is a subset of the graph's vertices with the property that the closed r-ball centered at any vertex in the graph contains an odd number of vertices in the subset. Odd open and closed dominating sets have been investigated by many authors.

This talk explores the existence of odd open and closed dominating sets in the direct and strong products of graphs. The n-fold direct product of simple graphs has an odd open dominating set if and only if each factor has an odd open dominating set. The n-fold strong product of simple graphs has an odd closed r-dominating set if and only if each factor has an odd closed r-dominating set.

We also explore several generalizations of this idea. (Received September 22, 2015)

1116-05-2473 **Sohail Farhangi*** (sohail3@vt.edu), 208 Turner Street Northwest Suite #215, Blacksburg, VA 24061. *On the 2-Large is Large conjecture. A Generalization of Van der Waerden's Theorem.* Preliminary report.

The classical theorem of Van der Waerden, which states that for any finite partition of the positive integers, at least one of the partition classes must contain arbitrarily long arithmetic progressions. One way in which we can try to generalize this theorem, is to restrict the set of allowable arithmetic progressions, and a reasonable way to do this is to take a subset S of the positive integers, and only look for arithmetic progressions whose common difference is an element of S (S-A.P.). We call a set S Large, if for any finite partition of the positive integers, at least one of the partition classes must contain arbitrarily long $S-$A.P.s. In attempt to classify all Large sets, we define a set of positive integers S to be $r-$Large, if for any partition of the positive integers into r classes, we have that at least one of the partition classes must contain arbitrarily long $S-$A.P.s. One would expect the existence of a set S such that S is $r-$Large for some r, but is not $(r+1)-$Large, and conseuquently, not Large. However, no such examples of a set S have been found, and this has lead to a conjecture of Landman, Brown, and Graham, that if a set is $2-$Large, then it is Large. (Received September 22, 2015)

1116-05-2488 **Tom Bohman*** (tbohman@math.cmu.edu), Carnegie Mellon University, 5000 Forbes Ave, Pittsburgh, PA 15213. *Random greedy hypergraph processes.*

Let $\mathcal{H}$ be a D-regular, r-uniform hypergraph on n vertices. In this talk we consider the random greedy algorithms for producing matchings and independent sets on $\mathcal{H}$. The random greedy matching algorithm builds a matching by adding edges selected uniformly at random one at a time, subject to the condition that each selected edge does not intersect any previously selected edge. The random greedy independent set algorithm builds an independent set by adding vertices one at a time which are chosen uniformly at random subject to the condition that the collection of selected vertices never contains an edge of $\mathcal{H}$. In this talk we survey some recent applications of these processes and discuss some open problems. (Received September 22, 2015)

1116-05-2495 **Rose McCarty*** (rmccarty3@gatech.edu), **Becky Eastham**, **Paul Han**, **Bill Kay** and **David Spencer**. *Total Acquisition in Diameter 2 Graphs and Tournaments.* Preliminary report.

Let G be a graph where each vertex is given an initial weight of 1. At each time step, a vertex u may **acquire** all of the weight from a vertex $v \in N(u)$ if $w(u) \geq w(v)$. After this acquisition move, the new weight on u is $w(u) + w(v)$ and the new weight on v is 0. The total acquisition number of a graph $a_t(G)$ is the smallest integer so that there exists a sequence of acquisition moves ending with $a_t(G)$ vertices having weight greater than 0. LeSaulnier, Prince, Wenger, West, and Worah prove that, for G a diameter 2 graph with no 4-cycles, $a_t(G) \leq 2$. They further show that if G has diameter 2, then $a_t(G) \leq 32 \ln n \ln \ln n$, and conjecture that in fact, the total acquisition number of any diameter 2 graph is less than 2. We show that when G is a diameter 2 graph where every 4-cycle in G induces a K_4, $a_t(G) \leq 2$. We also give an additional family of diameter 2 graphs with acquisition number less than or equal to 2. Finally, we prove that all tournaments have acquisition number less than or equal to 2 for a suitable variant of acquisition on directed graphs. (Received September 22, 2015)

1116-05-2502 **Thomas Barron**, **Christopher ONeill*** (coneill@math.tamu.edu) and **Roberto Pelayo**. *Computing the delta set of a numerical monoid.*

In this talk, we present a recent algorithm for computing the delta set, a combinatorial invariant of non-unique factorization, for any numerical monoid. Our algorithm utilizes dynamic programming methods and offers significant performance improvements over existing implementations by avoiding the need to compute any factorizations. The content of this talk appears in the preprint arXiv:1507.07435. (Received September 22, 2015)

1116-05-2516 **Peter J. Dukes**, **Alan C.H. Ling** and **Amanda Malloch*** (anjam@uvic.ca). *Thickly-Resolvable Block Designs.*

A σ*-parallel class* in a design with point set V and block set $\mathcal{B}$ is a set $\mathcal{A}$ such that $\mathcal{A} \subseteq \mathcal{B}$ and every point of V belongs to exactly σ of the blocks in $\mathcal{A}$. A balanced incomplete block design $(V, \mathcal{B})$ is said to be σ*-resolvable* if $\mathcal{B}$ admits a partition into σ-parallel classes. We show that the divisibility conditions required for the existence of a σ-resolvable BIBD(v, k, λ) are in fact sufficient whenever v is large enough. (Received September 22, 2015)

1116-05-2565 **Emma Cohen**, **Dhruv Mubayi**, **Peter Ralli** and **Prasad V Tetali***, Georgia Institute of Technology, Atlanta, GA 30332-0160. *Inverse Expander Mixing for Hypergraphs.*

Extensions of the powerful theory of quasirandomness in graphs to hypergraphs has motivated the study of the so-called expander mixing lemma and its converse, often referred to as an "inverse mixing lemma. These lemmas capture the role played by the eigenvalues of adjacency operators in quantifying quasirandomness. We formulate and prove inverse mixing lemmas in the settings of simplicial complexes and (k-uniform) hypergraphs, for $k \geq 3$. In the hypergraph setting, we extend results of Bilu and Linial for graphs. In the simplicial complex setting, our results answer a question of Parzanchevski et al. (Received September 22, 2015)

1116-05-2677 **Wendy Myrvold*** (wendym@cs.uvic.ca), Department of Computer Science, University of Victoria, P.O. Box 3055, Stn CSC, Victoria, BC V8W 3P6, Canada. *Algorithms and Obstructions for Graph Embedding.* Preliminary report.

A graph *embeds* on a surface S if it can be drawn on S with no crossing edges. A *topological obstruction* for a surface S is a graph G with minimum degree three that is not embeddable on S but for all edges e, $G-e$ embeds on S. A *minor order obstruction* has the additional property that for all edges e, G contract e embeds on S.

The aim of our research is to find all the obstructions to the torus (a surface that is a sphere with one handle added) and the Klein bottle (a surface that can be created by adding either a twisted handle or two crosscaps to a sphere). This talk discusses techniques for finding these obstructions, and algorithms for embedding graphs then concludes with suggested avenues for future research.

The work in this talk has been done in conjunction with Bill Kocay (University of Manitoba) and several students including Eugene Neufeld, John Chambers, Matthew Skala, Hongmei Wang, Jenni Woodcock, and Russell Campbell. (Received September 22, 2015)

1116-05-2692 **Michal Kotrbcik*** (kotrbcik@imada.sdu.dk). *Practical computations in topological graph theory.*

Extensive computations had been part of the topological graph theory for a long time, in particular in attempts to determine the minimum genus of various graphs and graph families. In recent years, the area is experiencing a renewed interest, motivated partly both by vast increase in the available computational resources, as well as by advances in theoretical computer science.

In the first part of the talk I will survey some of the recent results in the area, including both theoretical and practical aspects. The aim is to give an overview of the available methods and their limitations, and should be accessible also to non-specialists.

In the second part of the talk I will present our recent design and implementation of a framework for calculating minimum genus based on ILP and SAT formulations and solvers, focusing mostly on its applicability.

Partly joint work with T. Pisanski, P. Schmidt, respectively S. Beyer, I. Hedtke, and M. Chimani. (Received September 22, 2015)

1116-05-2727 **Lindsay Dever***, Smith College, Department of Mathematics and Statistics, 44 College Lane, Northampton, MA 01063, **Holly Mandel**, Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, **Elise Reed**, Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, **Stephanie Webster**, Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, **Julia Gibson**, Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, and **Meredith Wilde**, Smith College, Department of Mathematics and Statistics, Northampton, MA 01063. *Further results on generalized splines.*

Given an edge-labeled graph, a generalized spline is a labeling of the vertices so that the difference between adjacent vertex labels is a multiple of the corresponding edge label. This definition generalizes the notion of splines from classical analysis and applied mathematics. We discuss several new results on generalized splines involving bases and multiplication tables for special families of graphs. (Received September 22, 2015)

1116-05-2732 **Anton Dochtermann*** (dochtermann@math.utexas.edu). *Commutative algebra of generalized permutohedra.*

Realized as signed sums of simplices, the vertices and lattice points of 'generalized permutohedra' give rise to various monomial ideals. These include the class of matroidal ideals as well as certain artinian ideals with appealing combinatorial structure. We study cellular resolutions of these ideals and seek to interpret their Betti numbers - a simple motivating example is the Koszul resolution of the maximal ideal supported on a simplex.

For example we show that the ideal generated by the lattice points of a sum of simplices (of various dimensions) has a minimal resolution supported on any regular subdivision of the underlying polytope. These ideals are closely related to initial ideals of 'ladder determinantal ideals', and the polyhedral complexes supporting the resolutions are connected to the geometry of 'tropical' hyperplane arrangements. We discuss some combinatorial and algebraic applications of our results, including connections to a notion of generalized chip-firing. This is joint work with Alex Fink and Raman Sanyal. (Received September 22, 2015)

1116-05-2743 **Daniel Timothy Parry*** (dan.t.parry@gmail.com). *Asymptotic Estimation of the Andrews Zagier $G_k(q)$ function and its connection to the Wright's Generalized Hyper geometric function.* Preliminary report.

We resolve a conjecture of George Andrews and Donald Zagier on a q-hypergeometric function we call $G_k(q)$ which counts partitions into short sequences. We do this by applying an old special function commonly used in fractional calculus known as the Wright function. (Received September 22, 2015)

1116-05-2767 **Mirkó Visontai*** (visontai@math.kth.se), **Petter Brändén** and **Matthew Chasse**. *Seperation of the zeros of q-Eulerian polynomials.*

The MacMahon–Carlitz q-analog of the Eulerian polynomial is a two-variable generating function of the joint distribution of descent and the major index statistic over permutations, $A_n(x,q) = \sum_\pi x^{\mathrm{des}\pi} q^{\mathrm{maj}\pi}$. In this talk, we show that the zeros of these q-Eulerian polynomials are all real and are "logarithmically spaced", in the sense that the ratio of the consecutive zeros is at least q (for $q > 1$). The proof is then extended to signed permutations and is also used to settle a more general conjecture of Chow and Mansour for the case of colored permutations. (Received September 22, 2015)

1116-05-2774 **Nicholas M Ercolani***, ercolani@math.arizona.edu, and **Patrick Waters**. *Quantum Gravity and Quantum Groups.*

The (2D-)Quantum Gravity referred to here emerged in the study of discrete approximations for Polyakov's formulation of Liouville field theory and has been a fertile source for questions and ideas in the analysis of random combinatorial structures and their relation to various problems at the interface between probability theory and mathematical physics. In particular, it bears on the problem of constructing a measure on random surface metrics.

Our work applies in this latter context. Specifically we study scaling limits for discrete models of the conformal geometry of surfaces. These limits lead naturally to a class of conservation laws that can be analyzed via the bionomial Hopf algebra and its associated umbral calculus. Non-commutative extensions of this bring one to the setting of Quantum Groups and a new class of problems relating the characteristic geometry of conservation laws to the classical study of ruled surfaces in algebraic geometry. (Received September 22, 2015)

1116-05-2775 **Julianna Tymoczko*** (jtymoczko@smith.edu), Department of Mathematics and Statistics, Smith College, 44 College Lane, Northampton, MA 01063. *The geometry behind permutations and their subwords.*

The geometry of the flag variety and its subvarieties is intimately connected to the combinatorics of the permutation group. On a basic level, the permutations can be viewed as fixed points of the flag variety under a very natural group action. This extends to deeper structural connections involving subwords of permutations and subsets of roots negated by permutations. For instance Billey's formula defines polynomials that depend on pairs of permutations; these polynomials determine local features of the tangent space of Schubert varieties, as well as their cohomology classes. Other results use subwords of permutations to characterize the Betti numbers of Springer varieties. We will discuss these and other related results. (Received September 22, 2015)

1116-05-2789 **Quang T. Bach*** (qtbach@ucsd.edu) and **Jeffrey B. Remmel**. *Descent c-Wilf Equivalence.*

Let τ be a permutation. Let $\mathcal{NM}_n(\tau)$ denote the set of permutations σ of the symmetric group S_n which have no consecutive τ-matches and let $NM_n(\tau) = |\mathcal{NM}_n(\tau)|$. If α and β are elements of S_j, then we say that α *is c-Wilf-equivalent to* β if $NM_n(\alpha) = NM_n(\beta)$ for all $n \geq 1$. The main goal of this talk is to introduce refinements of the c-Wilf equivalence relation. We say that α and β are $(\mathbf{stat}_1, \ldots, \mathbf{stat}_k)$-c-Wilf equivalent if for all $n \geq 1$,

$$\sum_{\sigma \in \mathcal{NM}_n(\alpha)} \prod_{i=1}^{k} x_i^{\mathbf{stat}_i(\sigma)} = \sum_{\sigma \in \mathcal{NM}_n(\beta)} \prod_{i=1}^{k} x_i^{\mathbf{stat}_i(\sigma)}$$

where $\mathbf{stat}_1, \ldots, \mathbf{stat}_k$ are permutations statistics on permutations. We also give examples of $\mathbf{stat}$-c-Wilf equivalent permutations for $\mathbf{stat} = (\text{des, inv, LRmin})$, where $\text{des}(\sigma)$ is the number of descents, $\text{inv}(\sigma)$ is the number of inversions, and $\text{LRmin}(\sigma)$ is the number of left-to-right minima of σ. (Received September 22, 2015)

1116-05-2793 **Andrew Meier*** (ameier@nebrwesleyan.edu) and **Austin Mohr** (amohr@nebrwesleyan.edu). *Classification of Spanning Trees by Isomorphism.* Preliminary report.

A celebrated result of Cayley says there are n^{n-2} labeled trees on n vertices, and many elementary proofs are known. Significantly harder is the enumeration of unlabeled trees, for which no closed formula currently exists. We present a high-level description of an algorithm of McKay et al. that efficiently generates one copy of each unlabeled tree on a given number of vertices. Moreover, we know from Burnside's lemma that the size of the isomorphism class of a tree T on n vertices is $\frac{n!}{\text{Aut}(T)}$. Taken together, we may fully classify all labeled trees on n vertices according to isomorphism. The talk concludes with a demonstration of the algorithm implemented in Sage and discussion of a possible extension to classify the spanning trees of an arbitrary graph. (Received September 22, 2015)

1116-05-2804 **Rediet Abebe*** (rta36@cornell.edu). *A Bound for the Laplacian Spectra of Simplicial Complexes.*

We present a generalization of Brouwer's conjectural family of inequalities for the Laplacian specturm of graphs to the case of abstract simplicial complexes. This conjecture states, given a graph G with e edges and Laplacian eigenvalues $(\lambda_1 \geq \lambda_2 \geq \cdots \lambda_{n-1} \geq \lambda_n = 0)$,

$$\sum_{i=1}^{t} \lambda_i \leq e + \binom{t+1}{2}, \forall t \in [n].$$

We generalize to the case of abstract simplicial complexes (of any dimension $k-1$) with Laplacian eigenvalues $\lambda(S) = (\lambda_1 \geq \lambda_2 \geq \cdots)$ to the inequality,

$$\sum_{i=1}^{t} \lambda_i \leq (k-1) f_{k-1}(S) + \binom{t+k-1}{k},$$

where f_{k-1} is the number of facets.

We prove this family of inequalities for shifted simplical complexes and give tighter bounds (linear in the dimensions of the complexes) for simplicial trees. We show that the conjecture holds for the t^{th} partial sum for all simplicial complexes with dimension at least t and matching number greater than t as well as resolve the case for the first, second, and last partial sum completely. We also expand on a known proof for graphs to show that the conjecture holds with equality for threshold graphs when t is the number of cone vertices. (Received September 22, 2015)

1116-05-2827 **Rafael S. Gonzalez D'Leon** and **Michelle L. Wachs*** (wachs@math.miami.edu).
Connections between weighted partitions and graph associahedra. Preliminary report.

We examine the topology of the order complex of a weighted version of the bond lattice of a graph, and we present an intriguing connection with h-vectors of graph associahedra studied by Postnikov, Reiner and Williams, and others. (Received September 22, 2015)

1116-05-2828 **Jinseok An** and **Thomas Langley*** (langley@rose-hulman.edu). *Sorting permutations with finite-depth stacks and symmetries of the square.* Preliminary report.

We consider several sorting operators built from stack sorting with a finite-depth stack and a symmetry of the square. In particular, we characterize permutations that are sortable by the operator $\mathcal{S}_d \circ r \circ \mathcal{S}_d$ for $d = 2$ and $d = 3$, where $\mathcal{S}_d$ represents stack sorting with a depth-d stack and r denotes reverse. We also conjecture a general result. We then consider the operator $(\mathcal{S}_d \circ r)^k$, characterizing permutations that are sortable with $d = 2$ and $d = 3$, for any value of k. Many open questions will arise. (Received September 22, 2015)

1116-05-2855 **Nathan Reff*** (nreff@brockport.edu), Department of Mathematics, The College at Brockport, State University of New York, Brockport, NY 14420, and **Howard Skogman** (hskogman@brockport.edu), Department of Mathematics, The College at Brockport, State University of New York, Brockport, NY 14420. *A connection between Hadamard matrices, oriented hypergraphs and signed graphs.*

An oriented hypergraph is a hypergraph where every vertex-edge incidence is given a label of $+1$ or -1. With this labelling, the notion of a signed adjacency allows one to study the adjacency and Laplacian matrices associated to this hypergraph. It turns out that the problem of finding Hadamard matrices is equivalent to finding a special family of oriented hypergraphs. This gives rise to a condition on a collection of signed complete graphs which can be used to find Hadamard matrices. (Received September 22, 2015)

1116-05-2861 **Richard M Wilson*** (rmw@caltech.edu). *On the rank of matrices with few off-diagonal entries, and combinatorial applications.* Preliminary report.

Let M be a matrix of order n and of rank r. Let s be the number of distinct off-diagonal entries of M and assume that none of these values occur on the diagonal of M. Then

$$n \leq \binom{r+s}{s}.$$

For example, one immediate consequence is that the multiplicity of an eigenvalue $\lambda \neq 1, 0, -1$ of a $(0,1)$-matrix is less than $n - \sqrt{2n} + 2$.

Our talk will discuss applications and generalizations of this inequality. We recover known inequalities on systems of sets with restricted intersections and sets of points with restricted distances. In case the entries of M are integers, we give necessary conditions for equality and, under certain conditions, can reduce the bound for n to

$$n \leq \binom{r+t}{t}$$

with $t < s$. (Received September 22, 2015)

1116-05-2864 **Nafiseh Jahanbakht*** (nafisej@okstate.edu) and **Kourosh Tavakoli**. *Relationship between the energy of a directed graph and the energy of its underlying graph.*

The energy of a directed graph is defined to be the sum of the absolute values of the real parts of the eigenvalues of its adjacency matrix. The energy of a graph (undirected) is the sum of the absolute values of the eigenvalues of its adjacency matrix. Could there be any relation between the energy of a directed graph and the energy of its underlying graph? Under some conditions, the answer is yes. The question is still open in the general case. (Received September 22, 2015)

1116-05-2913 **Aihua Li*** (lia@mail.montclair.edu), Department of Mathematical Science, Montclair State University, 1 Normal Avenue, Montclair, NJ 07043, and **Christian Hyra**. *Interlace Polynomials of Certain Eulerian Graphs.*

Studying the graph polynomial of a considered graph has been an algebraic method to help understand the underground graph. Applications have been found in biology and other areas. In this research, we focus on the interlace polynomial of a special type of Eulerian graph, built from one cycle of size n and n triangles. We develop recursive and explicit formulas for the interlace polynomials of such graphs. The explicit formulas can be used to describe the graphs and can be applied to other areas of mathematics and sciences. One particular application is in matrix theory. (Received September 23, 2015)

1116-05-2979 **Eric Bucher*** (`ebuche2@lsu.edu<mailto:ebuche2@lsu.edu>`). *Sequences of Quiver Mutations on Surfaces*

Given a marked surface (S,M) we can add arcs to the surface to cr= eate a triangulation, T, of that surface. For each triangulation, T, we can= associate a cluster algebra. We will introduce how to construct a cluster = algebra and quiver from this surface and hen in the sense of work by Keller= we will produce a maximal green sequence for this quiver. Since all finite= mutation type cluster algebras can be associated to a surface, with some r= are exceptions, this work along with previous work by others seeks to estab= lish a base case in answering the question of whether a given finite mutati= on type cluster algebra exhibits a maximal green sequence. (Received September 29, 2015)

06 ► Order, lattices, ordered algebraic structures

1116-06-2151 **Kelli M Karcher*** (`kkarcher@vt.edu`). *The Space of Biorders on Some Solvable Groups.* Preliminary report.

A group is said to be biorderable if it has a total order invariant under left and right multiplication. These orders can be given a topology which is called the space of biorders on this group. There has been intensive study on the space of left-orders recently, but less on the space of biorders. We will focus on solvable groups to show under certain conditions the space of biorders is either finite or homeomorphic to the Cantor set. (Received September 21, 2015)

1116-06-2397 **Salma Kuhlmann*** (`salma.kuhlmann@uni-konstanz.de`), Fachbereich Mathematik und Statistik, Universitaet Konstanz, Universitaetsrasse 10, 78457 Konstanz, Germany. *Exponential-logarithmic power series fields and the surreal numbers.*

In joint work with M. Matusinski we studied Hardy type derivations (i.e., derivations satisfying the properties of derivations on Hardy fields) and how to extend this investigation to the field No of surreal numbers. In this talk, I will give a survey of our three papers on that topic. (Received September 22, 2015)

08 ► General algebraic systems

1116-08-234 **Margaret L. Rahmoeller*** (`rahmoeller@roanoke.edu`), Roanoke, VA 24019. *On Demazure Crystals for the Quantum Affine Algebra* $U_q\left(\hat{sl}(n)\right)$.

In 1968, Victor Kac and Robert Moody defined a class of infinite dimensional Lie algebras called affine Lie algebras. An affine Lie algebra can be viewed as the universal central extension of the Lie algebra of polynomial maps from the unity circle to a finite dimensional simple Lie algebra. Kashiwara showed that irreducible modules for the q-deformed universal enveloping algebra of an affine Lie algebra admit crystal bases. Kang, Kashiwara, Misra, Miwa, Nakashima and Nakayashiki gave the path realizations of affine crystals as a semi-infinite tensor product of some finite crystals called perfect crystals in 1991. In this talk, we use this path realization and show that the union and intersection of certain Demazure crystals for the quantum affine algebra $U_q\left(\hat{sl}(n)\right)$ are finite tensors of the corresponding perfect crystals. (Received August 15, 2015)

1116-08-2411 **Emily Gunawan*** (`egunawan@umn.edu`). *Notched Arcs of Cluster Algebras from Punctured Surfaces.* Preliminary report.

Cluster algebras, introduced by Sergey Fomin and Andrei Zelevinsky in 2000, are commutative algebras which are defined combinatorially by an iterated process. The notion of cluster algebra links together diverse fields of study, e.g. discrete dynamical systems, Riemann surfaces and Teichmüller theory, algebraic geometry, and representation theory of quivers. An important class of cluster algebras arise from triangulations of surfaces with marked points. We generalize Ralf Schiffler and Hugh Thomas' combinatorial T-path formula for arcs of unpunctured surfaces to tagged arcs (possibly with decorations called notchings at their endpoints) of punctured surfaces, and use this to investigate the existence of atomic bases for cluster algebras arising from punctured surfaces. (Received September 22, 2015)

11 ► Number theory

1116-11-1 **Sungjin Kim*** (i707107@math.ucla.edu), 3442 Jasmine Ave APT 5, Los Angeles, CA 90034. *Positivity of Constants Related to Elliptic Curves.*

Let E be an elliptic curve defined over $\mathbb{Q}$. It is known that the structure of the reduction $E(\mathbb{F}_p)$ is

$$E(\mathbb{F}_p) \simeq \mathbb{Z}/d_p\mathbb{Z} \oplus \mathbb{Z}/e_p\mathbb{Z}. \tag{1}$$

with $d_p|e_p$. The constant

$$C_{E,j} = \sum_{k=1}^{\infty} \frac{\mu(k)}{[\mathbb{Q}(E[jk]) : \mathbb{Q}]}$$

appears as the density of primes p with good reduction for E and $d_p = j$ (Under the GRH in the non-CM case, unconditionally in the CM case). We give appropriate conditions for this constant to be positive when $j > 1$. (Received March 29, 2015)

1116-11-2 **Cindy Tsang*** (cindytsy@math.ucsb.edu). *Realizable Classes and Embedding Problems.* Preliminary report.

Let K be a number field with ring of integers $\mathcal{O}_K$ and let G be a finite group. Given a finite Galois extension L/K with $\mathrm{Gal}(L/K) \simeq G$, the ring of integers $\mathcal{O}_L$ in L is an $\mathcal{O}_K G$-module. By a classical theorem of Noether, one knows that $\mathcal{O}_L$ is locally free over $\mathcal{O}_K G$ if and only if L/K is tame, in which case $\mathcal{O}_L$ defines a class $[\mathcal{O}_L]$ is the locally free class group $\mathrm{Cl}(\mathcal{O}_K G)$ of $\mathcal{O}_K G$. We call such a class *realizable* and we consider the set

$$R(\mathcal{O}_K G) := \{[\mathcal{O}_L] : L/K \text{ is a tame Galois extension with } \mathrm{Gal}(L/K) \simeq G\}$$

of all realizable classes. In the case that G is abelian, a result of McCulloh states that $R(\mathcal{O}_K G)$ is a subgroup of $\mathrm{Cl}(\mathcal{O}_K G)$. In this paper, we show that there is in fact a close connection between the group structure of $R(\mathcal{O}_K G)$ and the study of embedding problems. (Received September 13, 2015)

1116-11-138 **Chadwick Arthur Gugg*** (chadwick.gugg@gsw.edu), Department of Mathematics, Georgia Southwestern State University, 800 GSW State University Drive, Americus, GA 31709. *On relations of Koike and Somos for the Rogers-Ramanujan functions.* Preliminary report.

In his notebooks, Ramanujan recorded 40 relations for the Rogers-Ramanujan functions. This list has inspired work by a number of authors seeking to understand and prove these relations, as well attempts to find further such identities and extensions to analogues of the Rogers-Ramanujan functions. We focus on proofs of identities found variously and independently by M. Koike, M. Somos, and by the author. (Received August 04, 2015)

1116-11-143 **Sarah Blackwell**, **Gabriel Durham**, **Katherine Thompson** and **Tiffany Treece*** (treece@uga.edu). *A Generalization of Mordell to Ternary Quadratic Forms.*

Mordell in 1958 gave a new proof of the three squares theorem. We generalize those techniques to characterize the integers represented by the remaining six "Ramanujan-Dickson ternaries" as well as three other ternary forms. (Received August 06, 2015)

1116-11-144 **Alexi Block Gorman** (ablockgo@wellesley.edu), **Tyler Genao** (tgenao2013@fau.edu), **Heesu Hwang** (hshwang@princeton.edu), **Noam Kantor*** (noam.kantor@emory.edu), **Sarah Parsons** (parssy12@wfu.edu) and **Jeremy Rouse** (rouseja@wfu.edu). *The density of primes dividing a certain non-linear recurrence sequence.*

Define the sequence $\{b_n\}$ by $b_0 = 1, b_1 = 2, b_2 = 1, b_3 = -3$, and

$$b_n = \begin{cases} \frac{b_{n-1}b_{n-3} - b_{n-2}^2}{b_{n-4}} & \text{if } n \not\equiv 2 \pmod 3, \\ \frac{b_{n-1}b_{n-3} - 3b_{n-2}^2}{b_{n-4}} & \text{if } n \equiv 2 \pmod 3. \end{cases}$$

We relate this sequence $\{b_n\}$ to the coordinates of points on the elliptic curve $E : y^2 + y = x^3 - 3x + 4$. We use Galois representations attached to E to prove that the density of primes dividing a term in this sequence is equal to $\frac{179}{336}$. Furthermore, we describe an infinite family of elliptic curves whose Galois images match that of E. (Received August 06, 2015)

1116-11-197 **Reinier Broker*** (reinierbroker@gmail.com). *Fourier coefficients of metaplectic Eisenstein series.*

Metaplectic Eisenstein series for n-fold covers of GL_2 encode various arithmetic properties of number fields. Explicitly computing their Fourier coefficients has only been done for small n. In this talk we will detail various algorithms and explain how to push the computational boundaries further. Many examples will be given. (Received August 13, 2015)

1116-11-237 **Patrick Ingram**, Mathematics Department, Colorado State University, Fort Collins, CO 80523, **Joseph H Silverman***, Mathematics Department, Brown University, 151 Thayer Street, Providence, RI 02912, and **Katherine Stange**, Mathematics Department, University of Colorado, Boulder, CO 80309. *Divisibility sequences associated to higher dimensional algebraic groups.* Preliminary report.

Classical divisibility sequences such as $a^n - b^n$, Fibonacci and Lucas sequences, and elliptic divisibility sequences, are associated to multiples of a rational point P on a one-dimensional algebraic group $\mathcal{G}$. These divisibility sequences tend to grow rapidly, and their mod p and p-adic behaviors are quite interesting. Intrinsically they may be described as the arithmetic intersection $W_n = (nP) \cdot \mathcal{O}$ on some model of $\mathcal{G}$ over $\mathrm{Spec}(\mathbb{Z})$. Replacing $\mathcal{G}$ with a higher dimensional algebraic group again leads to interesting divisibility sequences $W_n = (nP) \cdot \mathcal{O}$, but these W_n tend to be quite small. We consider an alternative generalization in which P is replaced by an effective divisor $D \in \mathrm{Div}(\mathcal{G})$. We will discuss generalized divisibility properties, growth properties, and mod p and p-adic properties of the resulting sequences $W_n = (n_* D) \cdot \mathcal{O}$, concentrating on the case that $\mathcal{G} = \mathbb{G}_m^N$ is a torus. (Received August 16, 2015)

1116-11-333 **Ellen Eischen*** (eeischen@uoregon.edu). *p-adic families of Eisenstein series and applications.*

We will introduce certain p-adic properties of Eisenstein series and their pullbacks, extending results of N. Katz to the setting of automorphic forms on unitary groups. We will also discuss applications to L-functions and beyond. (Received August 25, 2015)

1116-11-360 **Ashvin Anand Swaminathan*** (aaswaminathan@college.harvard.edu), 388 Eliot Mail Center, Harvard College, 101 Dunster Street, Cambridge, MA 02138, and **Evan Chen** and **Peter S. Park**. *Elliptic Curve Variants of the Least Quadratic Nonresidue Problem and Linnik's Theorem.*

Let E_1 and E_2 be $\overline{\mathbb{Q}}$-nonisogenous, semistable elliptic curves over $\mathbb{Q}$, having respective conductors N_{E_1} and N_{E_2} and both without complex multiplication. For each prime p, denote by $a_{E_i}(p) := p + 1 - \#E_i(\mathbb{F}_p)$ the trace of Frobenius. Under the assumption of the Generalized Riemann Hypothesis (GRH) for the convolved symmetric power L-functions $L(s, \mathrm{Sym}^i E_1 \otimes \mathrm{Sym}^j E_2)$ where $i, j \in \{0, 1, 2\}$, we prove an explicit result that can be stated succinctly as follows: there exists a prime $p \nmid N_{E_1} N_{E_2}$ such that $a_{E_1}(p) a_{E_2}(p) < 0$ and

$$p < \left((32 + o(1)) \cdot \log N_{E_1} N_{E_2}\right)^2.$$

This improves and makes explicit a result of Bucur and Kedlaya.

Now, if $I \subset [-1, 1]$ is a subinterval with Sato-Tate measure μ and if the symmetric power L-functions $L(s, \mathrm{Sym}^k E_1)$ are functorial and satisfy GRH for all $k \leq 8/\mu$, we employ similar techniques to prove an explicit result that can be stated succinctly as follows: there exists a prime $p \nmid N_{E_1}$ such that $a_{E_1}(p)/(2\sqrt{p}) \in I$ and

$$p < \left((21 + o(1)) \cdot \mu^{-2} \log(N_{E_1}/\mu)\right)^2.$$

(Received August 27, 2015)

1116-11-374 **Saikat Biswas*** (saikat.biswas@asu.edu), School of Mathematical & Statistical Sciences, Wexler Hall, Arizona State University, Tempe, AZ 85287-1804. *Arithmetic of algebraic tori.* Preliminary report.

Let T be an algebraic tori defined over a global field K. In this talk, we first relate the adéle class group of T to the Tamagawa number of T. We then relate the arithmetic of T to that of a torsor X under T. (Received August 28, 2015)

1116-11-397 **Kevin McGown*** (kmcgown@csuchico.edu), **Enrique Treviño** and **Tim Trudgian**. *Resolving Grosswald's Conjecture on GRH.*

We examine Grosswald's conjecture on $g(p)$, the least primitive root modulo p. Assuming the Generalized Riemann Hypothesis (GRH), and building on previous work by Cohen, Oliveira e Silva and Trudgian, we resolve Grosswald's conjecture by showing that $g(p) < \sqrt{p} - 2$ for all $p > 409$. Our method also shows that under GRH we have $\hat{g}(p) < \sqrt{p} - 2$ for all $p > 2791$, where $\hat{g}(p)$ is the least prime primitive root modulo p. (Received August 30, 2015)

1116-11-435 **Lisa Joy Mueller*** (exceedinglyhappy@csu.fullerton.edu), 1981 Berkshire Drive, Fullerton, CA 92833, and **Kajal Chokshi**, **Nick Bohall**, **Jackie Emrich** and **Abdollah Khodkar**. *Edge-Magic Total Labelings.*

A graph with v vertices and e edges has an edge-magic total labeling if the vertices and edges can be labeled with the numbers 1 through $v + e$ such that the sum of any edge and its two adjacent vertices adds up to the same number. The main focus for this research project has been to explore different types of graphs to see which are edge-magic in general or for an entire spectrum of possible sums according to how many vertices and edges a given graph contains. (Received September 01, 2015)

1116-11-436 **Lisa Joy Mueller*** (exceedinglyhappy@csu.fullerton.edu), 1981 Berkshire Drive, Fullerton, CA 92833, and **Oliver Sawin**, **WonHyuk "Harry" Choi** and **Abdollah Khodkar**. *Study on Oddly Bipancyclic Graphs and Other N-Pancyclic Graphs.*

A graph of n vertices with a Hamiltonian cycle of length n is called a uniquely pancyclic cycle if it contains exactly one cycle of length $m\forall 3 \leq m \leq n$. Similarly, a uniquely bipancylic cycle is one with cycle lengths of all even cycles of length $2m\forall 2 \leq m \leq n/2$ where $n = 2k$. In this paper, we expand on these definitions to find a new type of uniquely pancyclic graphs, an uniquely oddly bipancyclic graph, which has n vertices with a Hamiltonian cycle of length $n-1$ where $n = 2k+1$; additionally, it contains exactly cycles of length $2m\forall 2 \leq m \leq (n-1)/2$. We provide the 6 non-isomorphic uniquely oddly bipancyclic graphs with 5 or less chords. We also present additional information on k-panyclic graphs, which contain exactly k cycles of length 3 through degree n. (Received September 01, 2015)

1116-11-451 **Eric Rowland*** (rowland@lacim.ca) and **Reem Yassawi**. *Congruences for diagonals of rational power series.*

In the last decade a number of results have appeared concerning congruence properties of integer sequences that arise in combinatorics, such as the Catalan and Motzkin numbers. The proofs have mostly relied on methods particular to each sequence. However, by realizing a sequence as the diagonal of a rational power series in multiple variables, we show that one can compute congruence information modulo prime powers in terms of finite automata. This method gives completely automatic proofs of known results, establishes a number of new theorems for well-known sequences, and allows us to resolve some conjectures regarding the Apéry numbers. (Received September 02, 2015)

1116-11-476 **Bianca A Thompson*** (bthompson@smith.edu) and **Xander Faber**. *A very elementary proof of a conjecture of B. and M. Shapiro for cubic rational functions.* Preliminary report.

Using essentially only algebra, we give a proof that a cubic rational function over $\mathbb{C}$ with only real critical points is equivalent to a real rational function. We also determine all fields $\mathbb{Q}_p$ over which a reasonable generalization holds. (Received September 03, 2015)

1116-11-534 **Tushar Das*** (tdas@uwlax.edu). *Extremality and measures from conformal dynamical systems.*

We present a new method of proving the Diophantine extremality of various dynamically defined measures, vastly expanding the class of measures known to be extremal. Extremal measures are locally finite Borel measures on $\mathbb{R}^d$ for which most points are not very well approximable by ones with rational coordinates. Our work generalizes and improves the celebrated theorem of Kleinbock and Margulis ('98) resolving Sprindzuk's conjecture, as well as its extension by Kleinbock, Lindenstrauss, and Weiss ('04), hereafter abbreviated KLW. The key technical idea, which has led to a plethora of new applications, is a significant weakening of KLW's sufficient conditions for extremality.

As applications we prove that Patterson–Sullivan measures of all nonplanar geometrically finite groups, and that Gibbs measures of nonplanar infinite iterated function systems (including those which do not satisfy the open set condition) and rational functions are quasi-decaying. This research is part of an ongoing collaboration with Lior Fishman (North Texas), David Simmons (York) and Mariusz Urbański (North Texas). (Received September 05, 2015)

1116-11-537 **Jingbo Liu*** (jliu02@wesleyan.edu). *Representations of integral Hermitian forms by sums of norms.*

In 1770, Lagrange proved the famous four square theorem, which says that each positive integer a can be represented as a sum of four squares. This theorem has been generalized in many directions since then. One interesting generalization is to consider the representation of integral quadratic forms of more variables by sums of squares.

We define $g_{\mathbb{Z}}(n)$ to be the smallest number of squares whose sum represents all positive definite integral quadratic forms of n variables over $\mathbb{Z}$ that are represented by some sums of squares. The existence of $g_{\mathbb{Z}}(n)$ and an explicit upper bound was given by M. Icaza in 1996. An improved upper bound was obtained later by Kim and Oh in 2005.

Similarly, for Hermitian forms over the ring of integers $\mathcal{O}_E$ of imaginary quadratic field E, we define $g_E(n)$ to be the smallest number of norms whose sum represents all positive definite integral Hermitian forms of n variables over $\mathcal{O}_E$ that are represented by some sums of norms. In this talk, we will present a generalization of Kim and Oh's method and give an explicit upper bound for $g_E(n)$ for any imaginary quadratic field E and positive integer n. (Received September 06, 2015)

1116-11-552 **Victor Y. Wang*** (vywang@mit.edu). *On Hilbert 2-class fields and 2-towers of imaginary quadratic number fields.*

Inspired by the Odlyzko root discriminant and Golod–Shafarevich p-group bounds, Martinet (1978) asked whether an imaginary quadratic number field $K/\mathbb{Q}$ must always have an infinite Hilbert 2-class field tower when the class group of K has 2-rank 4, or equivalently when the discriminant of K has 5 prime factors. No negative results are known. Benjamin (2001, 2002) and Sueyoshi (2004, 2009, 2010) systematically established infinite 2-towers for many K in question, by casework on the associated Rédei matrices. Others, notably Mouhib (2010), have also made progress, but still many cases remain open, especially when the the class group of K has small 4-rank.

Recently, Benjamin (2015) made partial progress on several of these open matrices when the class group of K has 4-rank 1 or 2. In this paper, we partially address many open cases when the 4-rank is 0 or 2, affirmatively answering some questions of Benjamin. We then investigate barriers to our methods and ask an extension question (of independent interest) in this direction. Finally, we suggest places where speculative refinements of Golod–Shafarevich or group classification methods might overcome the 'near miss' inadequacies in current methods. (Received September 06, 2015)

1116-11-570 **George E Andrews*** (gea1@psu.edu), Department of Mathematics, Pennsylvania State University, 306 McAllister Bldg., University Park, PA 16802. *Legendre Theorems for Subclasses of Overpartitions.*

This is a report on joint work with Ae Ja Yee. Legendre noted that Euler's pentagonal number theorem implies that the number of partitions of n into an even number of distinct parts almost always equals the number of partitions on n into an odd number of distinct parts (the exceptions occur when n is a pentagonal number). Building on ideas of Garvan and Jennings-Shaffer for smallest parts functions, we prove a number of Legendre type theorems for subclasses of overpartitions. For example, we call an overpartition top-heavy if the largest part appears both as an overlined parts and as a non-overlined part. We note that the number of top-heavy overpartitions of n equals the number of overpartitions of n that have no 1's. There is a surprising Legendre type theorem for top-heavy overpartitions: THEOREM. Let THE(n) denote the number of top-heavy overpartitions of n with and even number of parts minus the number of top-heavy overpartitions of n with an odd number of parts. Then if $j^2 < n < (j+1)^2, THE(n) = (-1)^n(2j-1), and if n = j^2, then THE(n) = (-1)^n(2j-2)$. Several other subclasses of overpartitions have similar theorems. (Received September 07, 2015)

1116-11-593 **Wade Hindes*** (whindes@gc.cuny.edu). *The average number of integral points in orbits.*

Over a number field K, a celebrated result of Silverman's states that if $\phi \in K(x)$ is a rational function whose second iterate is not a polynomial, the set of S-integral points in the orbit $\mathcal{O}_\phi(b) = \{\phi^n(b)\}_{n\geq 0}$ is finite for all $b \in \mathbb{P}^1(K)$. In this talk, we show that if we vary ϕ and b in a suitable family, the number of S-integral points of $\mathcal{O}_\phi(b)$ is absolutely bounded. In particular, if we fix $\phi \in K(x)$ and vary the base point $b \in \mathbb{P}^1(K)$, we show that $\#(\mathcal{O}_\phi(b) \cap \mathcal{O}_{K,S})$ is zero on average. Finally, we prove an analogous averaging result in general, assuming a standard conjecture in arithmetic geometry, and prove it unconditionally over global function fields. (Received September 08, 2015)

1116-11-657 **Alexandru Buium*** (buium@math.unm.edu), Department of Mathematics and Statistics, University of New Mexico, 1 University of New Mexico, Albuquerque, NM 87131. *The Riemannian geometry of the integers.* Preliminary report.

The spectrum of the integers can be viewed as an infinite dimensional manifold in which the directions are given by the primes and partial differentiation in the various directions is given by Fermat quotient operators. Then an arithmetic analogue of Riemannian geometry may be developed. The talk will offer a brief survey of this circle of ideas with special emphasis on open problems. (Received September 10, 2015)

1116-11-670 **Andrey Rukhin*** (andrey.rukhin@navy.mil). *On A Simple Recurrence In the Accelerated $3x+1$ Minimum-Inverse Problem.*

The aim of this talk is to discuss a simple recurrence within the *Accelerated* $3x+1$ *Minimum-Inverse Map*: we will consider the iterates of the function

$$\mathcal{F}(3k+t) = \begin{cases} 4k+1, & t=1 \\ 2k+1, & t=2 \end{cases}$$

on the set $\mathbb{Z}\backslash 3\mathbb{Z}$ where the argument $3k+t$ is an odd integer.

The talk will analyze the structural properties of rational expressions of the form

$$\frac{\sum_{0\leq u<\tau} 3^u 2^{a(u)}}{3^\tau - 2^{a(\tau)}}$$

where the exponents $\{a(u)\}_{u=0}^{\tau}$ are non-negative integers; such rationals naturally arise when analyzing the functional orbits of $\mathcal{F}$. This talk will highlight a simple recurrence on the set $\{0,1,2,3\}$ for generating the 3-adic canonical representations of such rational expressions; not only does this recurrence expedite the computations of such expressions when $\tau >> 1$, but it also reveals a simple and deep connection between all of the iterate values within a functional orbit of $\mathcal{F}$. (Received September 10, 2015)

1116-11-682 **Craig Costello**, **Alyson Deines*** (aly.deines@gmail.com), **Kristin Lauter** and **Tonghai Yang**. *Constructing Abelian Surfaces via Rosenhain Invariants.*

Algorithms to construct CM genus 2 curves have previously used the well-studied Igusa invariants. In this talk, I present an algorithm to construct CM genus 2 curves using instead the Rosenhain invariants. The Rosenhain invariants typically have much smaller height, so computing them requires less precision. In addition, the Rosenhain model for the curve can be written down directly given the Rosenhain invariants. Similarly, the parameters for a Kummer surface can be expressed directly in terms of rational functions of theta constants. CM-values of these functions are algebraic numbers, and when computed to high enough precision, LLL can recognize their minimal polynomials. Motivated by fast cryptography on Kummer surfaces, we investigate a variant of the CM method for computing cryptographically strong Rosenhain models of curves (as well as their associated Kummer surfaces) and use it to generate several examples of curves at different security levels that are suitable for use in cryptography. (Received September 10, 2015)

1116-11-729 **Hao Chen*** (chenh123@uw.edu), **Kristin Lauter** and **Katherine E Stange**. *Attacks on search-RLWE.*

We describe a new attack on search Ring learning-with-errors (RLWE) problem based on the chi-square statistical test, and give examples of Galois number fields vulnerable to our attack. We also analyze the security of cyclotomic fields under our attack using Fourier analysis on finite fields. (Received September 11, 2015)

1116-11-737 **B. Baker Swart**, **K. A. Beck**, **S. Crook**, **C. Eubanks-Turner**, **H. G. Grundman*** (grundman@brynmawr.edu), **M. Mei** and **L. Zack**. *On the Fixed Points of Certain Augmented Generalized Happy Functions.* Preliminary report.

For integers $c \geq 0$ and $b \geq 2$, we consider the augmented generalized happy function, $S_{[c,b]} : Z^+ \to Z^+$, is defined by

$$S_{[c,b]}\left(\sum_{i=0}^{n} a_i b^i\right) = c + \sum_{i=0}^{n} a_i^2,$$

where for each i, $0 \leq a_i \leq b-1$ and $a_n \neq 0$. In this talk, I will present a number of questions and some answers about the fixed points of these functions. (Received September 11, 2015)

1116-11-746 **Ruthi Hortsch*** (rhortsch@math.mit.edu), Department of Mathematics, E17-301F, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139. *Elliptic curves of bounded Faltings height.*

Previous results on counting elliptic curves over $\mathbb{Q}$ have used the naive height, which is tractable but less intrinsically defined than the Faltings height. Although the (exponential) Faltings height and naive height are related, the naive height is not bounded by a constant times the Faltings height, so these results do not apply to the Faltings height.

We count elliptic curves over $\mathbb{Q}$ using the Faltings height. Using a theorem of Silverman, we recast the problem as one of counting lattice points in a particular unbounded region with boundaries given by transcendental curves, and the difficulty then lies in understanding this region. (Received September 11, 2015)

1116-11-754 **Alon Levy*** (`alonlevy@kth.se`), Institutionen för matematik, KTH, 100 44 Stockholm, Sweden. *Questions in higher-dimensional non-archimedean dynamics.*

We develop some machinery to study self-morphisms of $\mathbb{P}^n$ and other higher-dimension varieties. At a fixed point, there's an action on tangent space, with n eigenvalues; we can decompose them into attracting, indifferent, and repelling directions. This allows local linearization in some cases, and allows generalizing some of the basic features of non-archimedean dynamics in one variable. (Received September 11, 2015)

1116-11-762 **Kirsten Eisentraeger*** (`eisentra@math.psu.edu`), Department of Mathematics, Penn State University, University Park, PA 16802. *Constructing genus 2 curves over finite fields.*

We present an algorithm for constructing genus 2 curves over a finite field with a given number of points on its Jacobian. This has important applications in cryptography, where groups of prime order are used as the basis for discrete-log based cryptosystems. For a quartic CM field K with primitive CM type, we compute the Igusa class polynomials modulo p for certain small primes p and then use the Chinese remainder theorem and a bound on the denominators to construct the class polynomials. We will also discuss some improvements to this. (Received September 11, 2015)

1116-11-798 **Jeffery E. Breeding-Allison*** (`jbreeding@fordham.edu`), Department of Mathematics, Fordham University, 441 East Fordham Road, Bronx, NY 10458. *Siegel modular forms: Representations, computing spaces, and abelian varieties.*

We discuss the theory of Siegel modular forms. We describe the associated automorphic representations and their relationship to representations of finite groups. We also discuss recent work on explicitly computing spaces of paramodular forms. These computations verify many cases of the Paramodular Conjecture of Brumer and Kramer, which relates abelian surfaces to weight two paramodular forms not in the span of Gritsenko lifts. (Received September 13, 2015)

1116-11-803 **Colin Defant*** (`cdefant@ufl.edu`), 18434 Hancock Bluff Rd., Dade City, FL 33523. *Ranges of Divisor Functions.*

For any complex number c, let $\sigma_c\colon \mathbb{N}\to\mathbb{C}$ be the divisor function defined by $\sigma_c(n)=\sum_{d|n} d^c$. Let ζ denote the Riemann zeta function. The range $\sigma_{-1}(\mathbb{N})$ of the divisor function σ_{-1} is dense in the interval $[1,\infty)$. However, although $\sigma_{-2}(\mathbb{N})\subset[1,\zeta(2))$, it turns out that $\sigma_{-2}(\mathbb{N})$ is not dense in $[1,\zeta(2))$. This leads to the following question. For which $r>1$ is $\sigma_{-r}(\mathbb{N})$ dense in $[1,\zeta(r))$? In this talk, we provide an answer to this question and discuss some recent results (which have spawned from this question) concerning the sets $\overline{\sigma_{-r}(\mathbb{N})}$. We will also explore the basic topological properties of the sets $\sigma_c(\mathbb{N})$ for general complex c. (Received September 13, 2015)

1116-11-824 **Amita Malik** and **Armin Straub*** (`straub@southalabama.edu`). *Divisibility properties of sporadic Apéry-like numbers.*

Apéry-like numbers are special integer sequences, going back to Beukers and Zagier, which are modelled after and share many of the properties of the numbers that underlie Apéry's proof of the irrationality of $\zeta(3)$. Among their remarkable properties are connections with modular forms and a number of p-adic properties, some of which remain conjectural. A result of Gessel shows that Apéry's sequence satisfies Lucas congruences. We prove corresponding congruences for all sporadic Apéry-like sequences. While, in several cases, we are able to employ approaches due to McIntosh, Samol–van Straten and Rowland–Yassawi to establish these congruences, there is one sequence in particular, often labeled (η), for which we require a finer analysis. As an application, we investigate modulo which numbers these sequences are periodic. In particular, we show that the Almkvist–Zudilin numbers are periodic modulo 8, a special property which they share with the Apéry numbers. (Received September 13, 2015)

1116-11-872 **Kevin Henriot*** (`khenriot@math.ubc.ca`), Deparment of Mathematics, The University of British Columbia, Room 121, 1984 Mathematics Road, Vancouver, BC V6T 1Z2, Canada. *Additive Diophantine equations in dense variables.*

Consider coefficients $\lambda_1,\dots,\lambda_s\in\mathbb{Z}\smallsetminus\{0\}$ such that $\lambda_1+\cdots+\lambda_s=0$, and a system of integer homogeneous polynomials $\mathbf{P}=(P_1,\dots,P_r)$ in d variables. We study translation-invariant systems of equations of the form

$$\lambda_1 P_j(\mathbf{n}_1)+\cdots+\lambda_s P_j(\mathbf{n}_s)=0 \qquad (1\le j\le r)$$

in variables $\mathbf{n}_1,\dots,\mathbf{n}_d\in[N]^d$. We show that, for essentially the same number of variables currently needed to count the number of solutions in $[N]^d$ via the circle method, there exist nontrivial solutions to the system of equations in any subset of $[N]^d$ of density at least $(\log N)^{-c(\mathbf{P},\boldsymbol{\lambda})}$. We employ the energy increment method in additive combinatorics together with a weak form of discrete restriction estimates. (Received September 14, 2015)

1116-11-904 **Jennifer M Johnson-Leung*** (jenfns@uidaho.edu) and **Brooks Roberts**. *On the modularity of hyperelliptic curves of genus 2.*

The paramodular conjecture of Brumer and Kramer states that there is a one-to-one correspondence between abelian surface of conductor N and Siegel modular forms of genus 2 and paramodular level N. In this talk, I will discuss a quadratic twisting map from the space of Siegel modular forms of paramodular level N to the space of Siegel modular forms of paramodular level Np^4 which corresponds to the quadratic twisting of the associated hyperelliptic curve. (Received September 15, 2015)

1116-11-906 **Jesse Patsolic** and **Jeremy Rouse*** (rouseja@wfu.edu). *Trinomials defining quintic number fields.*

Given a quintic number field $K/\mathbb{Q}$, we study the set of irreducible trinomials, polynomials of the form x^5+ax+b, that have a root in K. We show that there is a genus four curve C_K whose rational points are in bijection with such trinomials. This curve C_K maps to an elliptic curve defined over a number field, and using this map, we are able (in some cases) to determine all the rational points on C_K using elliptic curve Chabauty. (Received September 15, 2015)

1116-11-917 **Robert L Benedetto*** (rlbenedetto@amherst.edu). *Non-archimedean connected Julia sets with branching.*

Let K be a complete and algebraically closed non-archimedean field, such as the p-adic field $\mathbf{C}_p$. A rational function $f(z) \in K(z)$ acts on the Berkovich projective line $\mathbf{P}^1_{Ber}$ over K. The *Julia set* of f is a certain closed subset of $\mathbf{P}^1_{Ber}$ that is invariant under application of f. Until recently, the only known examples of non-archimedean Julia sets were either disconnected, homeomorphic to an interval, or just a single point. In this talk, we describe some recent constructions of functions f with non-archimedean connected Julia sets that are connected but much more complicated. As a result, these functions exhibit properties not previously seen both as regards their associated local canonical heights and their entropy.

No prior knowledge of Berkovich spaces or entropy will be assumed for this talk. (Received September 15, 2015)

1116-11-919 **John R Greene*** (jgreene@d.umn.edu), Department of Mathematics and Statistics, 140 Solon Campus Center, 1117 University Drive, Duluth, MN 55812-3000, and **Jesse Schmeig**. *A generalization of continued fractions.* Preliminary report.

Maxwell Anselm and Steven Weintraub investigated generalizations of classical continued fractions where the "numerator" 1 was replaced by an arbitrary positive integer. Here, we replace the "numerator" with an arbitrary real number $z \geq 1$. Much of what Anselm and Weintraub found still applies, but with many surprising differences. For example, when z is an integer, every rational number has a finite continued expansion. When $z = \frac{3}{2}$, again every rational number appears to have a finite expansion, but when $z = \frac{5}{3}$, some rational numbers have periodic expansions, and when $z = \frac{11}{8}$, there appear to be rationals with neither finite nor periodic expansions. For expansions of $\sqrt{n}$, Pell's equation often plays a role in the existence of periodic expansions. (Received September 15, 2015)

1116-11-921 **Jenny Fuselier**, **Ling Long*** (llong@math.lsu.edu), **Ravi Ramakrishna**, **Holly Swisher** and **Fang-Ting Tu**. *Hypergeometric functions over finite fields.*

Based on the developments of many people including Evans, Greene, Katz, McCarthy, and Rodriguez-Villegas, we study hypergeometric functions over finite fields in a manner that is parallel to the classical hypergeometric functions. Using this method, we obtain several types of hypergeometric formulas over finite fields, including some analogues of formulas by Ramanujan. (Received September 15, 2015)

1116-11-924 **Sneha Chaubey*** (chaubey2@illinois.edu), **Melinda Lanius** and **Alexandru Zaharescu**. *Pair Correlation of Fractional Parts Derived from Rational Valued Sequences.*

We investigate the pair correlation of the sequence of fractional parts of αx_n, $n \in \mathbb{N}$, where x_n is rational valued and α is a real number. As examples, we offer two classes of sequences x_n whose pair correlation behaves as that of random sequences for almost all real numbers α. First, sequences of the form $x_n = a_n/b_n$ where a_n is lacunary and b_n satisfies a certain growth condition. Second, sequences of the form $x_n = g^n/2^{\omega(n)}$ for a positive integer g which is not a power of 2 and where $\omega(n)$ denotes the number of distinct prime factors of n. We complement these results with a discussion on rational valued vector sequences. (Received September 15, 2015)

1116-11-925 **Alyson Deines**, **Jenny G. Fuselier**, **Ling Long** and **Holly Swisher*** (swisherh@math.oregonstate.edu), Oregon State University, 368 Kidder Hall, Corvallis, OR 97331, and **Fang-Ting Tu**. *Connections between hypergeometric series, hypergeometric algebraic varieties, and supercongruences.*

We investigate relationships between classical hypergeometric series, Gaussian hypergeometric series over finite fields, and truncated classical hypergeometric series through their connections with a family of hypergeometric algebraic varieties arising as higher dimensional analogues of generalized Legendre curves. (Received September 15, 2015)

1116-11-928 **Anne M. Ho*** (aho@coastal.edu). *Artin-Schreier Curves and Orbits of n-sets under* $\mathrm{PGL}_2(k)$*.* Preliminary report.

Let C be an Artin-Schreier curve of genus g over a finite field $k := \mathbb{F}_q$ of characteristic p. A number of authors have considered a weighted sum of C using the automorphism group of C over k, mostly in the cases when $p = 2$. For odd p, we consider a closely related weighted sum for C over finite fields of all characteristics p. Each Artin-Schreier curve C has an associated rational equation $y^p - y = u(x)$ for $u(x) \in k(x)$ with a set of n poles. In the process of determining the weighted sums, we consider the action of $\mathrm{PGL}_2(k)$ on these rational equations and their poles. In particular, the number of orbits of these n-sets is known if the field of definition is k (López and Nart), and we find the number of orbits for appropriate field extensions of k in our cases. (Received September 15, 2015)

1116-11-936 **Katherine E Stange*** (kstange@math.colorado.edu). *Visualising the arithmetic of imaginary quadratic fields.*

Let K be an imaginary quadratic field with ring of integers $\mathcal{O}_K$. The Schmidt arrangement of K is the orbit of the extended real line in the extended complex plane under the Mobius transformation action of the Bianchi group $\mathrm{PSL}(2, \mathcal{O}_K)$. The arrangement takes the form of a dense collection of intricately nested circles. Aspects of the number theory of $\mathcal{O}_K$ can be characterised by properties of this picture: for example, the arrangement is connected if and only if $\mathcal{O}_K$ is Euclidean. I'll explore this structure and its connection to Apollonian circle packings. Specifically, the Schmidt arrangement for the Gaussian integers is a disjoint union of all primitive integral Apollonian circle packings. Generalizing this relationship to all imaginary quadratic K, the geometry naturally defines some new circle packings and thin groups of arithmetic interest. (Received September 15, 2015)

1116-11-941 **Sneha Chaubey**, **Elena Fuchs**, **Robert Hines** and **Katherine E Stange*** (kstange@math.colorado.edu). *The dynamics of Apollonian circle packings.* Preliminary report.

Reduction to the root quadruple of an Apollonian circle packing can be considered a piece of Asmus Schmidt's continued fraction algorithm for Gaussian integers. We study the dynamics of this process, in analogy to the dynamical system $T : [0, 1] \to [0, 1]$ given by $x \mapsto \{1/x\}$ related to classical continued fractions. (Received September 15, 2015)

1116-11-965 **William Arthur Stein*** (wstein@uw.edu), Seattle, WA 98122. *Using SageMath for Number Theory and Cryptography.*

I will talk about how the SageMath (http://sagemath.org) software is incredibly useful for number theory and cryptography research. (Received September 15, 2015)

1116-11-1025 **Mckenzie West*** (mckenzierwest@gmail.com). *The Brauer-Manin obstruction and surfaces.*

The existence of rational points is a question applicable to a wide range of mathematical disciplines. There are many examples of surfaces that have local points at every prime yet have no global points. The Brauer-Manin obstruction can provide an explanation of this phenomenon. I will begin by defining the necessary details of the Brauer-Manin obstruction. Then I will present my results on the Brauer-Manin obstruction for a family of cubic surfaces which was first discussed by Birch and Swinnerton-Dyer in the 1970s. (Received September 16, 2015)

1116-11-1030 **Sungjin Kim*** (707107@gmail.com), 3442 Jasmine Ave APT 5, Los Angeles, CA 90034. *Average Results on the Order of a modulo p.* Preliminary report.

Let $a > 1$ be an integer. Denote by $l_a(p)$ the multiplicative order of a modulo primes p. We prove that if $\frac{x}{\log x \log\log x} = o(y)$, then

$$\frac{1}{y}\sum_{a\le y}\sum_{p\le x}\frac{1}{l_a(p)} = \log x + C\log\log x + O\left(\frac{x}{y\log\log x}\right)$$

which is an improvement over a theorem by Felix [**?**].

Additionally, we also prove two other average results

If $\log^2 x = o(\psi(x))$ and $x^{1-\delta}\log^3 x = o(y)$, then

$$\frac{1}{y}\sum_{a<y}\sum_{\substack{p<x\\ l_a(p)>\frac{x}{\psi(x)}}} 1 = \pi(x) + O\left(\frac{x\log x}{\psi(x)}\right) + O\left(\frac{x^{2-\delta}\log^2 x}{y}\right).$$

Furthermore, if $x^{1-\delta}\log^3 x = o(y)$, then

$$\frac{1}{y}\sum_{a<y}\sum_{\substack{p<x\\ p\nmid a}} l_a(p) = c\mathrm{Li}(x^2) + O\left(\frac{x^2}{\log^A x}\right) + O\left(\frac{x^{3-\delta}\log^2 x}{y}\right)$$

where

$$c = \prod_p \left(1 - \frac{p}{p^3-1}\right).$$

(Received September 16, 2015)

1116-11-1067 **Jaclyn A Lang*** (jaclynlang@math.ucla.edu). *Images of Galois representations associated to Hida families.*

We explain a sense in which Galois representations associated to non-CM Hida families have large images. This is analogous to results of Ribet and Momose for Galois representations associated to classical modular forms. In particular, we show how extra twists of the Hida family decreases the size of the image. (Received September 16, 2015)

1116-11-1111 **Anastassia Etropolski*** (aetropo@emory.edu), Dept. Of Math & CS, Emory University, 400 Dowman Dr., W401, Atlanta, GA 30322. *Class numbers of algebraic function fields, or Jacobians of curves over finite fields.*

In 1975, Leitzel, Madan, and Queen gave a classification of algebraic function fields with class number one. It was discovered recently that this classification was not complete, but with the addition of a genus 4 curve over $\mathbf{F}_2$ the classification is now complete. Since the original paper, work has been done on a complete classification of function fields with class number 2 and 3. The class number 2 problem has been solved by le Brigand using a combination of algebraic and geometric techniques, while the class number 3 problem has been solved in the case of function fields over $\mathbf{F}_q$ for q at least 3 as well as all quadratic function fields (i.e. Jacobians of hyperelliptic curves) by Picone using purely algebraic methods. I use a combination of these techniques to study the class number 3 case for higher genus curves over $\mathbf{F}_2$ as well as consider what happens for higher class numbers. (Received September 17, 2015)

1116-11-1174 **Heidi E Goodson*** (goods052@umn.edu). *Hypergeometric Point Counts for Dwork K3-Surfaces.*

In 1995, Koike showed that the trace of Frobenius for elliptic curves in the Legendre family can be expressed in terms of Greene's finite field hypergeometric series. Further connections between hypergeometric series and algebraic varieties have been studied since then, though the focus has largely been on elliptic curves and Calabi-Yau threefolds. We extend this work by showing that the number of points on Dwork K3-Surfaces over finite fields can be expressed in terms of Greene's finite field hypergeometric series. (Received September 17, 2015)

1116-11-1181 **Rafe Jones*** (rfjones@carleton.edu) and **Alon Levy**. *Eventually stable rational functions.*

Let K be a field, f a rational function with coefficients in K, and $\alpha \in K$. We say that the pair (f,α) is eventually stable over K if the the number of irreducible factors of the numerator of $f^n(x)-\alpha$ is bounded as n grows, where $f^n(x)$ denotes the nth iterate of f. This is a natural finiteness condition that should hold in great generality: we conjecture that a given pair (f,α) is eventually stable unless α is periodic under f. We summarize what little is known in the direction of this conjecture, and in the process give several equivalent conditions for eventual stability. We also give a new result showing that pairs (f,α) satisfying a weak version of the Eisenstein criterion are eventually stable. (Received September 17, 2015)

1116-11-1194 **Kristin Estella Lauter*** (klauter@microsoft.com). *How to Keep your Genome Secret.*

Over the last 10 years, the cost of sequencing the human genome has come down to around $1,000 per person. Human genomic data is a gold-mine of information, potentially unlocking the secrets to human health and longevity. As a society, we face ethical and privacy questions related to how to handle human genomic data. Should it be aggregated and made available for medical research? What are the risks to individual's privacy?

This talk will describe a mathematical solution for securely handling computation on genomic data, and highlight the results of a recent international contest in this area. The solution uses “Homomorphic Encryption”, based on hard problems in number theory related to lattices. This application highlights the importance of a new class of hard problems in number theory to be solved. (Received September 17, 2015)

1116-11-1203 **Tim Huber*** (timothy.huber@utrgv.edu) and **Daniel Schultz**. *Generalized Reciprocal Identities.*

Included in Ramanujan's Notebooks are two reciprocal identities. The first identity connects the Rogers-Ramanujan continued fraction with an eta quotient. The second identity is a level thirteen analogue. The Gölnitz-Gordon continued fraction satisfies a similar equation. These are special cases of a more general class of relations between eta quotients and modular functions defined by product generalizations of the Rogers-Ramanujan continued fraction. Each identity is a relation between generators for the field of functions invariant under a certain congruence subgroup. The degree, form, and symmetry of the identities is determined from behavior at cusps for the congruence subgroup whose field of functions the parameters generate. The reciprocal identities encode information about fundamental units and class numbers for real quadratic fields. (Received September 17, 2015)

1116-11-1209 **Dylan Airey*** (dylan.airey@utexas.edu) and **Bill Mance**. *Unexpected distribution phenomenon resulting from Cantor series expansions.*

We explore in depth the number theoretic and statistical properties of certain sets of numbers arising from their Cantor series expansions. As a direct consequence of our main theorem we deduce numerous new results as well as strengthen the known ones. (Received September 17, 2015)

1116-11-1210 **James Stankewicz***, Department of Mathematics, Howard House, Queen's Avenue, Bristol, BS8 1SN, United Kingdom. *Endomorphisms of Abelian Surfaces, Shimura curves, and counterexamples to the Hasse principle.* Preliminary report.

We give an infinite collection of indefinite quaternion algebras B such that B cannot be the geometric endomorphism $\mathbf{Q}$-algebra of any abelian surface A over the rational numbers.

We do so using Shimura curves, their quotients, and their arithmetic properties. More specifically, there is a curve X^D/w_D which we show has no rational points for a certain set of D where D is the discriminant of the quaternion algebra B, and so there is no abelian surface of the form above. To show there is no rational point, we show that all quadratic twists of the Shimura curve X^D formed using the involution w_D have no rational points by the descent obstruction. To use the descent obstruction, we use the structure of X^D as a Shimura variety itself to obtain étale covers.

If time remains we will discuss some analytic estimates for the family given here. (Received September 17, 2015)

1116-11-1222 **Joseph Hundley** (jahundle@buffalo.edu), Department of Mathematics, 244 Mathematics Building, University at Buffalo, Buffalo, NY 14260-2900, and **Qiao Zhang*** (q.zhang@tcu.edu), Department of Mathematics, Texas Christian University, Fort Worth, TX 76129. *Fourier Coefficients of Theta Functions at Cusps other than Infinity.*

In this paper we consider theta functions twisted by certain Dirichlet characters, and derive explicit formulas for their Fourier coefficients at cusps other than infinity. The method is based on expressing these theta functions in terms of explicit elements of the adelic Schwartz space and studying the action of the adelic metaplectic group on them. The formulae obtained are quite amenable to effective computations, in contrast to those available in the previous work of Goldfeld, Hundley and Lee on the integral weight case. In particular, we prove a conjecture of Goldfeld and Gunnells on twisted theta functions. (Received September 18, 2015)

1116-11-1231 **Alan Koch*** (akoch@agnesscott.edu), 141 E. College Ave., Decatur, GA 30030. *Primitively generated Hopf orders in characteristic p.*

Let R be a complete discrete valuation ring with field of fractions K, $\operatorname{char} K = p > 0$. Let H be a commutative, cocommutative K-Hopf algebra of p-power rank which is generated as a K-algebra by primitive elements. We construct all of the R-Hopf orders of H in K. Each Hopf order corresponds to a solution to a single matrix equation. We give some explicit examples of Hopf orders in the p^2 case. (Received September 18, 2015)

1116-11-1279 **Lubjana Beshaj*** (beshaj@oakland.edu), 385 MSC, Oakland University, Rochester, MI 48309. *Integral minimal models for binary forms.*

The reduction theory of binary quadratics is well understood. In this talk, we show how that can be extended to higher degree binary forms via the Julia quadratic. This leads to an algorithm of determining equations of superelliptic curves with minimal height. (Received September 18, 2015)

1116-11-1283 **Rachel Jade Domagalski*** (domag1rj@cmich.edu), MI, and **Dana Lacey** (dmlacey@noctrl.edu), **James E. Pangelinan III** (jamespangelinan3@gmail.com) and **Marly Cormar** (marlycormar@ufl.edu). *On the Catenary Degree of Numerical Monoids Generated by a Generalized Arithmetic Sequence.*

We give a closed form for the catenary degree of any element in a numerical monoid generated by a generalized arithmetic sequence in embedding dimension three. While it is known in general that the largest and smallest nonzero catenary degrees are attained at Betti elements, the current literature contains no information about the other realizable catenary degrees. By classifying each element in terms of its Betti element divisors, we identify all the catenary degrees achieved and where they occur. In addition, our research provides the dissonance number and the period value, even though previous works have shown only that the catenary degree is periodic using a non-existential proof. (Received September 18, 2015)

1116-11-1298 **F. G. Garvan*** (fgarvan@ufl.edu). *Extending Ramanujan's Dyson rank function identity to all primes greater than 3.* Preliminary report.

Let $R(z,q)$ be the two-variable generating function for Dyson's rank function. In his lost notebook Ramanujan gives the 5-dissection of $R(\zeta_p,q)$ where ζ_p is a primitive p-th root of unity and $p=5$. This result is related to Dyson's famous rank conjecture which was proved by Atkin and Swinnerton-Dyer. We show that there is an analogous result for the p-dissection of $R(\zeta_p,q)$ when p is any prime greater than 3. This extends previous work of Bringmann and Ono, and Ahlgren and Treneer. (Received September 18, 2015)

1116-11-1345 **Ping Ngai Chung*** (briancpn@math.uchicago.edu), **Craig Costello** and **Benjamin Smith**. *Fast, uniform, and compact scalar multiplication for elliptic curves and genus 2 Jacobians with applications to signature schemes.* Preliminary report.

We introduce a method to compute multi-dimensional scalar multiplication on a given one or two dimensional abelian variety using pseudo-multiplication algorithms on its Kummer variety (the abelian variety modulo the inverse map). The latter is typically more efficient and is exception-free, both desirable for cryptographic protocols for speed and security reasons, yet the former is required for some cryptographic protocols, for instance digital signatures. As an application, we introduce an efficient, uniform and compact digital signature scheme on genus 2 curves, using the efficient pseudo-addition formulae on its Kummer surface first introduced to cryptography by Pierrick Gaudry in 2007. (Received September 18, 2015)

1116-11-1349 **Michelle A Manes*** (mmanes@math.hawaii.edu), University of Hawaii Dept. of Mathematics, 2565 McCarthy Mall, Keller 401A, Honolulu, HI 96822, and **Katherine E Stange**. *Characterizing cyclic quartic extensions by automorphism polynomials.* Preliminary report.

Following Morton's work with cyclic cubic extensions, we use the dynamics of a family of cubic polynomials to characterize the cyclic quartic extensions of a field K, provided that K has characteristic different from 2 and 3. (Received September 18, 2015)

1116-11-1391 **Abbey Bourdon*** (abourdon@uga.edu) and **Paul Pollack**. *Torsion in Odd Degree.*

Let E be an elliptic curve defined over a number field F. It is a classical theorem of Mordell and Weil that the collection of points of E with coordinates in F form a finitely generated abelian group. We seek to understand the subgroup of points with finite order. In particular, given a positive integer d, we would like to know precisely which abelian groups arise as the torsion subgroup of an elliptic curve defined over a number field of degree d, and we would like to know how the size of the torsion subgroup grows as d increases. I will discuss recent progress on these problems for the special class of elliptic curves with complex multiplication under the assumption that d is odd. (Received September 19, 2015)

1116-11-1392 **Jason Bell**, **Dragos Ghioca** and **Thomas Tucker*** (tjtucker@gmail.com), Department of Mathematics, University of Rochester, Rochester, NY 14627. *Uniform boundedness for positive dimensional varieties.*

Let X be a variety over a number field K and let $f : X \to X$ be a morphism. Morton, Silverman, Zieve, Pezda, Hutz and others have proved that there are bounds on the number of f-periodic points in $X(K)$ that depend only on X, K, and the size of the residue field for a prime of good reduction for f. If one looks more generally at periodic subvarieties of arbitrary dimension, the situation becomes quite different. We present some partial results, joint with Bell and Ghioca, and present some simple questions that we cannot yet answer. (Received September 19, 2015)

1116-11-1397 **Nathan Salazar***, nathan-salazar@uiowa.edu. *A hybrid bound for sums of Fourier coefficients of cusp forms against $e(\alpha n^\beta)$.*

In this talk we examine the sum $\sum \lambda_f(n)e(\alpha n^\beta)\phi(n/X)$, where λ_f are the coefficients of a Maass cusp form f, ϕ is a smooth function of compact support and $\alpha, \beta \in \mathbb{R}$. The bounds we obtain are interesting in that they are explicitly related to the Laplace eigenvalue $1/4 + k^2$ of f. Moreover, we obtain non-trivial bounds for values of $\beta > 1$, which appears to be new. (Received September 19, 2015)

1116-11-1407 **Kim Laine*** (kim.laine@gmail.com) and **Kristin Lauter** (klauter@microsoft.com). *Key Recovery for LWE in Polynomial Time.*

The Learning With Errors problem (LWE) has attracted a lot of interest in recent years as a building block of homomorphic cryptosystems. To optimize the performance of these cryptosystems, it is essential to understand in great detail how the hardness of LWE depends on its parameters. This boils down to analyzing the performance of modern lattice reduction algorithms, which is a difficult task.

Our point of view is different. We look instead at what can be broken using a polynomial time lattice reduction algorithm (LLL). We show that the LWE secret can always be recovered in polynomial time when one of the parameters (the modulus) is large enough. This will be demonstrated with several enlightening examples. (Received September 19, 2015)

1116-11-1427 **James D Martin*** (jamesmartin3@my.unt.edu). *Rankin's Method and Hermitian Jacobi Forms.* Preliminary report.

In this talk I will report on joint work with Jayantha Senadheera. We consider the Petersson scalar product $\langle f, [g, E_{k_2,m_2}]_\nu \rangle$ of a Hermitian Jacobi cusp form f of weight k and index m with the Rankin-Cohen bracket $[g, E_{k_2,m_2}]_\nu$ of a Hermitian Jacobi Form of weight k_1 and index m_1 with the Hermitian Jacobi-Eisenstein series E_{k_2,m_2} of weight k_2 and index m_2, where $k = k_1 + k_2 + 2\nu$ and $m = m_1 + m_2$. (Received September 19, 2015)

1116-11-1431 **Douglas Ulmer*** (douglas.ulmer@math.gatech.edu). *Explicit high ranks in higher genus.*

For every genus $g > 0$ and many primes p, we write down a curve over $\mathbf{F}_p(t)$ with Jacobian of large rank and with explicit divisors filling out a finite index subgroup of the Mordell-Weil group. The height pairings among the explicit divisors have a very nice group-theoretic description, and we have an analytic class number formula of the form:

(order of Tate-Shafarevich group) = (square of index of the explicit subgroup in the full Mordell-Weil group).

(Received September 19, 2015)

1116-11-1441 **Jennifer S. Balakrishnan*** (balakrishnan@maths.ox.ac.uk). *p-adic heights on elliptic curves over number fields.*

p-adic heights play a key role in the p-adic Birch and Swinnerton-Dyer conjecture. They also figure prominently in parts of Kim's nonabelian Chabauty program and can be used to explicitly find rational points on curves. We give an overview of methods to compute p-adic heights on elliptic curves over number fields and discuss some of these applications. Along the way, we highlight some computational challenges that arise. (Received September 19, 2015)

1116-11-1455 **Michael J. Jacobson Jr.**, **Monireh Rezai Rad** and **Renate Scheidler*** (rscheidl@ucalgary.ca), Department of Mathematics and Statistics, 2500 University Drive NW, Calgary, Alberta T2N3Z4, Canada. *Comparison of scalar multiplication on real hyperelliptic curves.*

Real hyperelliptic curves admit two structures suitable for cryptography — the Jacobian (a finite abelian group) and the infrastructure (an "almost" abelian group). Mireles Morales described precisely the relationship between these two structures, and made the assertion that when implemented with balanced divisor arithmetic, the Jacobian generically yields more efficient arithmetic than the infrastructure for cryptographic applications. We confirm that this assertion holds for genus two curves, through rigorous analysis and the first detailed numerical performance comparisons, showing that cryptographic key agreement can be performed in the Jacobian without any extra operations beyond those required for basic scalar multiplication. However, for genus three curves, there is reason to believe that infrastructure scalar multiplication may slightly outperform scalar multiplication using balanced divisors; numerical experiments to that effect are currently work in progress as part of the second author's doctoral thesis. (Received September 19, 2015)

1116-11-1474 **Craig Larson*** (clarson@vcu.edu), 4106 Grace E. Harris Hall, 1015 Floyd Avenue, Richmond, VA. *Automated Conjecturing for Number Theory.*

We discuss conjectures of a open-source program designed to assist mathematical researchers in their investigations.

Some of these conjectures give bounds on $|\pi(x) - Li(x)|$ that seem to be stronger than von Koch's $\sqrt(x)\log(x)$ bound, bounds for the number of representations of an even integer as a sum of two primes, and upper bounds for the Merten's function.

Our hope is that the program makes novel and unexplored connections between number theoretic invariants, possibly overlooked by researchers, and inspires new investigations. (Received September 20, 2015)

1116-11-1514 **Andrew R. Booker** and **Andrew V. Sutherland*** (drew@math.mit.edu), Department of Mathematics, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139, and **John Voight** and **Dan Yasaki**. *A catalog of genus 2 curves over Q.* Preliminary report.

Cremona's tables of elliptic curves over $\mathbb{Q}$ are a well known and widely used resource that is now incorporated into the L-Functions and Modular Forms Database (LMFDB). The LMFDB was recently expanded to include a catalog of genus 2 curves over $\mathbb{Q}$, along with a wealth of associated data, including geometric and arithmetic invariants of the curve and its Jacobian, information about rational points, and, perhaps most significantly, its L-function. I will give an overview of this catalog, including details of its construction and a tour of some of its features. (Received September 20, 2015)

1116-11-1530 **Kenneth A. Ribet*** (ribet@berkeley.edu). *Kernels of Eisenstein ideals.*

We present joint work with Hwajong Yoo on the structure of $J[m]$ where J is the Jacobian of the modular curve $X_0(N)$ and m is an "Eisenstein prime," i.e., a maximal ideal of the full Hecke ring associated to J for which the corresponding two-dimensional Galois represenation is reducible.

We concentrate on the case where N is square free. The situation where N is prime was analyzed by B. Mazur in 1977; he proved, in particular, that $J[m]$ is 2-dimensional. When N is no longer prime (but still square free), the dimension of $J[m]$ can be computed in most cases and can be predicted conjecturally in many remaining cases. It is striking that the dimension of $J[m]$ is no longer necessarily 2. (Received September 20, 2015)

1116-11-1550 **Charles Doran**, **Tyler Kelly**, **Adriana Salerno*** (asalerno@bates.edu), **Steven Sperber**, **John Voight** and **Ursula Whitcher**. *Arithmetic Mirror Symmetry of K3 Surfaces and Hypergeometric Functions.*

Mirror symmetry predicts surprising geometric correspondences between distinct families of algebraic varieties. In some cases, these correspondences have arithmetic consequences. Among the arithmetic correspondences predicted by mirror symmetry are correspondences between point counts. In particular, we explore closed formulas for the point counts for our alternate mirror families of K3 surfaces, their relation to their Picard-Fuchs equations and hypergeometric functions. (Received September 20, 2015)

1116-11-1570 **Lola Thompson*** (lola.thompson@oberlin.edu). *On the degrees of divisors of $x^n - 1$.*

We discuss what is known about the following questions concerning the degrees of divisors of $x^n - 1$ in $\mathbb{Z}[x]$, as n ranges over the natural numbers:

1. How often does $x^n - 1$ have **at least one** divisor of every degree $1 \leq m \leq n$?
2. How often does $x^n - 1$ have **at most one** divisor of every degree $1 \leq m \leq n$?
3. How often does $x^n - 1$ have **exactly one** divisor of every degree $1 \leq m \leq n$?
4. For a given m, how often does $x^n - 1$ have a divisor of degree m?

This talk is based on several papers, including joint work with Paul Pollack, Carl Pomerance and Andreas Weingartner. (Received September 20, 2015)

1116-11-1668 **Spencer Hamblen*** (shamblen@mcdaniel.edu) and **Rafe Jones**. *Deeply Ramified Iterated Extensions.*

We address a question of Aitken, Hajir, and Maire about whether number fields generated by iterates of a polynomial of degree d must ramify deeply at places dividing d. This is in some sense a dynamical analogue of the Fontaine-Mazur conjecture. We study the higher ramification groups of such extensions using a Newton polygon method of Lubin; this method allows us to show that for certain integers c, the splitting field of all iterates of $x^2 + c$ is deeply ramified at 2. (Received September 21, 2015)

1116-11-1702 **Michael Griffin**, **Marie Jameson*** (mjameson@utk.edu) and **Sarah Trebat-Leder**. *On p-adic modular forms and the Bloch-Okounkov theorem.*

Bloch-Okounkov studied certain functions on partitions f called shifted symmetric polynomials. They showed that certain q-series arising from these functions (the so-called *q-brackets* $\langle f\rangle_q$) are quasimodular forms. We revisit a family of such functions, denoted Q_k, and study the p-adic properties of their q-brackets. To do this, we define regularized versions $Q_k^{(p)}$ for primes p. We also use Jacobi forms to show that the $\left\langle Q_k^{(p)}\right\rangle_q$ are quasimodular and find explicit expressions for them in terms of the $\langle Q_k\rangle_q$. (Received September 21, 2015)

1116-11-1724 **Matthew A. Papanikolas*** (map@math.tamu.edu), Department of Mathematics, Texas A&M University, 3368 TAMU, College Station, TX 77843. *Hyperderivatives and difference equations in function field arithmetic.*

Function fields of one variable over finite fields have been studied extensively as analogues of number fields. In this setting Drinfeld modules and Anderson t-modules provide a rich collection of objects that play the roles of elliptic curves and abelian varieties, including theories of periods, Galois representations, and L-series. In this talk we will review connections among periods and Frobenius difference equations and discuss new results on tensor powers of the Carlitz module that relate hyperderivatives of Anderson-Thakur polynomials to coordinates of periods. (Received September 21, 2015)

1116-11-1741 **Kyle J Czarnecki*** (kyle-czarnecki@uiowa.edu), 14 MacLean Hall, Department of Mathematics, University of Iowa, Iowa City, IA 52242-1419. *Resonance Sums for Rankin-Selberg Products of $SL_m(\mathbb{Z})$ Maass Cusp Forms.*

Let f and g be Maass cusp forms for $SL_m(\mathbb{Z})$ and $SL_{m'}(\mathbb{Z})$, respectively, with $2 \le m \le m'$. Let $\lambda_{f\times g}(n)$ be the normalized coefficients of $L(s, f\times g)$, the Rankin-Selberg L-function for f and g. We derive the asymptotics of a Voronoi-type summation formula for $\lambda_{f\times g}(n)$. As an application estimates are obtained for the smoothly weighted average of $\lambda_{f\times g}(n)$ against $e(\alpha n^\beta)$. When $\beta = \frac{1}{mm'}$ and α is close or equal to $\pm mm'q^{\frac{1}{mm'}}$ for a positive integer q, the average has a main term of size $|\lambda_{\tilde{f}\times\tilde{g}}(q)|X^{\frac{1}{2mm'}+\frac{1}{2}}$. Otherwise, when $0 < \beta < \frac{1}{mm'}$, it is shown that this average decays rapidly. This phenomenon is due to the oscillatory nature of the coefficients $\lambda_{f\times g}(n)$. (Received September 21, 2015)

1116-11-1763 **Rachel Davis*** (davis705@math.purdue.edu), West Lafayette, IN 47907, and **Edray Herber Goins**. *The arithmetic of a non-abelian cover of an elliptic curve.* Preliminary report.

Let E be an elliptic curve over $\mathbb{Q}$. Let $f : C \to E$ be an étale cover, ramified only above one point. The pair (C, f) is called an origami. The name comes from a picture that I will show during the talk. We study the pre-images of a rational point on E under such a map f. We will be especially interested in maps with non-abelian deck transformation group. We will also study Galois representations obtained by adjoining the coordinates of the pre-image set to $\mathbb{Q}$. (Received September 21, 2015)

1116-11-1777 **Colin Weir*** (colin.weir@cse-cst.gc.ca). *Computing the p-torsion of Jacobians in characteristic p.*

Over an algebraically closed field an elliptic curve in characteristic p is either ordinary or supersingular depending on whether or not it contains a point of order p. Moreover, this fully classifies the possible p-torsion of elliptic curves as only these 2 isomorphism types can occur. In general, there are 2^g possible isomorphism types for the p-torsion of an abelian variety of dimension g. We will present an algorithm to compute the isomorphism type of the p-torsion of the Jacobian of a curve of genus g in characteristic p, and present some interesting findings on the possible p-torsion types arising from hyperelliptic curves. (Received September 21, 2015)

1116-11-1804 **T. Alden Gassert*** (thomas.gassert@colorado.edu), Department of Mathematics, Campus Box 395, Boulder, CO 80309. *Discriminants of iterated quadratic extensions.*

Let $f(x) = x^2 + c \in \mathbb{Z}[x]$, and let K be a number field generated by a root of $f^n(x)$ (assuming $f^n(x)$ is irreducible). The purpose of this talk is to determine the multiplicities of primes dividing the discriminant of K. As a consequence of our result, we identify a sufficient condition for K to be monogenic. Namely, K is monogenic if $f(0)$, $f^2(0)$, $f^3(0), \ldots, f^n(0)$ are all square-free. (Received September 21, 2015)

1116-11-1835 **Lenny Jones** and **Tristan Phillips***, Department of Mathematics, Shippensburg University, Shippensburg, PA 17257, Shippensburg, PA 17257. *Primefree Shifted Lucas Sequences of the Second Kind.* Preliminary report.

We say a sequence $\mathcal{S} = (s_n)_{n\geq 0}$ is *primefree* if $|s_n|$ is not prime for all $n \geq 0$ and, to rule out trivial situations, we require that no single prime divides all terms of $\mathcal{S}$. Recently, the first author showed that, for any integer a, there exist infinitely many integers k such that both of the shifted sequences $\mathcal{U}_a \pm k$ are simultaneously primefree, where $\mathcal{U}_a = (u_n)_{n\geq 0}$ is the Lucas sequence of the first kind defined by

$$u_0 = 0, \quad u_1 = 1, \quad \text{and} \quad u_n = au_{n-1} + u_{n-2}, \quad \text{for } n \geq 2.$$

In this talk, we establish an analogous theorem for Lucas sequences $\mathcal{V}_a = (v_n)_{n\geq 0}$ of the second kind, defined by

$$v_0 = 2, \quad v_1 = a, \quad \text{and} \quad v_n = av_{n-1} + v_{n-2}, \quad \text{for } n \geq 2.$$

This result provides additional evidence in support of a conjecture of Ismailescu and Shim. (Received September 21, 2015)

1116-11-1836 **Joshua Harrington** and **Lenny Jones***, Department of Mathematics, Shippensburg University, Shippensburg, PA 17257, and **Alicia Lamarche**. *The Average Order of an Element of the Symmetric Group.*

Let μ_n denote the average order of an element of the symmetric group on n letters. In 1968, Erdős and Turán conjectured that

$$\log(\mu_n) = O\left(\sqrt{n/\log(n)}\right).$$

Schmutz proved this conjecture in 1989. His proof, which is nontrivial and relies on very technical results from partition theory, can be used to determine the smallest positive constant C such that

$$\mu_n \leq n!^C \quad \text{for all } n \geq 1.$$

We determine C using a technique that requires only elementary methods. (Received September 21, 2015)

1116-11-1846 **Sharon M. Frechette*** (sfrechet@holycross.edu), **Matthew Papanikolas**, **Jonathan Root** and **M. Valentina Vega**. *Gaussian Hypergeometric Series and Counting Points on Families of Hypersurfaces.* Preliminary report.

Hypergeometric functions over finite fields $\mathbb{F}_p$, also known as *Gaussian hypergeometric series*, were introduced by Greene in the 1980's as character sum analogues to the classical hypergeometric series first studied by Gauss. These functions possess many interesting properties analogous to the transformation laws and other formulas satisfied by their classical counterparts. In recent years, researchers have demonstrated connections between special values of Gaussian hypergeometric series and the likes of Fourier coefficients of modular forms, periods of elliptic curves, and the number of $\mathbb{F}_p$-points on algebraic varieties. We further explore this number-theoretic significance through new examples, including higher-dimensional analogues of the Hesse family of elliptic curves. In particular, we show how to express the number of $\mathbb{F}_p$-points on these hypersurfaces in terms of special values of Gaussian hypergeometric series. (Received September 21, 2015)

1116-11-1893 **Katherine Thompson*** (kthompson0721@gmail.com). *The sum of four squares over real quadratic number fields.*

That the sum of four squares represents all positive integers is a well-known and celebrated result–there even is a formula for the number of represented (often presented in undergraduate number theory classes). What happens in the number field analogue? Using Siegel's theory of local densities and Hilbert modular forms, we will answer this question in the case of real quadratic number fields. This includes providing explicit (and, on occasion, sharp) bounds on the Eisenstein coefficients of the associated theta series. (Received September 21, 2015)

1116-11-1932 **Amanda Folsom**, **Sharon Garthwaite**, **Soon-Yi Kang**, **Holly Swisher** and **Stephanie Treneer*** (stephanie.treneer@wwu.edu). *Quantum mock modular forms arising from eta-theta functions.*

We investigate mock modular forms whose shadows are theta functions that are also eta-quotients (hereafter called eta-theta functions). Recently Lemke Oliver classified all weight 1/2 and 3/2 eta-theta functions. Using the methods from Zwegers thesis, we catalog mock modular forms whose shadows are one of the six weight 3/2 eta-theta functions and which are further related to weight 1/2 eta-theta functions. We then prove quantum modularity properties for one canonical choice of mock modular form corresponding to each of the six shadows. (Received September 21, 2015)

1116-11-1935 **Patrick Ingram*** (pingram@rams.colostate.edu). *Canonical heights and preperiodic points for a special class of polynomials.* Preliminary report.

To each (non-linear) polynomial defined of a number field is a canonical height function, which vanishes precisely at points with finite orbit under that map. This function has a smallest positive value, and it is natural to ask for some lower bound on this quantity in terms of some data about the polynomial. We present some results in this direction for certain families generalizing or related to the unicritical family $z^d + c$. (Received September 21, 2015)

1116-11-2024 **Michelle R DeDeo*** (mdedeo@unf.edu), 1 UNF Dr., Jacksonville, FL 32259. *Tighter bounds on the Energy of Ramanujan graphs.*

Whenever a new graph energy is introduced, one of the first tasks is to find bounds for the energy. Generalized bounds have been reported for practically all of the types of graph energies, but these bounds are non-specific. What authors have yet to accomplish is to determine strict graph energy bounds for several important classes of graphs such as Ramanujan graphs. This talk is an extension of a talk presented last year. It is meant to share additional results regarding the energy of Ramanujan graphs end explore their meaning. (Received September 21, 2015)

1116-11-2066 **Jennifer Berg*** (jberg@math.utexas.edu). *Integral Brauer-Manin obstruction for generalized affine Châtelet surfaces.* Preliminary report.

In recent years, there has been a growing interest in obstructions to the existence of integral points on affine varieties. For example, given an extension K/k of number fields of degree n, one might ask when can values of a polynomial P(t) over k be represented by norms of elements of K? In 2012, Colliot-Thélène and Harari asked for the integral Hasse principle and strong approximation for the variety defined by $x^2 + ay^2 = P(t)$, where P(t) is separable of degree at least 3. They observed that known techniques did not allow for progress in this direction at the time. In this talk, we consider a particular family of varieties of this form, for which we construct explicit representatives of the classes in the Brauer group of X that can be used to compute the integral Brauer-Manin obstruction. (Received September 21, 2015)

1116-11-2076 **Pin-Hung Kao*** (kao1p@cmich.edu), Central Michigan University, Department of Mathematics, Pearce Hall 214, Mt Pleasant, MI 48859. *A modified Selberg's lower bound sieve and its applications.*

We study Selberg's $\Lambda^{-}\Lambda^{2}$ lower bound sieve. In particular, we incorporate the recent works by C. Franze and S. Blight with Laborde weights. We apply this modified lower bound sieve to products of linear form $\prod_{i=1}^{r}(a_i n + b_i)$, where a_i and b_i are integers, and $r \geq 3$. (Received September 21, 2015)

1116-11-2109 **Dawn C. Nelson*** (dnelson1@saintpeters.edu), Department of Mathematics, 2641 John F Kennedy Blvd, Jersey City, NJ 07306, and **M. Catral**, **P. Ford**, **P. Harris** and **S. J. Miller**. *The Fibonacci Quilt Sequence: A Generalization of Zeckendorf Decompositions with Non-Uniqueness.*

Zeckendorf's Theorem describes the Fibonacci sequence as the unique sequence from which every natural number can be expressed uniquely as a sum of nonconsecutive terms in the sequence. This can be viewed as a 1-dimensional process. The discovery of the Fibonacci Quilt sequence was motivated by a desire to create an analogous 2-dimensional process.

In this talk, we investigate some of the strange phenomena occurring among legal decompositions arising from the Fibonacci Quilt sequence. The decompositions are not unique and in fact the number of legal decompositions grows exponentially with the number being decomposed. The greedy algorithm only returns a legal decomposition (approximately) 93% of the time. So in its place we describe a variation on the greedy algorithm that always returns a legal decomposition and moreover returns a legal decomposition with the minimal number of summands. As time allows we will mention some of the new questions that can be asked when legal decompositions are not unique. (Received September 21, 2015)

1116-11-2118 **Ralf Schmidt** and **Salam Turki*** (sturki@newhaven.edu). *Triply imprimitive representations of GL(2).*

We give a criterion for an irreducible, admissible, supercuspidal representation π of $GL(2;K)$, where K is a p-adic field, to become a principal series representation under every quadratic base change. We determine all such π that have trivial central character and conductor 2, and explain their relevance for the theory of elliptic curves. (Received September 21, 2015)

1116-11-2124 **Tall Aadou***, amadou.tall@aims-senegal.org, and **Sanghare Yacin Aly**. *Fast exponentiation methods using the generalized continued fractions.*

Exponentiation is one the basic and most important operation. There are several methods of computing x^n. An optimal method for any integer n doesn't exist. The aim of this paper is to present a new way of computing short addition-subtraction chains using the generalized continued fractions where subtraction is allowed. We will recover the most exponentiation methods. (Received September 21, 2015)

1116-11-2184 **Anthony Várilly-Alvarado** and **Bianca Viray*** (bviray@uw.edu). *Uniform bounds on Brauer classes of certain K3 surfaces.* Preliminary report.

Let X be a K3 surface over a number field k. It is well known that the Brauer group of $X_{\overline{\mathbb{Q}}}$ is isomorphic to $(\mathbb{Q}/\mathbb{Z})^\rho$ with $1 \leq \rho \leq 19$. In contrast, Skorobogatov and Zarhin showed in 2008 that the quotient Br X/Br k is always finite. We consider the problem of whether #(Br X/Br k) is bounded by a constant depending only on the number field k and the geometric Picard group of X. (Received September 22, 2015)

1116-11-2204 **Jennifer Balakrishnan**, **Jennifer Berg**, **Alyson Deines**, **Yasemin Kara**, **Lily Khadjavi*** (lkhadjavi@lmu.edu), **Kristin Lauter** and **Victor Scharschkin**. *A computational approach to the ABC Conjecture.* Preliminary report.

The ABC Conjecture has a surprising number of implications and is viewed by some as a "holy grail" of number theory. While Shin Mochizuki's announcement of a proof drew increased attention, as of 2015 the details of his work are still being verified. A construction proposed by Noam Elkies takes a computational approach, exploiting maps with prescribed ramification properties (Belyi maps) and the group structure of elliptic curves. For suitable curves, we can give lowest possible degree Belyi maps and consider an induced sequences of triples, of interest for the Conjecture. Following this approach points to opportunities (and challenges) for a computational attack on the ABC Conjecture. This talk will explain the approach and describe work in progress, joint with Victor Scharschkin and with a Sage working group, including Jennifer Balakrishnan, Jennifer Berg, Alyson Deines, Yasemin Kara, and Kristin Lauter. (Received September 22, 2015)

1116-11-2500 **Misty Ostergaard***, Mathematics Department, 138 Cardwell Hall, Manhattan, KS 66506, and **Todd Cochrane** and **Craig Spencer**. *Solutions of Diagonal Congruences with Variables Restricted to Small Intervals.*

Our interest is in finding solutions to the diagonal congruence

$$\sum_{i=1}^{n} a_i x_i^k \equiv c \pmod{q} \tag{1}$$

in a cube $\mathcal{B}$ of side length b. As an example, for a sufficiently large prime modulus and $n \geq 2k^3$, we obtain a solution to (1) in any cube $\mathcal{B}$ of side length $b \geq p^{\frac{1}{k}+\frac{2(k-2)}{n}+\varepsilon}$. Similar results are found for fewer variables. Refinements are obtained for the case of small solutions, and for the case where the number of variables is very large. Results are also given for a general modulus q. (Received September 22, 2015)

1116-11-2559 **May Mei*** (meim@denison.edu) and **Andrew Read-McFarland** (readmc_a1@denison.edu). *Numbers and the Heights of their Happiness.*

"Don't they teach recreational mathematics anymore?" the Tenth Doctor laments after having to explain that "Any number that reduces to one when you take the sum of the squares of its digits and continue iterating until it yields one is a happy number. Any number that doesn't isn't." Fear not, Doctor! This talk explores the heights of happy numbers - the number of iterations needed to reach one. We will give a criteria under which the smallest happy number of height $h+1$ necessarily maps to the smallest happy number of height h. (Received September 22, 2015)

1116-11-2568 **Aaron Levin*** (adlevin@math.msu.edu). *Points of bounded degree on curves.*

If a curve C over a number field k admits a map of degree d to the projective line or an elliptic curve with positive rank, then C will possess infinitely many algebraic points of degree d over k. It is known that a converse holds for small degree d, but not in general. We will discuss an analogue for integral points, giving a complete characterization of affine curves with infinitely many integral points of degree d (over some number field). (Received September 22, 2015)

1116-11-2684 **Kevser Aktas*** (kevseraktas@gmail.com), Gazi University, Ankara, Turkey. *On the number of Special Numbers.*

A number is special if it has mutually distinct exponents in its canonical prime factorisaton for all exponents. Let $V(x)$ be the number of special numbers $\leq x$. We will prove that there is a constant $c > 1$ such that $V(x) \sim \dfrac{cx}{\log x}$.

We will make some remarks on determining the error term at the end. We will also show that it is impossible to find 24 consecutive special integers and we will make some remarks about the existence of 23 consecutive special integers.This is a joint work with Prof. M. Ram Murty. (Received September 22, 2015)

1116-11-2718 **Corey M Manack*** (cmanack@fandm.edu), 719 College Ave Apt 2, Lancaster, PA 17603, and **Steven J Miller** (steven.j.miller@williams.edu), 16 John St, Williamstown, MA 01002. *Leading digit laws on Linear Lie Groups.*

We study the leading digit laws for the matrix entries of a linear Lie group G. For non-compact G, these laws generalize the following observations: (1) the normalized Haar measure of the Lie group $\mathbb{R}^+$ is dx/x and (2) the scale invariance of dx/x implies the distribution of the digits follow Benford's law. Viewing this scale invariance as left invariance of Haar measure, we see either Benford or power law behavior in the significands from one matrix entry of various such G. When G is compact, the leading digit laws we obtain come as a consequence of digit laws for a fixed number of components of a unit sphere. The sequence of digit laws for the unit sphere exhibits periodic behavior as the dimension tends to infinity. (Received September 22, 2015)

1116-11-2849 **Zhu Cao*** (zcao@kennesaw.edu), 1100 S Marietta Pkwy, Marietta, GA 30060, and **Shichao Chen**. *Some Arithmetic Properties of Partitions and Quadratic Forms.* Preliminary report.

One of the important problems in number theory is to study the number of representations of integers by quadratic forms. In this talk, we will present some arithmetic relations on these representing functions, which are obtained via elementary q-series manipulation and the theory of modular forms. As applications, we obtained some arithmetic properties for certain partition functions. (Received September 22, 2015)

1116-11-2919 **Sandi Xhumari*** (sandi.xhumari@uconn.edu). *Generalized Gauss sums: congruences and p-adic properties.*

The Gross-Koblitz formula expresses Gauss sums over finite fields essentially as a product of values of the p-adic Gamma function at rational numbers, and it is a p-adic lifting of Stickelberger's congruence for Gauss sums. In this talk I will outline a proof of the Gross-Koblitz formula by Dwork and Lang. It relies on a differential operator whose index on formal power series and overconvergent p-adic power series are not the same. I will then discuss how these ideas extend to generalized Gauss sums. (Received September 23, 2015)

1116-11-2942 **Kevin M Mugo*** (kevin.mugo@gmail.com), W. Lafayette, IN 47906. *Mod 4 Representations Arising From Elliptic Curves.*

Given a continuous, surjective mod 4 representation $\rho : G_K \longrightarrow GL_2(\mathbb{Z}/4\mathbb{Z})$, we show that ρ arises from the Galois action on the 4-torsion of some elliptic curve if the fixed field of ρ contains a quartic extension, $K(\alpha)/K$, where α is the root of a polynomial of the form $u^4 + Au + B$ and when the normal closure M of $K(\alpha)$ is octahedral. We characterize these *principal*, quartic extensions as K-rational points on a certain variety and relate this property to the cohomology group $H^2(G_{M/K}, \mathbb{Z}/2\mathbb{Z})$. (Received September 23, 2015)

1116-11-2966 **Timothy James All*** (allt@wabash.edu), 301 W. Wabash Ave, Crawfordsville, IN 47933. *Stickelberger Elements for $\mathbb{Q}(\zeta_{p^{n+1}})^+$ and p-adic L-functions.*

Let k_n denote the cyclotomic field of conductor p^{n+1}. Stickelberger's theorem states that an explicit element, called the Stickelberger element, in the Galois group ring (with rational coefficients) essentially annihilates the ideal class group of k_n. Let χ be an odd character of conductor p not equal to ω, the Teichmüller character. Iwasawa noticed that the χ-components of these Stickelberger elements were coherent in the cyclotomic $\mathbb{Z}_p$-extension k_∞ thus giving rise to what we call a distribution. What's more, Iwasawa showed that the Fourier transform of this distribution is essentially the p-adic L-function attached to $\chi^{-1}\omega$. In this paper, we show that the above theory can be duplicated on the "plus" side. We construct Stickelberger elements for k_n^+, the maximal real subfield of k_n. These Stickelberger elements have p-adically defined coefficients and annihilate the p-part of the ideal class group of k_n^+. Moreover, the $\chi\omega^{-1}$-components of these Stickelberger elements are coherent in the cyclotomic $\mathbb{Z}_p$-extension k_∞^+, and the Fourier transform of the associated distribution is essentially the twisted p-adic L-function attached to $\chi^{-1}\omega$. (Received September 23, 2015)

12 ► Field theory and polynomials

1116-12-291 **Eric Y Chen**, **John T Ferrara*** (jtf019@bucknell.edu) and **Liam M Mazurowski**.
Constructive Galois Theory with Linear Algebraic Groups.

A fundamental aspect of the Inverse Galois Problem is describing all extensions of a base field K with a given Galois group G. A constructive approach to this problem involves the theory of generic polynomials. For a finite group G, a polynomial $f(t_1, \ldots, t_n; x) \in K(t_1, \ldots, t_n)[x]$ is G-generic if $\mathrm{Gal}(f/K(t_1, \ldots, t_n)) \cong G$ and for any Galois G-extension M/L with $L \supset K$, the parameters $t_1, \ldots, t_n$ can be specialized to L such that f has splitting field M/L.

In our work, we show the existence of and explicitly construct generic polynomials for various groups, over fields of positive characteristic. The methods we develop apply to a broad class of connected linear algebraic groups defined over finite fields satisfying certain conditions on cohomology. In particular, we use our techniques to study constructions for unipotent groups, certain algebraic tori, and certain split semisimple groups. An attractive consequence of our work is the construction of generic polynomials in the optimal number of parameters for all cyclic 2-groups over most fields of positive characteristic. This contrasts with a theorem of Lenstra, which states no cyclic 2-group of order ≥ 8 has a generic polynomial over $\mathbb{Q}$. (Received August 22, 2015)

1116-12-557 **Chad Awtrey**, **Kristen Mazur**, **Sara Rodgers*** (srodgers6@elon.edu), **Nicole Soltz** and **Jesi Weed**. *Galois Groups of Degree 15 p-adic Polynomials.*

Polynomials whose coefficients are p-adic numbers play a central role in abstract algebra and number theory. A classical result states that given a prime number p and a positive integer n, there exist only finitely many “distinct” degree n polynomials with p-adic coefficients. Researchers have therefore focused on methods for counting the number of such polynomials as well as computing useful characteristics of each polynomial. One of the most important such characteristics is the polynomial’s Galois group, an object which encodes arithmetic information concerning the polynomial’s roots. The most difficult cases arise when the prime p divides the composite degree n. In this case, past research has dealt with all degrees less than or equal to 14. Therefore, our research focuses on our newly-developed methods for computing Galois groups of degree 15 polynomials with 5-adic coefficients. (Received September 07, 2015)

1116-12-561 **Chad Awtrey**, **Robin French**, **Peter L Jakes*** (pjakes@elon.edu) and **Alan Russell**.
Degree 6 Polynomials and Their Solvability by Radicals.

For about 500 years, formulas have existed to find exact solutions to quadratic, cubic and quartic polynomials. However, it was proven later that not all solutions to quintic polynomials can be found exactly, or solved by radicals. As a result, a method was created in the 20th century using a property of each function called its Galois group in order to determine which degree five polynomials could be solved exactly and which could not. This project expands upon this discovery by exploring degree six polynomials. By using computer software, the Galois group of a degree six polynomial can be determined by only using two resolvent polynomials, improving upon prior methods. From this information, it can then be determined whether or not the polynomial is solvable by radicals. Further research can explore higher degree polynomials as well as reducible polynomials, as the current method is only viable for irreducible polynomials. (Received September 07, 2015)

1116-12-634 **Neville Fogarty*** (neville.fogarty@uky.edu), Department of Mathematics, 715 Patterson Office Tower, University of Kentucky, Lexington, KY 40504. *Idempotents in Skew-Constacyclic Codes.*

A skew-constacyclic code is a submodule of the skew-polynomial ring $\mathbb{F}_q[x; \theta]$ modulo the left ideal generated by a polynomial of the form $x^n - a$. In the classical cyclic case, when $\gcd(n, q) = 1$, each code contains a unique generating idempotent. We discuss potential generalizations of well-known results on idempotents to the skew-constacyclic case. This talk reflects work from the presenter’s dissertation under the guidance of his advisor, Dr. Heide Gluesing-Luerssen. (Received September 09, 2015)

1116-12-773 **Tamalika Mukherjee*** (txm1809@rit.edu). *Homomorphic Encryption: Ring Learning With Errors.*

Homomorphic Encryption (HE), sometimes considered the ”Holy Grail of Cryptography”, is a method of performing calculations on encrypted data. Fully Homomorphic Encryption (FHE) schemes can perform an arbitrary number of additions and multiplications but are currently practically inefficient to implement for industry standards. On the other hand, Somewhat Homomorphic Encryption (SWHE) schemes can perform a limited number of multiplications on encrypted data and are much more efficient. Some SWHE schemes are based on the Ring Learning With Errors (Ring-LWE) security assumption, we will present one such scheme based on the scheme developed by Brakerski and Vaikuntanathan. The Ring-LWE assumption holds for $\mathbb{Z}[x]$ modulo any cyclotomic polynomial, we will explore the properties of the cyclotomic polynomial used in our scheme as well as the experiments that we performed on it. (Received September 12, 2015)

1116-12-869 **S. Twareque Ali*** (`twareque.ali@concordia.ca`), Department of Mathematics and Statistics, Concordia University, Montreal, Quebec H3G 1M8, Canada. *An interesting connection between complex orthogonal polynomials and nonlinear coherent states.*

A general construction for bivariate complex orthogonal polynomials has recently been proposed by Ismail, et al. In this talk we point out an interesting connection between such polynomials and the so-called nonlinear coherent states of physics, in particular quantum optics. We show that, under some restrictions, the existence of one implies that of the other and vice versa. (Received September 14, 2015)

1116-12-1035 **Michael Robert Keenan*** (`mkeenan3@elon.edu`) and **Chad Awtrey**. *Symmetries of Quartic Polynomials.*

In the 1500s mathematicians discovered all quartic polynomials are solvable by radicals, meaning we can find a quartic polynomial's roots using only using the coefficients of the polynomial, the basic arithmetic functions, and radicals. It wasn't until the 1800s when mathematicians showed why quartic polynomials are solvable by radicals and why not all polynomials of degree greater than four are. By attaching a group structure to a polynomial (called the polynomial's Galois group), we can determine whether the polynomial is solvable by radicals. We can also see the relationships among the roots. Naturally, a branch of mathematical research has emerged to develop methods to determine Galois groups of polynomials. Previous methods for determining Galois groups of quartic polynomials involve factoring and creating larger polynomials (called resolvent polynomials); a process which can be computationally inefficient. We will discuss how to compute the Galois group of a quartic polynomial that does not rely on factoring large-degree resolvents. Instead, we use only two pieces of data about the polynomial: (1) the number of roots in the field extension it defines, and (2) its discriminant. We will also compare the efficiency of this method to the efficiency of resolvent-based methods. (Received September 16, 2015)

1116-12-1477 **Carlos E Arreche*** (`cearrech@math.ncsu.edu`), Mathematics Department, North Carolina State University, Campus Box 8205, Raleigh, NC 27605. *Computing Galois groups for functional equations.*

There are several Galois theories that describe the relations among solutions to functional equations. As an application of these theories, one can prove that the Gamma function $\Gamma(x)$ does not satisfy any $\frac{d}{dx}$-equations with polynomial coefficients, and that the incomplete Gamma function $\gamma(x,t)$ does not satisfy any $\frac{d}{dt}$-equations with polynomial coefficients. Although these results were already known, the Galois theoretic point of view gives a more conceptual explanation of these facts than many of the earlier proofs, based only on the defining functional equations $\Gamma(x+1) = x\Gamma(x)$ and $\frac{\partial^2\gamma}{\partial x^2}(x,t) = \frac{t-1-x}{x}\frac{\partial\gamma}{\partial x}(x,t)$ for each of these functions. More importantly, the computations involved are symbolic, which allows us to discover similar facts about other special functions automatically, based only on their defining functional equation. (Received September 20, 2015)

1116-12-1478 **Carlos E Arreche*** (`cearrech@math.ncsu.edu`), Mathematics Department, North Carolina State University, Campus Box 8205, Raleigh, NC 27605. *On the computation of the difference-differential Galois group for a second-order linear difference equation.*

Given a linear difference equation, there is a difference-differential Galois group that encodes the differential-algebraic dependencies among the solutions of the equation. After giving a brief introduction to this theory, I will describe algorithms to compute the Galois group associated to a second-order linear difference equation over $C(x)$, the field of rational functions over a computable field C of characteristic zero, with respect to the C-linear shift automorphism that sends x to $x+1$. I will also discuss some concrete examples to illustrate these algorithms, and show explicitly in the examples how to derive the differential-algebraic dependencies among the solutions from the knowledge of the defining equations for the Galois group. (Received September 20, 2015)

1116-12-1752 **Julia F. Knight*** (`knight.1@nd.edu`) and **Karen M. Lange**. *Lengths of roots of polynomials in Hahn fields.*

It is well-known [3] that for a divisible ordered Abelian group G, and a field K that is algebraically closed, or real closed, the *Hahn field* $K((G))$ is also algebraically closed, or real closed. The ideas go back to Newton and Puiseux. Each element r of $K((G))$ is a generalized power series with terms corresponding to elements of a well-ordered subset of G and with coefficients in K. The *length* of r is the order type of the set of $g \in G$ with non-zero coefficient. We give a technical theorem, for the case where G is Archimedean, bounding the length of a root r of a polynomial $p(x)$ in terms of the lengths of the coefficients in $p(x)$. To obtain the technical theorem, we follow unpublished notes of Starchenko, adding further ordinal calculations.

Using the technical theorem, we can prove the conjecture from [1], stated in Lange's talk.

References

[1] J. F. Knight and K. Lange, "Complexity of structures associated with real closed fields", *Proc. of London Math. Society*, vol. 107(2013), pp. 177-197.

[2] S. Maclane, "The universality of formal power series fields", *Bull. Amer. Math. Soc.*, vol. 45(1939), pp. 888-890.

(Received September 21, 2015)

1116-12-2226 **Chad Awtrey*** (cawtrey@elon.edu). *Groups of order 16 as Galois groups over the 2-adic numbers.*

Let K be a Galois extension of the 2-adic numbers $\mathbf{Q}_2$ of degree 16, and let G be the Galois group of $K/\mathbf{Q}_2$. We show that G can be determined by the Galois groups of the octic subfields of K. We also show that all 14 groups of order 16 occur as the Galois group of some Galois extension $K/\mathbf{Q}_2$ except the elementary abelian group of order 16. For the other 13 groups G, we give a degree 16 polynomial $f(x)$ such that the Galois group of f over $\mathbf{Q}_2$ is G. (Received September 22, 2015)

1116-12-2663 **Joseph Michael DiMuro*** (joseph.dimuro@biola.edu), 13800 Biola Ave., La Mirada, CA 90639. *On On_p.*

One of John Conway's creations is the Field On_2. This Field consists of the Class of all ordinals, with the "minimal" definitions of addition and multiplication which turn the ordinals into a Field of characteristic 2. Much is known about the structure of this Field, due to the work of Hendrik Lenstra.

The question can then be asked: is there an analogous construction to turn the ordinals into a Field of characteristic p, for odd primes p? In this talk, we will give such a construction, and analyze the resulting Fields On_p. It turns out that there are strong similarities between the Fields On_p for all primes p. (Received September 22, 2015)

13 ► Commutative rings and algebras

1116-13-115 **Jung Wook Lim*** (jwlim@knu.ac.kr), Department of Mathematics, Kyungpook National University, 80 Daehakro, Bukgu, Daegu, 702-701, South Korea. *A note on Gaussian series rings.* Preliminary report.

In this talk, we introduce the concept of Gaussian series rings and study some properties. (Received July 29, 2015)

1116-13-212 **Jennifer Biermann*** (jbierman@mtholyoke.edu), **Christopher A. Francisco**, **Huy Tài Hà** and **Adam Van Tuyl**. *Partial coloring, vertex decomposability, and sequentially Cohen-Macaulay simplicial complexes.*

In attempting to understand how combinatorial modifications alter algebraic properties of monomial ideals, several authors have investigated the process of adding "whiskers" to graphs. We study a similar construction to build a simplicial complex Δ_χ from a coloring χ of a subset of the vertices of Δ, and give necessary and sufficient conditions for this construction to produce vertex decomposable simplicial complexes. Using combinatorial topology, we strengthen and give new proofs for results of the second and third authors about sequentially Cohen-Macaulay edge ideals that were originally proved using algebraic techniques. (Received August 14, 2015)

1116-13-238 **Sarah M. Fleming**, **Lena Ji**, **S. Loepp**, **Peter M. McDonald**, **Nina Pande*** (ngp3@williams.edu) and **David Schwein**. *Rings, Completions, and Strange Formal Fibers.*

Let R be a Noetherian ring with exactly one maximal ideal. We can define a metric on R based on its maximal ideal and complete R with respect to that metric. The relationship between a ring R and its completion can be studied through the natural map from the prime ideals of the completion of R to the prime ideals of R given by intersecting ideals of the completion with R. If $\mathfrak{p}$ is a prime ideal of R, the inverse image of $\mathfrak{p}$ under this map is called the formal fiber of R at $\mathfrak{p}$. The dimension of the formal fiber of R at $\mathfrak{p}$ is the length of the longest chain of prime ideals the formal fiber of R at $\mathfrak{p}$ contains. For a typical ring R, the dimension of its formal fiber at a particular prime ideal $\mathfrak{p}$ is equal to $n-1-\operatorname{ht}\mathfrak{p}$ where n is the Krull dimension of R. In this talk, we show that there are excellent unique factorization domains with the unusual property that the dimensions of their formal fibers do not follow this pattern. We show that, in fact, the dimensions of the formal fibers at the zero ideal and height one prime ideals can be exactly controlled over a large range of values. (Received August 16, 2015)

1116-13-250 **Hannah Robbins*** (robbins@roanoke.edu). *Associated primes of local cohomology after adjoining indeterminates part 2: the general case.* Preliminary report.

Let A be a domain finitely generated as an algebra over a field, k, of characteristic zero, $R = A[t_1, \ldots, t_\ell]$ or $A[[t_1, \ldots, t_\ell]]$, and I an ideal of R. If A has a resolution of singularities, Y_0, which is the blowup of A along an ideal of depth at least two and is covered by a finite number of open affines with $H^j(Y_0, \mathcal{O}_{Y_0})$ of finite length over A for $j > 0$, we prove that $\mathrm{Ass}_R H^i_I(R)$ is finite for every i. In particular this holds when A is a finite dimensional normal domain with an isolated singularity which is a finitely generated algebra over a field of characteristic 0.

This generalizes my previous result which required that the blow up of A be covered by 2 or 3 open affines instead of any finite number. (Received August 18, 2015)

1116-13-388 **Hannah Altmann*** (haltmann@morris.umn.edu). *Semidualizing DG Modules over Tensor Products.*

Let R be a commutative, noetherian ring with identity. A finitely generated R-module C is *semidualizing* if the homothety map $\chi^R_C : R \to \mathrm{Hom}_R(C, C)$ is an isomorphism and $\mathrm{Ext}^i_R(C, C) = 0$ for all $i > 0$. For example, R is semidualizing over R, as is a dualizing module, if R has one. In some sense the number of semidualizing modules measures the severity of the singularity of R. We are interested in that number. We can extend this idea to semidualizing complexes of R and generalize even further over Differential Graded (DG) algebras. We will discuss constructing semidualizing DG modules over tensor products of algebras over a field. In particular, this gives us a lower bound on the number of semidualizing DG modules over the tensor product. (Received August 30, 2015)

1116-13-408 **Haohao Wang*** (hwang@semo.edu), Math Department, MS6700, Southeast MO State University, Cape Girarduea, MO 63701. *Implicit Equations and Rees Algebra.*

In this presentation, we will provide computational algorithms in determining the implicit equations of parametrized curves and surfaces, and study the geometry of the generators. We will explore the connections between the implicit equations and the defining equations of the Rees Algebra of rational space curves and surfaces. (Received August 31, 2015)

1116-13-416 **Mehdi Garrousian*** (m.garrousian@uniandes.edu.co), Departamento de Matematicas, Univ ersidad de los Andes, Cra 1 No. 18A-12, Bogota, Colombia, and **Stefan Tohaneanu** (tohaneanu@uidaho.edu), Department of Mathematics, University of Idaho, 83844-1103, Moscow, ID. *The minimum distance of a linear code and the α-invariant.* Preliminary report.

The Fitting module of a finitely generated module is a standard construction in commutative algebra, formed by taking the consecutive quotients of its Fitting ideals. These are determinantal ideals that tell us whether the module can be generated by a given number of elements. From a linear code, we naturally construct a Fitting module and show that its α-invariant (the smallest nonzero graded part) determines the minimum distance of the linear code. The goal of this talk is to show how various commutative/homological algebra invariants capture the minimum distance of linear codes. (Received August 31, 2015)

1116-13-462 **David Eisenbud*** (de@msri.org). *Duality for Residual Intersections.*

It is well-known that S is a power series ring of dimension d and $a_1, \ldots, a_d$ is a regular sequence in S then the Artinian module $S/(a_1, \ldots, a_d)$ is self-dual (that is, Gorenstein). About 25 years ago Duco van Straten pointed out a remarkable extension: if the ideal $J = (a_1, \ldots, a_d)$ has codimension only $d - 1$, and I is its unmixed part, then J/I is a self-dual module.

It turns out that this is the beginning of a general theory of duality for residual intersections. I will describe work of Craig Huneke and Bernd Ulrich, and a recent collaboration with Bernd Ulrich on this topic. (Received September 02, 2015)

1116-13-538 **Thomas Polstra*** (thomaspolstra@gmail.com), Math Sciences Building, 810 E. Rollins Street, Columbia, MO 65211. *Lower Semi-Continuity of the F-Signature.*

In this talk, we will discuss some strong Hilbert-Kunz length bounds found in all Noetherian characteristic p rings which are either F-finite or essentially of finite type over an excellent local ring. These numerical bounds will lead to a number of interesting applications. One such application will be an affirmative answer to if the F-signature function is lower semi-continuous on such rings, a problem that has been asked by several people. (Received September 06, 2015)

1116-13-556 **Omprokash Das** and **Karl Schwede*** (schwede@math.utah.edu). *The geometry of the F-different.*

We study the behavior of Frobenius splittings, and generalizations thereof, when restricted to compatible quotient rings (or equivalently subvarieties). I will discuss connections with the canonical bundle formula and subadjunction as studied in algebraic geometry. (Received September 07, 2015)

1116-13-704 **Brooke S. Ullery*** (brookeullery@gmail.com). *Constructing ideals with high Castelnuovo-Mumford regularity.*

The Castelnuovo-Mumford regularity of a module is a homological invariant that roughly measures complexity. Though straight-forward to define, it is difficult to find ideals in polynomial rings with high Castelnuovo-Mumford regularity. I will demonstrate a method that takes as input well-understood modules and outputs ideals which cut out schemes supported on linear spaces with high Castelnuovo-Mumford regularity and other desirable homological properties. (Received September 10, 2015)

1116-13-804 **James J Madden*** (madden@math.lsu.edu), 222 Prescott Hall, LSU, Baton Rouge, LA 70803, and **Trevor McGuire**, North Dakota State University, NDSU Dept #2750, Fargo, ND. *Neighbors, Generic Sets and Buchberger Hypersurfaces.* Preliminary report.

The Buchberger graph of a monomial ideal in $k[x,y,z]$ is described in Miller & Sturmfels' book, *Combinatorial Commutative Algebra*. We describe a generalization. In place of the set of exponent vectors of a minimal generating set of a generic monomial ideal, we take an arbitrary discrete generic antichain A in $\mathbb{R}^n$. From this, we construct a PL hypersurface embedded in $\mathbb{R}^n$ and a triangulation $B(A)$ of that. In case A the set of exponent vectors of a minimal generating set of a generic monomial ideal $S = k[x_1,\ldots,x_n]$, $B(A)$ a equivalent to a barycentric subdivision of the Scarf complex of A, and if $n = 3$, the Buchberger graph is the one-skeleton of $B(A)$. In the general case, $B(A)$ interesting object about which little is yet known. (When A is not closed, $B(A)$ may fail be simply connected.) We apply basic facts about $B(A)$ to describe minimal free resolutions of S-submodules of the Laurent algebra $k[x_1^{\pm 1},\ldots,x_n^{\pm 1}]$ and (by means of the equivariant methods described in Miller-Sturmfels, chapter 9) to derive from this combinatorial descriptions of resolutions of ideas of S generated by monomials and binomials. (Received September 14, 2015)

1116-13-834 **Claudia Polini*** (cpolini@nd.edu), 255 Hurley Building, Department of Mathematics, University of Notre Dame, Notre Dame, IN 46556-5641. *Rees rings and singularities of curves.*

Let $f_1,\ldots,f_n$ be forms of the same degree in the polynomial ring $R = k[x_1,x_2]$ that define a regular map $\Phi : \mathbb{P}^1 \to \mathbb{P}^{n-1}$. The bi-homogeneous coordinate ring of the graph of Φ as a subvariety of $\mathbb{P}^1 \times \mathbb{P}^{n-1}$ is the Rees algebra $\mathcal{R}(I) = R[f_1t,\ldots,f_nt]$ of the ideal $I = (f_1,\ldots,f_n) \subset R$, whereas the homogeneous coordinate ring of the closed image of Φ, the curve $X \subset \mathbb{P}^1$ parametrized by $f_1,\ldots,f_n$ is the subalgebra $k[f_1t,\ldots,f_nt] \cong \mathcal{R}(I)\otimes k$. It is a fundamental problem in elimination theory, commutative algebra, algebraic geometry, and applied mathematics to determine the defining ideals of these rings. Since this is a very ambitious goal, an important first step is to determine or at least bound the (bi)-degrees of the defining equations. In this talk I will survey several approaches to solve this problem. In addition, I will explain how features of the defining ideals correspond to the types and the constellation of the singularities of the curve X. (Received September 14, 2015)

1116-13-871 **Greg Oman** and **Adam Salminen*** (as341@evansville.edu), 1800 Lincoln Avenue, Evansville, IN 47722. *Residually Small Commutative Rings.* Preliminary report.

Let R be a ring. Following the literature, R is called *residually finite* if for every $r \in R\backslash\{0\}$, there exists an ideal I_r of R such that $r \notin I_r$ and R/I_r is finite. In this talk, we define a commutative ring R with identity to be *reisdually small* if for every $r \in R\backslash\{0\}$, there exists an ideal I_r of R such that $r \notin I_r$ and $|R/I_r| < |R|$. We will discuss such rings, extending results on residually finite rings. (Received September 14, 2015)

1116-13-897 **Hailong Dao** (hdao@ku.edu) and **Tony Se*** (tonyse@ku.edu). *Finite F-type and F-abundant Modules.*

We introduce and study basic properties of two types of modules over a commutative Noetherian ring R of positive prime characteristic. The first is the category of modules of finite F-type. They include reflexive ideals representing torsion elements in the divisor class group. The second class is what we call F-abundant modules. These include, for example, the ring R itself and the canonical module when R has positive splitting dimension. We are able to prove many facts about these two categories and how they are related, for example that $\mathrm{Hom}_R(M,N)$ is maximal Cohen-Macaulay when M is of finite F-type and N is F-abundant, plus some extra conditions. Our methods allow us to extend previous results by Patakfalvi-Schwede, Yao and Watanabe.

They also afford a deeper understanding of these objects, including complete classifications in many cases of interest. (Received September 14, 2015)

1116-13-955 **Sara Malec*** (malec@hood.edu). *The Intersection Algebra of Ideals.*

The intersection algebra of a collection of ideals in a Noetherian ring captures information about how the intersections of powers of those ideals change. While these algebras are simple to define, little is known about them in general. This talk presents some new developments by investigating these objects through their combinatorial and algebraic properties. (Received September 15, 2015)

1116-13-994 **Sarah Mayes-Tang*** (sarah.mayes-tang@questu.ca), Quest University Canada, 3200 University Blvd., Squamish, BC V0N1T0, Canada. *Stabilization of Boij-Söderberg decompositions of systems of ideals.*

While much work has been done to understand Boij-Söderberg decompositions, the meaning of the diagrams and coefficients that appear in them is not well understood in general. In this talk, we will discuss patterns in the decompositions of Betti tables of systems of related polynomial ideals. In particular, we will describe a stability that characterizes the asymptotic behaviour of these decompositions in certain cases. (Received September 15, 2015)

1116-13-1023 **Sarah Fleming**, **Lena Ji** and **Susan Loepp*** (sloepp@williams.edu), Bronfman Science Center, 18 Hoxsey Street, Williamstown, MA 01267, and **Peter McDonald**, **Nina Pande** and **David Schwein**. *Dimensions of Formal Fiber Rings.* Preliminary report.

Let R be a local ring with maximal ideal M and let $\widehat{R}$ denote the M-adic completion of R. It has long been known that the formal fiber rings of R encode important information about R. If P is a prime ideal of R, the formal fiber ring of R at P is defined to be $\widehat{R} \otimes_R k(P)$ where $k(P) = R_P/PR_P$. In this talk, we will discuss the dimensions of these formal fiber rings. We will give a history of known results as well as present new results. (Received September 16, 2015)

1116-13-1079 **Ali Alilooee*** (alilooy@yahoo.com), Macomb, IL 61455, and **Arindam Banerjee**, **Selvi Beyarslan** and **Huy Tai Ha**. *An optimal upper bound on the regularity of powers of edge ideals.*

Let $R = K[x_1, \ldots, x_n]$ be a polynomial ring over a field K and $I \subset R$ an ideal. It is well known that if I is a homogeneous ideal whose generates all have the same degree, $reg(I^s)$ is asymptotically linear for $s \gg 0$. One question that arises here is to find the exact form of this linear function.

Beyarslan, Há and Trung identified this linear function for the edge ideals of trees and cycles. They finished their paper with the following question.

Question 1. *Let G be a graph with edge ideal $I(G)$. Let $\nu(G)$ denote the induced matching number of G. For which graphs G are the following true?*

$$reg(I(G)^s) = 2s + \nu(G) - 1 \quad \textit{for } s \gg 0.$$

Here in this talk we first give an upper bound for the regularity of powers of edge ideals and then we partially answer this question. (Received September 16, 2015)

1116-13-1096 **Alessandro De Stefani*** (ad9fa@virginia.edu), University of Virginia, Charlottesville, VA 22904, and **Luis Núñez-Betancourt** (lcn8m@virginia.edu), University of Virginia, Charlottesville, VA 22904. *F-thresholds of graded rings.*

The F-pure threshold, the diagonal F-threshold, and the a-invariant are three important invariants for standard graded rings of positive characteristic. Hirose, Watanabe, and Yoshida conjectured some relations between these numbers for strongly F-regular rings. We prove their conjecture, only assuming that the ring is F-pure. Furthermore, we give an interpretation of the F-pure threshold of a standard graded Gorenstein algebra in terms of the maximal length of a regular sequence that preserves F-purity at each step. (Received September 16, 2015)

1116-13-1138 **Ian Aberbach**, **Aline Hosry** and **Janet Striuli*** (jstriuli@fairfield.edu), North Benson, Fairfield, CT 06824. *Uniform Bounds of Artin-Rees type for free resolutions.*

Let (R, m) be a local noetherian ring of dimension d. Given a finitely generated R-module M we study a free resolution of M, which we denote by $(F^M_\bullet, \partial^M_i)$. We show that there exists a positive integer h such that $I^n F^M_i \cap Im(\partial^M_{i+1}) \subseteq I^{n-h} Im(\partial^M_{i+1})$ for all $i \geq 0$, for all $n > h$, for all the ideals $I \subseteq R$ and for all modules that are d-th syzygies. The proof of this statement involves the definition of Koszul annihilator sequence which we will introduce for the talk. (Received September 17, 2015)

1116-13-1147 **Janet Vassilev*** (jvassil@math.unm.edu), Department of Mathematics and Statistics, University of New Mexico, Albuquerque, NM 87131. *Interior operations on the set of ideals of a ring.* Preliminary report.

In a recent paper, Epstein and Schwede introduced the tight interior operation which is defined as a dual operation to tight closure. We will discuss interior operations more generally on the set of ideals of a ring and properties that hold when an interior operation and a closure operation are dual to each other. (Received September 17, 2015)

1116-13-1199 **Luigi Ferraro*** (lferraro2@math.unl.edu). *On the bimodule structure of bounded cohomology.*

Stable cohomology is a $\mathbb{Z}$-graded multiplicative cohomology theory generalizing Tate cohomology and first defined by Pierre Vogel. It is connected through a short exact sequence to the absolute cohomology and another cohomology theory called bounded cohomology. In this talk we investigate the structure of the bounded cohomology as a graded bimodule using the Hopf algebra structure of the Ext algebra. We use the information on the bimodule structure of the bounded cohomology to study the stable cohomology algebra as a trivial extension algebra. (Received September 17, 2015)

1116-13-1217 **Josephine Yu*** (jyu@math.gatech.edu). *Do generic polynomials generate a prime ideal?*

Do *most* set of sparse polynomials generate a proper prime ideal? The answer depends on the support. We give necessary and sufficient combinatorial conditions for when this happens, analogously to the conditions for sparse resultants to be identically zero. (Received September 17, 2015)

1116-13-1273 **Robert M. Walker*** (robmarsw@umich.edu), 2074 East Hall, Ann Arbor, MI 48109-1043. *Rational singularities and Uniform Symbolic Topologies.*

A Noetherian ring R satisfies the uniform symbolic topology property (USTP) if there's an integer $D > 0$ such that the symbolic power $P^{(da)} \subseteq P^a$ for all prime ideals P in R and all integers $a > 0$. In the previous decade, two classes of rings were shown to satisfy the USTP: regular rings of finite type over a field (the Ein-Lazarsfeld-Smith theorem); and reduced isolated singularities that either are F-finite and contain a field of positive characteristic, or are essentially of finite type over a field of characteristic zero (Huneke-Katz-Validashti). In contrast with the regular case, however, the proof in the isolated singularity case is nonconstructive, confirming that a D exists without giving an explicit, effective bound. In this talk, we explain how to find explicit multipliers D for a large class of algebro-geometric surface singularities R (e.g., toric, du Val (ADE)). By reinterpreting classical results of Lipman on rational singularities, we also deduce that all two-dimensional regular rings satisfy the USTP with $D = 1$, partially extending the Ein-Lazarsfeld-Smith theorem to mixed characteristic. (Received September 18, 2015)

1116-13-1299 **Christine Berkesch Zamaere*** (cberkesc@math.umn.edu), Minneapolis, MN, **Jens Forsgård** (jensf@math.tamu.edu), College Station, TX , and **Laura Felicia Matusevich** (laura@math.tamu.edu), College Station, TX. *The parametric variation of A-hypergeometric functions.*

A-hypergeometric systems are the D-module counterparts of toric ideals, and their behavior is linked closely to the combinatorics of toric varieties. I will discuss recent work that aims to explain the behavior of the solutions of these systems as their parameters vary. Our goal is to stratify the parameter space so that solutions are locally analytic within each (connected component of a) stratum, and this turns out to be closely related to certain local cohomology modules. (Received September 18, 2015)

1116-13-1301 **Thanh Q Vu*** (tvu@unl.edu). *Betti splittings and syzygies of Veronese embeddings of the projective plane.*

Let X be the dth Veronese embedding of $\mathbb{P}^2$ into $\mathbb{P}^n$. Let R be the homogeneous coordinate ring of X and S be the homogeneous coordinate ring of $\mathbb{P}^n$. The shape of the Betti table of R as an S-module is known; in particular its Betti table has only two strands. Nevertheless, the exact values of the Betti numbers are not known. In this talk, we will introduce the notion of Betti splitting to study those Betti numbers. Using the method, we will give a recursive formula for them. (Received September 18, 2015)

1116-13-1318 **Vivek Mukundan*** (vmukunda@purdue.edu), 150 N. University Street, Office 1037, West Lafayette, IN 47906, and **Jacob Boswell**. *Rees algebra of Ideals.*

The talk is about the defining ideal of the Rees algebra of ideals. One of the cases we consider is a grade 2 perfect ideal I in $R = k[x_1, \cdots, x_d]$ which is generated by forms of the same degree. Assume that the presentation matrix φ is almost linear, that is, all but the last column of φ consist of entries which are linear. For such ideals, we find explicit forms of the defining ideal of the Rees algebra $\mathcal{R}(I)$. We also introduce the notion of iterated Jacobian duals and present properties such as Cohen-Macaulayness, regularity, relation type of the Rees algebra of ideals whose second analytic deviation is one. (Received September 18, 2015)

1116-13-1430 **Peder Thompson*** (pthompson4@math.unl.edu). *Stable local cohomology.*
Let R be a Gorenstein local ring, I an ideal in R, and M an R-module. The local cohomology of M supported at I can be computed by applying the I-torsion functor to an injective resolution of M. Since R is Gorenstein, M has a complete injective resolution, so it is natural to ask what one gets by applying the I-torsion functor to it. Following this lead, we define stable local cohomology for modules with complete injective resolutions. This gives a functor to the stable category of Gorenstein injective modules. We show that in many ways this behaves like the usual local cohomology functor. Our main result is that when there is only one non-zero local cohomology module, there is strong connection between that and stable local cohomology; in fact, the latter gives a Gorenstein injective approximation of the former. (Received September 19, 2015)

1116-13-1445 **Ruimin Cai**, **James Farre**, **Jessica Sidman*** (jsidman@mtholyoke.edu), **Audrey St. John**, **Louis Theran** and **Xilin Yu**. *Polynomials in rigidity theory: special positions of frameworks.* Preliminary report.
In rigidity theory, a framework is specified by giving n full-dimensional rigid bodies in R^d and a set of geometric constraints among them. The fundamental question is to determine if the framework is rigid or if it admits relative motions between the bodies. Such a framework has an associated multigraph G encoding the combinatorics of the constraints, a rigidity matrix describing the conditions imposed on infinitesimal motions, and a bracket polynomial P_G that lives in the homogeneous coordinate ring of a certain Grassmannian. The polynomial P_G is the determinant of the rigidity matrix, and the variety it defines consists of special embeddings of the framework with nongeneric behavior. We will discuss how the combinatorics of G can be used to understand the structure of P_G. (Received September 19, 2015)

1116-13-1450 **Daniel J. Hernández**, **Luis Núñez-Betancourt**, **J. Felipe Pérez*** (jperezvallejo@gsu.edu) and **Emily E. Witt**. *Lyubeznik numbers, connectivity, and cohomological dimension in mixed characteristic.*
In this short talk we present an extension of the Second Vanishing Theorem for local cohomology modules over regular rings to the (unramified) mixed characteristic situation. We use this theorem, together with new results about Lyubeznik Numbers in mixed characteristic of cohomological complete intersection rings, to give results about the connectedness of the spectrum. (Received September 19, 2015)

1116-13-1453 **Hendrik W. Lenstra**, Mathematisch Instituut, Leiden, Netherlands, and **Alice Silverberg***, Mathematics Department, UCI, Irvine, CA 92697-3875. *Some discrete log questions in $\mathbb{Q}$-algebras.*
As a by-product of our work on lattice-based cryptography, we use number theory and commutative algebra to construct deterministic polynomial-time algorithms to solve discrete logarithm problems in multiplicative subgroups of commutative $\mathbb{Q}$-algebras. (Received September 19, 2015)

1116-13-1526 **Denise A. Rangel Tracy*** (detracy@syr.edu), 215 Carnegie Building, Syracuse University, Syracuse, NY 13244-1150, and **L. Sega**, **R. Dellaca**, **J. Hoffmeier**, **P. Thompson** and **G. Sosa**. *Koszul Homology.* Preliminary report.
In this talk, we will discuss the Koszulness of a local ring. As well as, a generalization of a Koszul algebra, given by Cassidy and Shelton in 2008, known as $\mathcal{K}_2$. Specially, whether the structure of the homology classes of the Koszul complex can be used to detect Koszulness.
(Received September 20, 2015)

1116-13-1534 **Sanath K Devalapurkar*** (sanath@cfrce.com). *Higher commutative algebra through homotopy theory.* Preliminary report.
André-Quillen cohomology, defined using homotopy theory, has been very useful in commutative algebra. One can view E_∞-rings as generalizations of commutative rings, and therefore commutative algebra has also proved to be tremendously useful in homotopy theory. In this talk, I will present a generalization of the notion of an E_∞-ring using the notion of a stable ∞-category.

We do this by introducing the notion of a *stable* $(\infty, 2)$*-category.* A commutative algebra object (in a higher homotopy coherent sense) in a certain stable $(\infty, 2)$-category provides us with a robust notion of a “2-ring”, which differs from the ordinary notion of a 2-ring as defined, for example, by Baez-Dolan. This sets the foundation for a generalization of commutative algebra itself since an ordinary commutative ring can be thought of as a "0-ring", and an E_∞-ring as a "1-ring". We provide a definition of the Spec of a 2-ring.

We conclude by providing possible interactions between this new notion of a 2-ring and ordinary commutative algebra; we also state a few problems left open by this study which are motivated by homotopy-theoretic considerations (e.g., why defining the notion of a "n-ring" is open). (Received September 21, 2015)

1116-13-1581 **Louiza Fouli*** (lfouli@math.nmsu.edu), Department of Mathematical Sciences, New Mexico State University, Las Cruces, NM 88003, and **Paolo Mantero** and **Yu Xie**. *Conjectures on Symbolic Powers.* Preliminary report.

Given a finite set of points X in the projective space $\mathbb{P}_k^N$, for some N, it is natural to ask what is the least degree, α_m, of a hypersurface $F \neq 0$ passing through all the points with a given multiplicity m. Chudnovksy conjectured in 1981 that $\frac{\alpha_m}{m} \geq \frac{\alpha(X)+N-1}{N}$, where $\alpha(X)$ is the minimum degree of a hypersurface passing through every point in X. He established his conjecture in the case $N = 2$, but the conjecture is still open in full generality. We will discuss known results and some further progress towards this conjecture. This is joint work with Paolo Mantero and Yu Xie. (Received September 20, 2015)

1116-13-1712 **Daniel Erman**, **Gregory G. Smith*** (ggsmith@mast.queensu.ca) and **Christine Berkesch Zamaere**. *Splendid complexes on products of projective space.* Preliminary report.

Syzygies capture subtle geometric properties of a subscheme in projective space. However, when the ambient space is a product of projective spaces or a general smooth toric variety, minimal free resolutions over the Cox ring are too long and contain many geometrically superfluous summands. In this talk, we will construct some much shorter free complexes that better encode the intrinsic geometry. (Received September 21, 2015)

1116-13-1799 **Sara Shirinkam*** (sara.shirinkam@utsa.edu), Department of Mathematics, University of Texas, San Antonio, TX 78249. *On the ideal based zero-divisor graph of a semiring.*

Let R be a commutative semiring with nonzero identity and $Z(R)$ its set of zero-divisors. The zero-divisor graph of R is $\Gamma(R)$, with vertices $Z(R) \setminus \{0\}$ and distinct vertices x and y are adjacent if and only if $xy = 0$. For a proper ideal I, an ideal based zero-divisor graph, denoted by $\Gamma_I(R)$ is a graph whose vertices are $\{x \in R \setminus I \mid xy \in I \ for\ some\ y \in R \setminus I\}$, and two distinct vertices x and y are adjacent if and only if $xy \in I$. In this paper, some of the properties of $\Gamma(R)$ and $\Gamma_I(R)$ and their relationship are investigated when R/I is a semiring. (Received September 22, 2015)

1116-13-1838 **Rebecca R.G.*** (rirg@umich.edu). *Closure operations that induce big Cohen-Macaulay modules and algebras, module closures, and classification of singularities.* Preliminary report.

Geoffrey Dietz introduced a set of axioms for a closure operation on a complete local domain R such that the existence of a closure operation satisfying these axioms is equivalent to the existence of a big Cohen-Macaulay module. These are called Dietz closures. In characteristic $p > 0$, solid closure, tight closure, and plus closure all satisfy the axioms. I will give an additional axiom for a closure operation such that the existence of a Dietz closure satisfying this axiom is equivalent to the existence of a big Cohen-Macaulay algebra.

I will also discuss module closures, including those coming from modules of syzygies and from canonical modules. As an application, I will show that under mild conditions, a ring R is regular if and only if all Dietz closures on R are trivial. The proof of this statement leads to results relating Dietz closures to familiar closures such as integral closure and regular closure. (Received September 21, 2015)

1116-13-1853 **Alex Fink**, **Jenna Rajchgot*** (rajchgot@umich.edu) and **Seth Sullivant**. *Matrix Schubert varieties and Gaussian conditional independence models.*

Matrix Schubert varieties are certain varieties in the affine space of square matrices determined by putting rank conditions on submatrices. I will discuss analogs of these varieties for the spaces of upper triangular and symmetric matrices and show that, as in the traditional matrix Schubert setting, defining ideals have nice Gröbner bases, and primary decomposition of sums of defining ideals can be computed combinatorially.

Our motivation for discussing these upper triangular and symmetric matrix Schubert varieties comes from algebraic statistics. I will explain how to use matrix Schubert varieties to solve two problems concerning Gaussian random variables.

This is joint work with Alex Fink and Seth Sullivant. (Received September 21, 2015)

1116-13-1864 **Karen E Smith*** (kesmith@umich.edu), Math Department, University of Michigan, 511 Church Street, Ann Arbor, MI 48109. *The Power of Noether's Ring Theory in Understanding Singularities of Complex Algebraic Varieties.*

In one of the tremendous innovations of twentieth century mathematics, Emmy Noether introduced the rigorous definition of commutative rings and their homomorphisms. One of her main motivating examples was the ring of polynomial functions on a complex algebraic variety. The algebraic study of these rings can have deep geometric consequences for the corresponding variety. In this talk, I hope to explain one example of this phenomenon: namely, how reduction to prime characteristic can give us insight into the singularities of the corresponding algebraic variety. Of course, I will need to convince you that we gain something powerful in reducing modulo p, since we have given up all the tools of analysis in doing so. What we gain is the *Frobenius operator* on the ring, which raises elements to their p-th powers, and is a *ring homomorphism* in characteristic p. I hope to explain how the Frobenius operator is helpful in understanding the singularities. As an application, I will describe some work with Angelica Benito, Jenna Rajchgot and Greg Muller on the singularities of varieties that arise in the theory of cluster algebras in combinatorics. (Received September 21, 2015)

1116-13-1962 **Evan M. O'Dorney*** (emo916math@gmail.com). *Rings of small rank over a Dedekind domain and their ideals.*

In 2001, M. Bhargava stunned the mathematical world by extending Gauss's 200-year-old group law on integral binary quadratic forms, now familiar as the ideal class group of a quadratic ring, to yield group laws on a vast assortment of analogous objects. His method yields parametrizations of rings of degree up to 5 over the integers, as well as aspects of their ideal structure, and can be employed to yield statistical information about such rings and the associated number fields.

I will speak about my Harvard senior thesis, which extends a selection of Bhargava's most striking parametrizations to cases where the base ring is not $\mathbb{Z}$ but an arbitrary Dedekind domain R. We find that, once the ideal classes of R are properly included, we readily get bijections parametrizing quadratic, cubic, and quartic rings, as well as an analogue of the $2 \times 2 \times 2$ cube law reinterpreting Gauss composition for which Bhargava is famous. We expect that these results will shed light on the analytic distribution of extensions of degree up to 5 of a fixed number field and their ideal structure. (Received September 21, 2015)

1116-13-1967 **Courtney R. Gibbons*** (crgibbon@hamilton.edu), 198 College Hill Road, Clinton, NY 13323, and **Luchezar Avramov** and **Roger Wiegand**. *A ring without a Boij-Soederberg theory.* Preliminary report.

A graded short Gorenstein ring R can be thought of as a ring with Hilbert series $1 + es + s^2$, where e is the multiplicity of the ring. In joint work with Avramov and Wiegand, we show that when $e \geq 3$, there are Betti diagrams of modules over R that cannot be realized as rational sums of diagrams that lie along extremal rays in the cone of Betti diagrams over R. (Received September 21, 2015)

1116-13-1983 **Hannah Altmann*** (haltmann@morris.umn.edu), **Eloisa Grifo**, **Srikanth Iyengar**, **Jonathan Montano**, **William Sanders** and **Thanh Vu**. *Perfect complexes over commutative rings.* Preliminary report.

Let R be a commutative ring. An R-complex F is *perfect* if it is quasiisomorphic to a bounded complex of finitely generated projective modules. A useful invariant associated to every perfect complex is its level. We can think of the level of F as the number of steps it takes to build F out of R. We will discuss finding bounds on the level of a perfect complex. In particular, we will show that the length of the largest gap in the homology of a complex F gives a lower bound for the level of F. (Received September 21, 2015)

1116-13-2005 **Eric Canton*** (ecanton2@math.unl.edu). *Frobenius actions and a type of singularity in characteristic $p > 0$.*

The singularities of rings with prime characteristic $p > 0$ are often studied using the p th-power ("Frobenius") homomorphism. In this talk, we study certain mild singularities of hypersurfaces in characteristic p using a Frobenius homomorphism on a particular module associated to the hypersurface. (Received September 21, 2015)

1116-13-2031 **Tracy Dawn Hamilton*** (hamilton@csus.edu). *Zariski-Samuel Associated Prime Ideals.* Preliminary report.

When studying non-Noetherian rings, one must be careful when discussing associated prime ideals. The many characterizations used in Noetherian ring theory are no longer equivalent. Many authors choose to work with what we call Zariski-Samuel associated prime ideals. However, not all authors use the same characterization of these associated primes. In this talk we will discuss the differences between these two characterizations. We will also look at conditions under which the two characterizations are equivalent. (Received September 21, 2015)

1116-13-2046 **Thomas McKenzie*** (mckenzie@gonzaga.edu). *The book thickness of zero divisor graphs with genus at most one.* Preliminary report.

Let R be a finite commutative ring with identity. We form the zero divisor graph of R by taking the nonzero zero divisors as the vertices and connecting two vertices, x and y, by an edge if and only if $xy = 0$. We determine the book thickness of all zero divisor graphs with genus at most one. (Received September 21, 2015)

1116-13-2178 **Liana M Sega*** (segal@umkc.edu) and **Melissa Menning**. *Cohomology of finite modules over short Gorenstein rings.*

Let R be a Gorenstein local ring with maximal ideal $\mathfrak{m}$ satisfying $\mathfrak{m}^3 = 0$. Set $k = R/\mathfrak{m}$ and $e = \operatorname{rank}_k(\mathfrak{m}/\mathfrak{m}^2)$. If $e > 2$ and M, N are finitely generated R-modules, we show that the formal power series

$$\sum_{i=0}^{\infty} \operatorname{rank}_k \left(\operatorname{Ext}^i_R(M,N) \otimes_R k\right) t^i \quad \text{and} \quad \sum_{i=0}^{\infty} \operatorname{rank}_k \left(\operatorname{Tor}^R_i(M,N) \otimes_R k\right) t^i$$

are rational, with denominator $1 - et + t^2$. (Received September 22, 2015)

1116-13-2280 **Jeff Madsen*** (jmadsen@nd.edu), University of Notre Dame, 219 Hayes-Healy Center, Notre Dame, IN 46556-5641. *Equations of Rees algebras of ideals in two variables.*

Let $R = k[x_0, x_1]$ and let I be a grade 2 ideal in R generated by forms of the same degree. I will give a method for computing equations of the Rees algebra of I based on the presentation matrix of I, generalizing the method of Kustin, Polini, and Ulrich for almost linearly presented ideals. In general this does not compute all the equations of the Rees algebra, but only those of large degree. A refinement in the case of 3-generated ideals gives a connection between the equations of lower degree and the singularities of the curve parametrized by I. (Received September 22, 2015)

1116-13-2313 **Eliana M Duarte*** (emduart2@illinois.edu) and **Hal Schenck** (schenck@illinois.edu). *Tensor Product surfaces and linear syzygies.*

A tensor product surface is the image of a rational map $\varphi : \mathbb{P}^1 \times \mathbb{P}^1 - > \mathbb{P}^3$. Such surfaces arise in geometric modeling and in this context it is useful to know the implicit equation of the closure of the image. In the first part of this talk I will explain how the syzygies of the defining polynomials of φ determine its implicit equation. For the second part and I will present recent progress on improving syzygy based algorithms to solve the implicitization problem for tensor product surfaces. (Received September 22, 2015)

1116-13-2319 **Daniel J Hernández*** (dhernan@umich.edu), dhernan@umich.edu, and **Emily E Witt**. *Explicit descriptions of F-thresholds.*

Using the Frobenius endomorphism, one can associate to any polynomial over a finite field a numerical invariant called an F-threshold. In this talk, we describe some explicit formulas for F-thresholds, and time permitting, we will discuss an interesting application of these formulas (originally observed by Mustata, Takagi, and Watanabe) to the problem of determining roots of Bernstein-Sato polynomials. This is joint work with Emily Witt. (Received September 22, 2015)

1116-13-2407 **Haydee M Lindo*** (lindo@math.utah.edu), 820 Main St, Apt 2, Williamstown, MA 01267. *Centers of endomorphism rings of modules.*

In my talk, I will present some new results concerning the center of the endomorphism ring of a finitely generated module over a commutative noetherian ring. The gist of the results is that the properties of the center are closely related to those of the module itself, especially in the context of one-dimensional Gorenstein rings. Trace ideals of modules are a key ingredient in the proofs. (Received September 22, 2015)

1116-13-2486 **George E Whelan*** (gwhelan@masonlive.gmu.edu). *Generalized Associated Primes and Depth in the Perfect Closure.* Preliminary report.

Let (R, m) be a local ring and M a module over R. If R is not Noetherian, the concept of an associated prime of M generalizes to definitions of weakly associated primes and strong Krull primes. Similarly the notion of depth requires finer definitions, which were first investigated by Barger and Hochster in the 1970s. In this talk we will establish the relationship between these prime ideals and their corresponding types of depth.

Here we will let (R, m) be a Noetherian ring of characteristic $p > 0$, and we investigate the perfect closure R^∞. The extension $R \to R^\infty$ has two relevant features: 1) the map $\operatorname{Spec}(R^\infty) \to \operatorname{Spec}(R)$ is an order isomorphism, and 2) R^∞ is almost always Non-Noetherian. We will discuss an arbitrary ideal $I \subset R$ and find a direct correspondence between the strong Krull primes of the cyclic module R^∞/IR^∞ and the associated primes of

$R/(I^{[p^e]})^F$ for $e \in \mathbb{N}$. We will consider corresponding notions of depth, and generalize the results to $(R^\infty \otimes M)$ for a finitely generated R-module M. (Received September 22, 2015)

1116-13-2489 **Greg Muller*** (morilac@umich.edu), **Jenna Rajchgot** and **Bradley Zykoski**. *Lower bound cluster algebras: presentation and properties.*

Cluster algebras are generated by a set of *cluster variables* which are produced by a recursive process called *mutation*. Unfortunately, these generating sets are often infinite, even when the algebra can be finitely generated. One workaround is to truncate the recursive process after a finite number of steps; the resulting algebra is called a *lower bound cluster algebra*.

This talk will review recent work which produced a uniform presentation of every lower bound cluster algebra. We consider a degeneration of the ideal of relations, which allows us to use techniques from combinatorics to prove that lower bound cluster algebras are always normal and Cohen-Macaulay. (Received September 22, 2015)

1116-13-2599 **Michael Axtell**, **Nicholas Baeth** and **Joe Stickles*** (jstickles@millikin.edu). *Cut Structures in Zero-Divisor Graphs of Commutative Rings.*

Zero-divisor graphs, and more recently, compressed zero-divisor graphs are well-represented in the commutative ring literature. In this work, we consider various cut structures, sets of edges or vertices whose removal disconnects the graph, in both compressed and non-compressed zero-divisor graphs. In doing so we connect these graph-theoretic concepts with algebraic notions and provide realization theorems of zero-divisor graphs for commutative rings with identity. (Received September 22, 2015)

1116-13-2601 **Jason Hardin*** (jhardin@worcester.edu). *Bounding the Degrees of Ext-Modules over Complete Intersections.*

Given a module M over a complete intersection R of codimension c, $\mathrm{Ext}^*_R(M,k)$ can be viewed as a graded module over the polynomial ring in c variables with an action given by the Eisenbud operators. We provide an upper bound on the degrees of the generators of this graded module in terms of the regularities of two associated coherent sheaves. In the codimension two case, this bound recovers a bound of Avramov and Buchweitz in terms of the Betti numbers of M. (Received September 22, 2015)

1116-13-2608 **Pye Phyo Aung*** (paung@pacific.edu). *Gorenstein Dimensions of Module-finite Extensions.* Preliminary report.

Enochs and Jenda's Gorenstein dimensions are generalized by Holm and Jørgensen to C-Gorenstein dimensions, where C is a semidualizing R-module, in their study of connections between C-Gorenstein dimensions of an R-complex and Gorenstein dimensions of the same complex viewed as a complex over the trivial extension $R \ltimes C$. We generalize these connections to a certain type of retract diagram, recovering $R \ltimes C$ as a special case. Furthermore, we simplify the retract diagram into a module finite extension, assuming the existence of a dualizing R-complex. We investigate along the way the "local-global property" of some C-Gorenstein dimensions and a characterization of semidualizing modules in our generalized setting. (Received September 22, 2015)

1116-13-2627 **Hailong Dao*** (hdao@ku.edu), Lawrence, KS 66045. *On the relationship between depth and cohomological dimension.*

(joint work with Shunsuke Takagi) Let (S,m) be an n-dimensional regular local ring essentially of finite type over a field and let I be an ideal of S. We prove that if $\mathrm{depth} S/I \geq 3$, then the cohomological dimension $\mathrm{cd}(S,I)$ of I is less than or equal to $n-3$. We also show, under the assumption that S has an algebraically closed residue field of characteristic zero, that if $\mathrm{depth} S/I \geq 4$, then $\mathrm{cd}(S,I) \leq n-4$ if and only if the local Picard group of the completion $\widehat{S/I}$ is torsion. We give a number of applications, including sharp bounds on cohomological dimension of ideals whose quotients satisfy good depth conditions such as Serre's conditions (S_i). (Received September 22, 2015)

1116-13-2771 **Paul Baginski*** (pbaginski@fairfield.edu), Department of Mathematics, Fairfield University, 1073 North Benson Rd, Fairfield, CT 06824. *Elasticity in Arithmetic Congruence Monoids.*

For integers $0 < a \leq b$, the arithmetic progression $M_{a,b} := a + b\mathbb{N}$ is closed under multiplication if and only if $a^2 \equiv a \mod b$. Any such multiplicatively closed arithmetic progression is called an arithmetic congruence monoid (ACM). Though these $M_{a,b}$ are multiplicative submonoids of $\mathbb{N}$, their factorization properties differ greatly from the unique factorization one enjoys in $\mathbb{N}$. This talk will explore the known factorization properties of these monoids, with a particular emphasis on recent results about the elasticity. When $a > 1$, these monoids are not Krull and thus do not have a class group which fully captures the factorization behavior. Nonetheless, a certain finite abelian group associated to it does convey some of the information one would expect from a class group. The analysis of elasticity properties requires studying the additive combinatorics of this group, hinging on the existence of certain combinatorial configurations. (Received September 22, 2015)

14 ► Algebraic geometry

1116-14-107 **Daniel Chan** and **Adam Nyman*** (adam.nyman@wwu.edu). *Species and non-commutative $\mathbb{P}^1$'s over non-algebraic bimodules.*

By realizing the derived categories of certain K-species as derived categories of non-commutative $\mathbb{P}^1$-bundles, we generalize, and give a geometric interpretation for, results of C. Ringel. (Received July 26, 2015)

1116-14-254 **Kaitlyn A. Perry*** (kaperry1@crimson.ua.edu), Tuscaloosa, AL 35404. *Polydegree Properties of Polynomial Automorphisms.*

The group of automorphisms of the affine plane has the structure of an amalgamated free product of the triangular and affine subgroups. This leads us to the polydegree: the unique sequence of degrees of the triangular automorphisms in the amalgamated free product decomposition of the automorphism. The automorphism group is also endowed with the structure of an infinite dimensional algebraic variety. The interaction between these two structures is not well understood. We will discuss the general problem and a new result that a class of automorphisms with a polydegree of length one are contained in the closure (in the Zariski topology) of a set of automorphisms with a polydegree of length 2. In particular, the set of automorphisms with a polydegree (d+2) is contained in the closure of a set of automorphisms with a polydegree (d,3). (Received September 22, 2015)

1116-14-293 **Cameron Farnsworth*** (cfarnsworth@math.tamu.edu). *Secants of the Veronese and the Determinant.*

Let $\det_n \in S^n(\mathbb{C}^{n^2})$ be the homogeneous polynomial obtained by taking the determinant of an $n \times n$ matrix of indeterminates. In this presentation linear maps called Young flattenings will be defined. It will then be shown how these maps may be used to demonstrate new lower bounds on the symmetric border rank of $\det_n$. (Received August 24, 2015)

1116-14-425 **Natalie Hobson*** (nhobson@uga.edu), UGA Department of Math, Boyd Graduate Research Center, Room 438, Athens, GA 30605. *Quantum Kostka and the rank one problem for $\mathfrak{sl}_{2m}$.*

Vector bundles of conformal blocks on $\overline{M}_{g,n}$, the moduli space of stable n-pointed curves of genus g, are determined by a simple Lie algebra $\mathfrak{g}$, a positive integer ℓ, and an n-tuple $\vec{\lambda}$ of dominant integral weights for $\mathfrak{g}$ at level ℓ. On $\overline{M}_{0,n}$ these bundles are globally generated and their first Chern classes are base point free. The ranks of the bundles, when $\mathfrak{g} = \mathfrak{sl}_{r+1}$, can be computed using Schubert calculus. In this talk, using quantum Kostka and other tools, I classify ranks of $\mathfrak{sl}_{2m}$ bundles with so-called rectangular weights. Using similar techniques I show that the subcone of the nef cone spanned by the infinite family of first Chern classes of bundles of rank one is actually polyhedral, the convex hull of a finite number of extremal rays. (Received September 04, 2015)

1116-14-447 **Brooke Susanna Ullery*** (ullery@math.utah.edu). *Normality of Secant Varieties.*

If X is a smooth variety embedded in projective space, we can form a new variety by looking at the closure of the union of all the lines through 2 points on X. This is called the secant variety to X. Similarly, the Hilbert scheme of 2 points on X parametrizes all length 2 zero-dimensional subschemes. I will talk about how these two constructions are related. More specifically, I will show how we can use certain tautological vector bundles on the Hilbert scheme to help us understand the geometry of the secant variety, leading to a proof that for sufficiently positive embeddings of X, the secant variety is a normal variety. (Received September 02, 2015)

1116-14-486 **Bernd Sturmfels*** (bernd@berkeley.edu), Department of Mathematics, University of California, Berkeley, CA 94720. *The Hurwitz form of a projective variety.*

The Hurwitz form of a variety is the discriminant that characterizes linear spaces of complementary dimension which intersect the variety in fewer than degree many points. We study computational aspects of the Hurwitz form, relate this to the dual variety and Chow form, and show why reduced degenerations are special on the Hurwitz polytope. (Received September 03, 2015)

1116-14-492 **Aaron Landesman*** (aaronlandesman@college.harvard.edu) and **David Zureick-Brown**. *Smoothability of Genus 6 Petri General Curves.* Preliminary report.

We introduce and study the log Petri scheme, a generalization of Schreyer and Little's Petri scheme. As an application, we prove that the Petri general locus of the Hilbert scheme of canonically embedded curves is irreducible for genus $g \leq 6$, fixing an error in a paper of Little. (Received September 04, 2015)

1116-14-512 **Jose Luis Gonzalez*** (jose.gonzalez@yale.edu) and **Kalle Karu** (karu@math.ubc.ca). *The moduli space of stable n-pointed genus zero curves is not a Mori dream space when n is at least 13.*

We prove that the moduli space $\overline{M}_{0,n}$ of stable n-pointed genus zero curves is not a Mori dream space when n is at least 13. We build on the work of Ana-Maria Castravet and Jenia Tevelev who recently obtained the same conclusion when n is at least 134. (Received September 05, 2015)

1116-14-540 **Rekha Thomas*** (rrthomas@uw.edu). *Algebraic Methods in Computer Vision.*

A foundational problem in computer vision is the reconstruction of 3-dimensional scenes from camera images of the scene. In the absence of noise, this reconstruction problem is often equivalent to the existence of a real solution to a system of polynomial equations. This allows one to study these problems using tools from algebraic geometry, commutative algebra, combinatorics and polynomial optimization. In this talk I will describe recent results that have been possible by approaching 3D reconstruction problems from such an algebraic point of view. (Received September 06, 2015)

1116-14-619 **James E Freitag*** (freitagj@gmail.com), 15335 Magnolia BLVD, 114, Sherman Oaks, CA 91403, and **Rahim Moosa**. *Around the Jouanolou-Hrushovski-Ghys Theorem.*

Given a smooth variety and a vector field, a theorem of Jouanolou relates the existence of enough integrable hypersurfaces for a given Pfaffian equation the existence of meromorphic first integrals. The theorem was later generalized by Hrushovski and applied to differential algebraic geometry. Ghys also later generalized Jouanolou's theorem and provided a simplified proof.

Hrushovski used his generalization of Jouanolou's theorem to prove that if a system of ordinary differential equations with constant coefficients has infinitely many co-order one subvarieties, then there is a nonconstant differential rational map from the solution set to the constants.

We generalize the Jouanolou-Hrushovski-Ghys Theorem to a form suitable for application to partial differential equations, and establish the analog of Hrushovski's result in that setting. We also generalize the Hrushovski's theorem to include systems of differential equations with nonconstant coefficients. (Received September 09, 2015)

1116-14-653 **Ada Boralevi**, **Jan Draisma*** (j.draisma@tue.nl), **Emil Horobeţ** and **Elina Robeva**. *Unitarily decomposable tensors.*

The singular value decomposition shows that a complex matrix can be written, almost uniquely, as a sum of rank-one matrices of which the column spaces are pairwise orthogonal relative to a Hermitian form, and likewise for the row spaces. Higher-order tensors do not, in general, admit such a decomposition. In this talk I will present an intrinsic characterisation, by means of polynomial equations, of those tensors that do. I will do so in the three realms of ordinary, symmetric, and skew-symmetric tensors. Such unitarily decomposable tensors and their real-orthogonal counterparts appear in various applications, such as topic models in machine learning. (Received September 10, 2015)

1116-14-796 **Brett Frankel*** (lastnamefirstinitial@math.upenn.edu). *Counting Local Systems on Supersingular Abelian Varieties.* Preliminary report.

In a 2008 paper, Hausel and Rodriguez-Villegas studied the moduli space of (twisted) local systems on a Riemann surfaces by computing the number of representations of the fundamental group in $GL_n(q)$. We will discuss some situations where instead of a Riemann surface, one considers an abelian variety defined over an algebraically closed field of characteristic p. The space of such representations turns out to be a constructible set. For a supersingular abelian variety A, we count the number of representations of the etale fundamental group of A to $GL_n(q)$, where q is a power of p. This count (for fixed n) turns out to be a polynomial in q. We give an explicit formula for this polynomial, then state a few theorems which elucidate its features. In particular, we state a new result which generalizes to cosets a theorem of Frobenius about the number of solutions to $x^n = 1$ in a finite group. (Received September 13, 2015)

1116-14-799 **Mee Seong Im*** (meeseong.im@usma.edu), 646 Swift Road, Department of Mathematical Sciences, United States Military Academy, West Point, NY 10996, and **Ben Cox** (coxbl@cofc.edu). *On the categorification of Verma modules for $\mathfrak{sl}_2$.* Preliminary report.

The quiver-graded Springer and the Grothendieck-Springer resolutions are extremely interesting geometric objects as they appear in the geometric construction of quiver Hecke algebras, modified Steinberg varieties, quantum shuffle algebras and quantum cluster algebras, to name a few. I will talk about the general notion of categorification, leading us to the current work-in-progress of categorifying Verma modules for the Lie algebra $\mathfrak{sl}_2$. This is joint with Ben Cox, a faculty at the College of Charleston. (Received September 14, 2015)

1116-14-822 **Padmavathi Srinivasan*** (padma_sk@math.mit.edu), Building E18, Room 369, 77 Massachusetts Avenue, Cambridge, MA 02139-4307. *Conductors and minimal discriminants of hyperelliptic curves with rational Weierstrass points.*

Conductors and minimal discriminants are two measures of degeneracy of the singular fiber in a family of hyperelliptic curves. In the case of elliptic curves, the Ogg-Saito formula shows that (the negative of) the Artin conductor equals the naive minimal discriminant. In the case of genus two curves, equality no longer holds in general, but the two invariants are related by an inequality. We investigate the relation between these two invariants for hyperelliptic curves of arbitrary genus. (Received September 13, 2015)

1116-14-903 **Angelica Benito*** (angelica.benito@icmat.es), Instituto de Ciencias Matemáticas (ICMAT), C/ Nicolás Cabrera, 13-15, Campus de Cantoblanco, UAM, 28049 Madrid, Madrid, Spain, and **Orlando E. Villamayor U.** (villamayor@uam.es), Dpto Matemáticas - Fac. Ciencias, Universidad Autónoma de Madrid, Ciudad Universitaria de Cantoblanco, 28049 Madrid, Madrid, Spain. *Resolution of singularities: new invariants in positive characteristic.*

In this talk we present some new invariants of the singularities defined in the case of positive characteristic using commutative algebra tools. These invariants are an extension of some others defined in previous jobs (used, in particular, to prove resolution of singularities of 2-dimensional schemes). The improvement of these new ones is that they are now upper semicontinuous. This is a joint work with Orlando E. Villamayor U. (Received September 15, 2015)

1116-14-1011 **Aaron Tyler Wagner*** (awagne18090@viterbo.edu), 710 8th Street South, Clare Apartments, #302, La Crosse, WI 54601, and **Kainalu Barino**, **Monica Busser** and **Vanessa Aguirre**. *Determining Unique Hamiltonicity Using Gröbner Bases.*

Recent advances in computational algebraic geometry by De Loera et al. allow us to recognize certain graph theoretic properties, such as graph colorability and Hamiltonicity with polynomial ideals. These results allow us to test for such properties in an automated way using the computer. We employ these results to develop and implement algorithms written in the mathematical software system Sage to systematically test various combinatorial conjectures in graph theory. In particular, we have used our methods to test Sheehan's Conjecture (1975) which states that every Hamiltonian 4-regular graph has at least two distinct Hamiltonian cycles. Our results verify Sheehan's Conjecture for 4-regular graphs on up to 10 vertices and give support for other combinatorial conjectures. Our software can be easily modified to test other combinatorial conjectures for graphs. (Received September 16, 2015)

1116-14-1019 **Grigoriy Blekherman*** (greg@math.gatech.edu), **Rainer Sinn** and **Mauricio Velasco**. *Spectrahedral Cones with rank 1 extreme rays.* Preliminary report.

A sprectrahedral cone C is a slice of the cone of positive semidefinite matrices with a linear subspace L. The ranks of extreme rays of spectrahderal cones have been a subject of extensive study. It is natural to ask for what subspaces L do all of the extreme rays of C have rank 1? When L is a union of coordinate subspaces the answer was given by Agler-Helton-McCullough-Rodman. It turns out that this question has an unexpected connection to algebraic geometry and we will present soem steps toward a full classification of such spectrahedral cones based on the classification of small reduced schemes by Eisenbud-Green-Hulek-Popescu. This is joint work with Rainer Sinn and Mauricio Velasco. (Received September 16, 2015)

1116-14-1082 **Valerie Peterson**, **Jacob Russell** and **Aaron Wootton***, 5000 North Willamette Blvd, Portland, OR 97203. *Maximal Group Actions on Compact Oriented Surfaces.* Preliminary report.

We consider the problem of when a cyclic group of orientation preserving automorphisms C_p of prime order p on a compact oriented surface S of genus $\sigma \geq 2$ is finitely maximal, meaning there is no non-trivial finite supergroup $G > C_p$ of orientation preserving automorphisms of S. We show that such a supergroup always exists unless the number of fixed points of the action is maximal (or equivalently, the quotient genus S/C_p is minimal). Moreover, we exhibit an infinite sequence of genera within which C_p is never finitely maximal. (Received September 16, 2015)

1116-14-1127 **David Swinarski*** (dswinarski@fordham.edu), 113 W 60th St Room 813, New York, NY 10023. *Equations of Riemann surfaces with automorphisms via partial flattening stratifications.* Preliminary report.

Riemann surfaces with automorphisms have been studied since the 19th century, but many questions remain open. Computer searches have yielded lists of possible automorphism groups of Riemann surfaces. Equations of many of these surfaces are known, but in general there is no algorithm to determine these equations. I will present one such strategy which uses a mixture of group theory, representation theory, and algebraic geometry. In particular, computing partial flattening stratifications has allowed me to compute equations of many new examples of equations for genus 6 through 10 Riemann surfaces. (Received September 17, 2015)

1116-14-1202 **Noah Giansiracusa*** (noahgian@uga.edu) and **Patricio Gallardo**. *A moduli space of points in affine space as a Chow quotient.*

I'll discuss joint work with Patricio Gallardo in which we revisit the Chen-Gibney-Krashen moduli space compactifying configurations of n distinct points in affine space up to translation and homothety. This is a smooth, projective compactification with normal crossings boundary and a nice modular interpretation in terms of blown-up projective spaces. I'll explain how this space can be constructed as a Chow quotient and explore the geometry related to this idea. (Received September 17, 2015)

1116-14-1366 **Yuan Wang*** (ywang@math.utah.edu). *Generic vanishing and classification of irregular surfaces in positive characteristics.*

Classification of surfaces is a very classical topic. A classification for surfaces with Kodaira dimension -1,0 and 1, known as the Enriques-Kodaira Classification, has been given in the last century. But after that the classification of surfaces of general type is much more difficult. There were results in characteristic 0 made between 1982 and 2003. My recent work provides a classification result for surfaces of general type with Euler characteristic 1 and Albanese dimension 4 in positive characteristics, and to the best of my knowledge this is the first explicit classification result for surfaces of general type in positive characteristics. The construction of this result is inspired by a paper of Hacon and Pardini but contains a lot of new ideas, including the construction of a generic vanishing theorem for surfaces that lift to $W_2(k)$, the second Witt vector space. In my talk I will present the generic vanishing theorem and explain how it helps in studying the structure of irregular surfaces. (Received September 19, 2015)

1116-14-1439 **Michael Joswig** and **Joe Kileel*** (jkileel@math.berkeley.edu), Department of Mathematics, UC Berkeley, CA 94720, and **Bernd Sturmfels** and **André Wagner**. *Rigid Multiview Varieties.*

The multiview variety from computer vision is generalized to images by n cameras of points linked by a distance constraint. The resulting five-dimensional variety lives in a product of $2n$ projective planes. We determine defining polynomial equations, and we explore generalizations to scenarios of interest in applications. (Received September 19, 2015)

1116-14-1460 **Ada Boralevi**, **Jan Draisma**, **Emil Horobet** and **Elina Robeva*** (erobeva@berkeley.edu). *Orthogonal Tensor Decomposition.*

A tensor is orthogonally decomposable if it can be written as a linear combination of rank-one tensors $a_i \otimes b_i \otimes c_i \otimes \cdots$ such that the a_i are orthonormal, the b_i are orthonormal, the c_i are orthonormal, etc. Every matrix is orthogonally decomposable because of the singular value decomposition theorem. In this work we give equations that cut out the variety of orthogonally decomposable tensors. (Received September 20, 2015)

1116-14-1469 **Hirotachi Abo*** (abo@uidaho.edu) and **Nick Vannieuwenhoven** (nick.vannieuwenhoven@cs.kuleuven.be). *Most secant varieties of tangential varieties to Veronese varieties are nondefective.*

The main goal of this talk is to present a result related to a conjecture suggested by Catalisano, Geramita, and Gimigliano in 2002, which claims that the secant varieties of tangential varieties to Veronese varieties are nondefective modulo a few known exceptions. This is joint work with Nick Vannieuwenhoven. (Received September 20, 2015)

1116-14-1479 **Andrew Niles*** (aniles@holycross.edu). *The Picard groups of the stacks* $Y_0(2)$ *and* $Y_0(3)$.

We compute the Picard group of the stack of elliptic curves equipped with a cyclic subgroup of order 2, and of the stack of elliptic curves equipped with a cyclic subgroup of order 3, over any base scheme on which 6 is invertible. This generalizes a result of Fulton-Olsson, who computed the Picard group of the stack of elliptic curves (with no level structure) over a wide variety of base schemes. (Received September 20, 2015)

1116-14-1481 **S. Allen Broughton*** (brought@rose-hulman.edu), Department of Mathematics, Rose-Hulman Institute of Technology, 5500 Wabash Avenue, Terre Haute, IN 47803. *Quasi-platonic actions of some simple groups on Riemann surfaces and their dessins d'enfant.* Preliminary report.

A quasi-platonic action of the group G on the Riemann surface S is a conformal action of G on S such that S/G is a sphere and the projection $S \to S/G$ is branched over $\{0, 1, \infty\}$. The action is induced by a triple of $(a, b, c) \in G^3$, generating G, with $abc = 1$. The quasi-platonic action induces a regular dessin d'enfant on S, and S is defined over a number field. The absolute Galois group $\mathrm{Gal}(\overline{\mathbb{Q}}/\mathbb{Q})$ acts on dessins, hence quasi-platonic actions, by acting on the coefficients of a defining equation of S. The action of $\psi \in \mathrm{Gal}(\overline{\mathbb{Q}}/\mathbb{Q})$ on triples is $(a, b, c) \to (ua^tu^{-1}, vb^tv^{-1}, wc^tw^{-1})$, for some $(u, v, w) \in G^3$, according to the branch cycle argument. The integer t is characterized by the action of ψ on cyclotomic subfields of $\overline{\mathbb{Q}}$, and (u, v, w) is determined by the action of ψ away from cyclotomic subfields. In this talk we discuss the action of the absolute Galois group on quasi-platonic actions on some simple groups. In particular, we show that the Galois action on quasi-platonic actions of $PSL_2(q)$ depends only the action on cyclotomic subfields. (Received September 20, 2015)

1116-14-1505 **Rohini Ramadas*** (ramadas@umich.edu). *Hurwitz Correspondences on* $\overline{\mathcal{M}}_{0,N}$.

We consider Hurwitz spaces $\mathcal{H}$ parametrizing maps between smooth marked genus zero curves, with prescribed ramification. $\mathcal{H}$ defines a rational correspondence from the moduli space $\mathcal{M}_{0,N_2}$ to the moduli space $\mathcal{M}_{0,N_1}$, parametrizing target and source curves, respectively. For given compactifications X_2 and X_1 of $\mathcal{M}_{0,N_2}$ and $\mathcal{M}_{0,N_1}$, this induces pushforward maps $\mathcal{H}_* : H_{2k}(X_2) \to H_{2k}(X_1)$. This *Hurwitz correspondence* arises naturally when studying the Thurston pullback map on Teichmüller space.

We show that $\mathcal{H}_*$ satisfies a desirable stability condition on the stable curves compactifications $\overline{\mathcal{M}}_{0,N}$ and find a natural filtration of $H_{2k}(\overline{\mathcal{M}}_{0,N})$ indexed by the poset {partitions of k} that is preserved by $\mathcal{H}_*$. We use this filtration to find an alternate modular compactification of $\mathcal{M}_{0,N}$ on which $\mathcal{H}_*$ is stable on half of the homology groups, and prove that no similar result is possible for the other half. We finally discuss applications to computing dynamical degrees of this correspondence. (Received September 20, 2015)

1116-14-1507 **Sándor J Kovács*** (skovacs@uw.edu) and **Zsolt Patakfalvi**. *Subadditivity of log-Kodaira dimension.*

This is a report on joint work with Zsolt Patakfalvi. We prove several positivity results for fiber spaces whose general fiber is of log general type and use them to confirm the Iitaka-Viehweg conjecture on the subadditivity of log-Kodaira dimension. (Received September 20, 2015)

1116-14-1509 **Sándor J Kovács*** (skovacs@uw.edu) and **Zsolt Patakfalvi**. *Projectivity of the moduli space of stable log-varieties.*

This is a report on joint work with Zsolt Patakfalvi. We prove a strengthening of Kollár's Ampleness Lemma and use it to prove that any proper coarse moduli space of stable log-varieties of general type is projective. (Received September 20, 2015)

1116-14-1519 **Dawei Chen** and **Nicola Tarasca*** (tarasca@math.utah.edu). *Extremality of Weierstrass points on genus-two curves.*

The locus of genus-two curves with n marked Weierstrass points has codimension n inside the moduli space of genus-two curves with n marked points, for $n \leq 6$. It is well known that the class of the divisor obtained for $n = 1$ spans an extremal ray of the cone of effective divisor classes of the moduli space of stable genus-two curves with one marked point. We generalize this result for all n: we show that the class of the closure of the locus of genus-two curves with n marked Weierstrass points spans an extremal ray of the cone of effective classes of codimension n, for $n \leq 4$, and spans an extremal ray of the sub-cone of effective tautological classes of codimension n, for $n \leq 6$. (Received September 21, 2015)

1116-14-1525 **Kristian Ranestad*** (ranestad@math.uio.no). *Tensor decompositions and cubic sections of rational surface scrolls.* Preliminary report.

The variety of multi secant spaces to a projective variety X through a point P in projective space has been studied as a variety a tensor decompositions of a symmetric tensor, when X is a d-uple Veronese variety. For the cubic reembedding X of a rational surface scroll and P general, the variety is a surface that can be interpreted as a variety of tensor decompositions. I shall report on work in progress with Nelly Villamizar and Matteo Gallet on this topic. (Received September 20, 2015)

1116-14-1529 **Lorenzo Prelli*** (lorenzop@uw.edu), University of Washington, Department of Mathematics, Box 354350, Seattle, WA 98195-4350. *On rationalizing divisors.*

Rational pairs generalize the notion of rational singularities to reduced pairs (X, D). In this talk we will deal with the problem of determining whether a normal variety X has a rationalizing divisor, i.e. a reduced divisor D such that (X, D) is a rational pair. We will give a criterion for cones to have a rationalizing divisor, and relate the existence of such a divisor to the locus of rational singularities of a variety. (Received September 20, 2015)

1116-14-1531 **Aaron Pixton*** (apixton@mit.edu). *Families of tautological relations.*

The tautological ring of the moduli space of smooth curves of genus g is the subring of its Chow ring generated by the kappa classes. The Faber-Zagier relations are a large family of polynomial relations between the kappa classes, conjectured to give all such relations. In 2012 Qizheng Yin described a method of constructing relations in the tautological ring using the geometry of the universal Jacobian. I will discuss recent work connecting Yin's relations to the Faber-Zagier relations. (Received September 20, 2015)

1116-14-1607 **Mario Kummer** and **Cynthia Vinzant*** (clvinzan@ncsu.edu). *Reciprocal linear spaces and their Chow forms.*

A reciprocal linear space is the image of a linear space under coordinate-wise inversion. This nice algebraic variety appears in many contexts and its structure is governed by the combinatorics of the underlying hyperplane arrangement. A reciprocal linear space is also an example of a hyperbolic variety, meaning that there is a family of linear spaces all of whose intersections with it are real. This special real structure is witnessed by a determinantal representation of its Chow form in the Grassmannian. In this talk, I will introduce reciprocal linear spaces and discuss the relation of their algebraic properties to their combinatorial and real structure. (Received September 20, 2015)

1116-14-1780 **Anand Deopurkar***, anandrd@math.columbia.edu, and **Anand Patel**. *Picard groups of Hurwitz spaces.*

Hurwitz spaces are moduli spaces of simply branched covers of the projective line. I will address a fundamental question about their geometry–the question of their Picard group. It is conjectured that the Picard group is torsion. I will motivate this conjecture and sketch a proof for Hurwitz spaces of covers of degree up to five. (Received September 21, 2015)

1116-14-1785 **Anand Deopurkar***, anandrd@math.columbia.edu. *Limits of plane quintics via covers of stacky curves.*

Which stable curves are limits of smooth plane curves? I will describe the answer explicitly in the first non-trivial case, namely the case of plane quintics. To do so, we will interpret such a curve in terms of a branched cover, but with a twist: the base of the cover will be a stack. The answer will then follow from a nice compactification of the moduli space of stacky branched covers. (Received September 21, 2015)

1116-14-1788 **Adrian Clingher**, **Charles Doran*** (charles.doran@ualberta.ca) and **Andreas Malmendier**. *Generalized hypergeometric function identities from superelliptic curves and their associated Kummer varieties.* Preliminary report.

We prove that the factorization of Appell's generalized hypergeometric series satisfying the so-called quadric property amounts to the decomposition of a holomorphic period integral on a Kummer variety built from a pair of two super elliptic curves, with respect to a natural pair of isotrivial and a non-isotrivial fibrations. (Received September 21, 2015)

1116-14-1803 **Inna I Zakharevich*** (zakh@math.uchicago.edu), 5734 S University Ave, Eckhart 208, Chicago, IL 60637. *Deriving the Grothendieck ring of varieties.*

The Grothendieck ring of varieties over a base field k—written $K_0[\mathcal{V}_k]$—is defined to be the free abelian group generated by varieties over k, modulo the relations that for any closed immersion $Y \hookrightarrow X$, $[X] = [Y] + [X \backslash Y]$. The multiplication is induced by the Cartesian product of varieteies. The abelian group $K_0[\mathcal{V}_k]$ is the universal additive invariant: any function of varieties χ that satisfies $\chi(X) = \chi(Y) + \chi(X \backslash Y)$ factors through $K_0[\mathcal{V}_k]$. In this talk we construct a topological space whose π_0 is $K_0[\mathcal{V}_k]$, and whose higher homotopy groups produce invariants of automorphisms of varieties. This allows us to construct a spectral sequence whose differentials measure the difference between two varieties being birational and stably birational. We use this spectral sequence to show that any element in the annihilator of $[\mathbb{A}^1]$ can be written as $[X] - [Y]$, where $X \times \mathbb{A}^1$ and $Y \times \mathbb{A}^1$ are stably birational but not birational. (Received September 21, 2015)

1116-14-1953 **Ragnar-Olaf Buchweitz** and **Eleonore M Faber*** (emfaber@umich.edu), Department of Mathematics, 530 Church Street, Ann Arbor, MI 48109, and **Colin Ingalls**. *A McKay correspondence for reflection groups.* Preliminary report.

The classical McKay correspondence relates the geometry of so-called Kleinian surface singularities with the representation theory of finite subgroups of $SL(2, C)$. There is also an algebraic version of the correspondence, initiated by M. Auslander: let G be a finite subgroup of $SL(2, K)$ for a field K whose characteristic does not divide the order of G. The group acts linearly on the polynomial ring $S = K[x, y]$ and then the so-called skew group algebra $A = G * S$ can be seen as an incarnation of the correspondence.

We want to establish an analogous result when G in $GL(n, K)$ is a finite group generated by reflections, assuming that the characteristic of K does not divide the order of the group. Therefore we consider again the skew group algebra $A = G * S$, where S is the polynomial ring in n variables, and its quotient A/AeA, where e is the idempotent in A corresponding to the trivial representation. With D the coordinate ring of the discriminant of the group action on S, we show that the ring A/AeA is the endomorphism ring of the direct image of the coordinate ring of the associated hyperplane arrangement.

In this way one obtains a noncommutative resolution of singularities of that discriminant, a hypersurface that is singular in codimension one. (Received September 21, 2015)

1116-14-1991 **David R Morrison*** (drm@math.ucsb.edu). *Elliptic curves over function fields and algebraic groups.* Preliminary report.

A construction from physics associates an algebraic group to every elliptic curve over a function field in characteristic zero. We will explain this construction, and explore the possibility of a similar construction in the arithmetic case. (Received September 21, 2015)

1116-14-2110 **Anand Patel*** (anand.patel@bc.edu). *Slopes of families of curves.*

We will survey known results about the "slope" of a one parameter family of curves, especially its relationship with geometric properties of the generic fiber. We will then invoke the traditional "function field/ number field analogies" and discuss analogous results for arithmetic surfaces. (Received September 21, 2015)

1116-14-2164 **Christopher Swierczewski*** (cswiercz@gmail.com), University of Washington, Dept. of Applied Mathematics, Lewis Hall #202, Box 353925, Seattle, WA 98105-3925. *Computing the Riemann Constant Vector.*

The Riemann constant vector is a fundamental ingredient in the study of Riemann surfaces and their Jacobians. It is necessary to discuss the Jacobi inversion problem, for the study of the theta divisor, and for periodic solutions to integrable partial differential equations.

We present recent improvements to a mathematical algorithm and an implementation for computing the Riemann constant vector on a Riemann surface given by the desingularization and compactification of a complex plane algebraic curve. The source code of the implementation is provided in the Python software package "abelfunctions". (Received September 22, 2015)

1116-14-2246 **Yuval Dor*** (yuval.dor@mail.huji.ac.il). *Zeta functions of difference varieties.* Preliminary report.

Let X be an algebraic variety defined over a finite field with p elements, and let $f : X \to X$ be a dominant map. Let N_k denote the number of solutions to the equation $f(x) = x^{p^k}$; if f is the identity, then this is the number of $\mathbb{F}_q$ rational points of X.

Results due to E. Hrushovski give estimates on N_k analogous to the Lang Weil bounds. In particular, it can be shown that N_k is nonzero for k sufficiently large. This has applications in group theory, model theory and algebraic geometry.

We explain some of the methods used to prove this and how they can be used to establish rationality of the generating function $\sum N_k t^k$

This is part of a master's thesis supervised by Ehud Hrushovski (Received September 22, 2015)

1116-14-2328 **Serkan Hosten***, San Francisco State University, Department of Mathematcis, 1600 Holloway Avenue, San Francisco, CA 94707. *Maximum Likelihood Degree of Toric Models in Algebraic Statistics.* Preliminary report.

The Maximum likelihood degree of a toric variety is the Euler characteristic of a hypersurface associated to the log likelihood function in that toric variety. Despite this general result, computing the maximum likelihood degree of a specific toric variety is a challenge. We will report on progress for computing the maximum likelihood degree of toric varieties that appear in algebraic statistics, such as hierarchical log-linear models. (Received September 22, 2015)

1116-14-2382 **Ursula Whitcher*** (whitchua@uwec.edu). *Mirror symmetry and K3 surface zeta functions.*

Mirror symmetry predicts surprising geometric correspondences between distinct families of algebraic varieties. In some cases, these correspondences have arithmetic consequences. We use Berglund-Huebsch-Krawitz mirror symmetry to make and test predictions about the zeta functions of certain K3 surfaces described by quartic polynomials, generalizing the notion of isogeny for elliptic curves. (Received September 22, 2015)

1116-14-2465 **Jacob P. Matherne*** (jmath34@lsu.edu). *Derived geometric Satake equivalence, Springer correspondence, and small representations.* Preliminary report.

A recurring theme in geometric representation theory is the ability to describe representations in terms of the geometry or topology of certain spaces. Two major theorems in this area are the geometric Satake equivalence and the Springer correspondence, which state:

(1) For G a semisimple algebraic group, we can realize $\mathrm{Rep}(G)$ as intersection cohomology of the affine Grassmannian for the Langlands dual group.

(2) For W a Weyl group, we can realize $\mathrm{Rep}(W)$ as intersection cohomology of the nilpotent cone.

In the late 90s, M. Reeder computed the Weyl group action on the zero weight space of the irreducible representations of G, thereby relating $\mathrm{Rep}(G)$ to $\mathrm{Rep}(W)$. More recently, P. Achar, A. Henderson, and S. Riche have established a functorial relationship between the two phenomena above. In my talk, I will discuss my thesis work which extends their functorial relationship to the setting of mixed, derived categories. (Received September 22, 2015)

1116-14-2596 **Cris Negron*** (cnegron@lsu.edu). *Morita equivalences of Azumaya algebras as sheaves of bimodules.* Preliminary report.

Given a sheaf of Azumaya algebras A on a quasi-compact and quasi-separated scheme X, I will discuss how a certain class of autoequivalences of the category of quasi-coherent sheaves of A-modules $\mathrm{Qcoh}A$ are in bijection with sheaves of invertible A-bimodules. As a consequence of this fact, as well as Antieau/Rosenberg's reconstruction theorem, we (a) understand the group of autoequivalences of $\mathrm{Qcoh}A$ as an extension of the stabilizer of the Brauer class of A under the natural action of $\mathrm{Aut}(X)$ and the Picard group of X, and (b) realize any autoequivalence of $\mathrm{Qcoh}(A)$ as pullback along an automorphism of the gerbe associated to A. I will explain how this work fits in with the many results relating invariants of A to those of the underlying scheme X. (Received September 22, 2015)

1116-14-2619 **Alberto Chiecchio*** (alberto.chiecchio@gmail.com) and **Lance E Miller**. *Derived S Systems.*

In his work, A canonical linear system associated to adjoint divisors in characteristic $p > 0$, Schwede introduced the linear system S that in positive characteristic exhibits similar behaviors to the cohomology in characteristic 0. We discuss the possibility - and the issues - in deriving such systems. Joint with L. E. Miller (Received September 22, 2015)

1116-14-2712 **Timo de Wolff*** (dewolff@math.tamu.edu), Department of Mathematics, Mailstop 3368, Texas A&M University, College Station, TX 77843-3368, and **Sadik Iliman**. *Nonnegative Polynomials and Sums of Squares Supported on Circuits.*

Deciding nonnegativity of real polynomials is a key question in real algebraic geometry with crucial importance in polynomial optimization. Since this problem is NP-hard, one is interested in finding sufficient conditions (certificates) for nonnegativity, which are easier to check. The standard certificates are sums of squares (SOS), which trace back to Hilbert (see Hilbert's 17th problem).

In this talk we completely characterize sections of the cones of nonnegative polynomials and sums of squares with polynomials supported on circuits, a genuine class of sparse polynomials. Nonnegativity of polynomials supported on circuits is characterized by an invariant, which can immediately be derived from the initial polynomial.

Based on these results, we obtain a completely new class of nonnegativity certificates independent from SOS certificates. These results significantly extend known geometric programming approaches for the computation of lower bounds. For polynomials with simplex Newton polytope these new bounds are much faster computable and often better than bounds obtained via semidefinite programming, which is the current standard method for nonlinear polynomial optimization. (Received September 22, 2015)

1116-14-2772 **Francois Greer*** (`fgreer@stanford.edu`), 2869 Alma Street, Palo Alto, CA 94306. *Lines on Elliptic Calabi-Yau Threefolds.* Preliminary report.

Counting rational curves on Calabi-Yau threefolds has been the focus of much enumerative geometry in recent years. I will present an approach which exhibits actual line counts as the coefficients of a modular form, using the cohomological theta correspondence of Kudla and Millson. (Received September 22, 2015)

1116-14-2800 **Anton Dzhamay*** (`adzham@unco.edu`), School of Mathematical Sciences, University of Northern Colorado, Campus Box 12, 501 20th Street, Greeley, CO 80639, and **Tomoyuki Takenawa**, Faculty of Marine Technology, Tokyo Univ. of Marine Science and Technology, 2-1-6 Etchu-jima, Koto-ku, Tokyo, 135-8533, Japan. *On the Geometry of Difference Painlevé Equations.*

Essentially by definition, a discrete Painlevé equation is just a translation element in the extended affine Weyl symmetry group of some algebraic surface that is called the Okamoto space of initial conditions of the equation. Such elements can be represented as compositions of elementary reflections and Dynkin diagram automorphisms. In this talk we will discuss how to use such decompositions and the corresponding elementary birational transformations of the underlying Okamoto surface to compare different equations (directions), to find explicit identification between them, and to obtain good coordinate representations of these equations. This study is motivated by our attempts to understand the structure of difference Painlevé equations that appear as reductions of elementary Schlesinger transformations of Fuchsian systems. (Received September 22, 2015)

1116-14-2815 **Kalina Mincheva*** (`mincheva@math.jhu.edu`), Johns Hopkins Universtiy, 3400 N Chalres Street, Baltimore, MD 21218. *Nullstellensatz for tropical polynomials.*

We improve on a result of A. Bertram and R. Easton which can be regarded as a Nullstellensatz for tropical polynomials. In order to do that we give a new definition of prime congruences in additively idempotent semiring using twisted products. This class turns out to exhibit some analogous properties to the prime ideals of commutative rings. In order to establish a good notion of radical congruences we show that the intersection of all primes of a semiring can be characterized by certain twisted power formulas. We give a complete description of prime congruences in the polynomial and Laurent polynomial semirings over the tropical semifield $\mathbb{R}_{max}$, the semifield $\mathbb{Z}_{max}$ and the Boolean semifield $\mathbb{B}$. The minimal primes of these semirings correspond to monomial orderings, and their intersection is the congruence that identifies polynomials that have the same Newton polytope. We show that the radical of every finitely generated congruence in each of these cases is an intersection of prime congruences with quotients of Krull dimension 1. (Received September 22, 2015)

1116-14-2958 **Daniel O. Chupin*** (`daniel.o.chupin@gmail.com`), 12518 Enchanted Forest, Austin, TX 78727. *Toric degenerations of incomplete flag varieties and their Schubert varieties.*

In 2005, Mikhail Kogan and Ezra Miller constructed an explicit toric degeneration of the complete flag variety built from $GL_n(\mathbb{C})$ by realizing the special toric fiber as the result of a "twisting" of a family of flag varieties. Here, we extend the result by exhibiting a similarly concrete toric degeneration of *incomplete* flag varieties built from $GL_n(\mathbb{C})$ and detail what happens to their Schubert varieties. In addition, we indicate how we can modify our approach to accommodate toric degenerations of flag varieties built from algebraic groups of different type, and use our constructed degenerations to compute some equivariant cohomology of the varieties involved. (Received September 23, 2015)

15 ► Linear and multilinear algebra; matrix theory

1116-15-602 **Anna L Seigal***, seigal@berkeley.edu. *Eigenconfigurations of Tensors.*

Diagonalizing a matrix is very useful in many applications. We discuss how to obtain a similar decomposition of a tensor. We define the notion of an eigenvector of a tensor and describe possible configurations of points in projective space which can occur as the eigenvectors of some tensor. This is based on joint work with Bernd Sturmfels and Hirotachi Abo. (Received September 08, 2015)

1116-15-643 **Rainer Sinn*** (sinn@math.gatech.edu), School of Mathematics, Georgia Institute of Technology, 686 Cherry Street NW, Atlanta, GA 30332-0160, and **Grigoriy Blekherman**. *Real Rank with Respect to Varieties.*

We study the real rank of points with respect to a real variety X. This is a generalization of various tensor ranks, where X is in a specific family of real varieties like Veronese or Segre varieties. We will see an upper bound on the maximal real rank in terms of the codimension of X and establish its tightness by construction of examples. We will also give examples of varieties X for which the gap between maximal complex and the maximal real rank is arbitrarily large. (Received September 09, 2015)

1116-15-848 **Daniel Alan Spielman*** (spielman@cs.yale.edu). *Graphs, Vectors, and Matrices.*

I will explain how we use linear algebra to understand graphs and how recently developed ideas in graph theory have inspired progress in linear algebra.

Graphs can take many forms, from social networks to road networks, and from protein interaction networks to scientific meshes. One of the most effective ways to understand the large-scale structure of a graph is to study algebraic properties of matrices we associate with it. I will give examples of what we can learn from the Laplacian matrix of a graph.

We will use the graph Laplacian to define a notion of what it means for one graph to approximate another, and we will see that every graph can be well-approximated by a graph having few edges. For example, the best sparse approximations of complete graphs are provided by the famous Ramanujan graphs. As the Laplacian matrix of a graph is a sum of outer products of vectors, one for each edge, the problem of sparsifying a general graph can be recast as a problem of approximating a collection of vectors by a small subset of those vectors. The resulting problem appears similar to the problem of Kadison and Singer in Operator Theory. We will sketch how research on the sparsification of graphs led to its solution. (Received September 14, 2015)

1116-15-972 **Anthony Iarrobino**, **Leila Khatami*** (khatamil@union.edu), **Bart Van Steirteghem** and **Rui Zhao**. *Nilpotent matrices having a given Jordan type as maximum commuting nilpotent orbit.*

The Jordan type of a nilpotent matrix is the partition giving the sizes of the Jordan blocks in the normal Jordan form of the matrix. In this talk we discuss pairs of partitions (P, Q), where $Q = Q(P)$ is the Jordan type of a generic element of the nilpotent commutator of the Jordan matrix of type P. In particular, we report on a joint work with A. Iarrobino, B. Van Steirteghem and R. Zha in which we prove a conjecture formulated by P. Oblak in 2012 concerning the cardinality of $Q^{-1}(Q)$ when Q has two parts. We also propose a generalization for an arbitrary partition Q. (Received September 15, 2015)

1116-15-1062 **Jason J Molitierno*** (molitiernoj@sacredheart.edu), Sacred Heart University, Department of Mathematics, 5151 Park Avenue, Fairfield, CT 06825. *An upper bound on the algebraic connectivity of outerplanar graphs.*

The Laplacian matrix $L = [\ell_{i,j}]$ for a graph on n vertices is the $n \times n$ matrix where $\ell_{i,i}$ is the degree of vertex i, $\ell_{i,j} = -1$ if vertices i and j are adjacent, and $\ell_{i,j} = 0$ if vertices i and j are not adjacent. Since L is positive semidefinite, its eigenvalues can be ordered $0 = \lambda_1 \leq \lambda_2 \leq \ldots \leq \lambda_n$. The eigenvalue λ_2 is known as the algebraic connectivity of a graph because it is a measure of how connected a graph is. Since outerplanar graphs can have a limited number of edges, we expect λ_2 to be small. In this talk, we find upper bounds on λ_2. Focusing on maximal outerplanar graphs, we show that for all maximal outerplanar graphs on $n \geq 12$ vertices, that $\lambda_2 \leq 1$ with the exception of a certain class of maximal outerplanar graphs. In addition, we show that there is a unique maximal outerplanar graph on 12 vertices outside this class where the inequality is sharp and that it is strict for all such graphs on $n \geq 13$ vertices. (Received September 16, 2015)

1116-15-1249 **Jenna Reis*** (jreis5@fitchburgstate.edu) and **Tom Bella**. *The spectral connection matrix for any change of basis within the classical real orthogonal polynomials.*

An introduction to the so–called spectral connection matrix will be presented, as well as an explanation of its relationship to changes of basis into the classical real orthogonal polynomials from a Bochner-type set that allows for an order of magnitude improvement in computations to produce the connection matrix. (Received September 18, 2015)

1116-15-1704 **Aaron Carl Smith*** (aaron.smith@ucf.edu), Department of Mathematics, University of Central Florida, 4393 Andromeda Loop N, Orlando, FL 32816. *The Aesthetic of Circulant Unistochastic Eigenpaths.* Preliminary report.

The group of n by n unitary matrices is connected. When paths of unitary matrices are mapped to their unistochastic images, and the unistochastic eigenvalues are plotted, many of the figures will have an aesthetic quality. This talk gives a construction of such figures with circulant unitary matrices, provides several examples, and a technique to greatly improve the computation time needed to find eigenpaths. (Received September 21, 2015)

1116-15-1729 **Leonard Stevenson*** (ls879@drexel.edu), 315 Madison Street, Sayre, PA 18840. *Higher Order Non-commutative Functions.*

Non-commutative functions are mappings on square matrices of all sizes which respect direct sums and similarities. Differentiating non-commutative functions iteratively, one arrives at functions of increasingly more matrix variables, whose values are multi-linear forms, which also respect direct sums and similarities, in a certain way. We call them nc functions of higher order. In my talk, I will discuss the Taylor-Taylor formula and other results for higher order non-commutative functions. (Received September 21, 2015)

1116-15-1745 **Ke Ye*** (kennyyeke@gmail.com), University of Chicago, Chicago, IL 60637. *Structural tensors of bilinear maps.* Preliminary report.

Bilinear maps are very important in both Multilinear Algebra and Complexity Theory. For example, matrix multiplication is a bilinear map and its computational complexity is still a mystery. In most situations, computational complexity of a bilinear map is characterized by the rank of its structural tensor. In this talk, we will discuss the study of structural tensors of bilinear maps. We will present a framework to calculate an upper bound for the rank of the structural tensor of a bilinear map. Using this framework, we are able to write down a tensor decomposition of the structural tensor and hence an algorithm to compute the bilinear map. This is joint work with Lek-Heng Lim. (Received September 22, 2015)

1116-15-1989 **Cody J Griffith*** (cody.griffith94@gmail.com), 19611 E 40th Ave, Denver, CO 80249, and **Aaron Phillip Parker** (aaronparker2319@gmail.com), 2810 Fillmore St, Denver, CO 80205. *An Exploration of Iterative Matrix Transformations.* Preliminary report.

In this presentation, we analyze iterations of matrix transformations and the associated geometry. We have built a Mathematica notebook to help visualize the geometry of each iteration. From there we look at what happens to these iterative matrix transformations in their limit and observe behaviors of the objects being transformed. We make connections from these observations to the Power Method as a means to explain the behavior observed.

We will extend this idea to incorporate matrices that do not satisfy the hypotheses of the Power Method. For example we will explore a process analogous to the Power Method for rectangular matrices through Singular Value Decomposition (SVD) and study possible relationships between the limit of the iterative process and the singular values of the matrix. (Received September 21, 2015)

1116-15-2029 **Hon-Leung Lee*** (hllee@uw.edu). *Orthogonally invariant matrix varieties.*

The problem of finding the closest point in a set, with respect to Euclidean distance, arises frequently in applications. In this talk we focus on orthogonally invariant matrix varieties and provide a framework, based on "transfer principles" and singular value decomposition, for computing and counting the real smooth critical points of this minimization problem, as well as finding the minimizers. We will also discuss the connections of this theory to the notion of Euclidean distance degree of a variety. This is a joint work with Dmitriy Drusvyatskiy, Giorgio Ottaviani and Rekha R. Thomas. (Received September 21, 2015)

1116-15-2083 **Amanda Ellis Francis*** (amanda@mathematics.byu.edu), 275 TMCB, Department of Mathematics, Brigham Young University, Provo, UT 84602, and **B Webb**, **W Barrett**, **R Echols** and **D Sorenson**. *Equitable Decompositions Using Automorphisms of Graphs.* Preliminary report.

It is well-known that for any equitable partition of a graph, the characteristic polynomial of the divisor matrix of the partition divides the characteristic polynomial of the original adjacency matrix. In this talk I will consider those equitable partitions arising from automorphisms of the graph and present new results which show that the original adjacency matrix is similar to a direct sum of smaller matrices, one of which is exactly the divisor matrix of the partition. Further, our results give bounds on the number of simple eigenvalues in the spectra of the graph, and relate this matrix decomposition to a decomposition of the original graph into smaller graphs. These results hold for any edge-weighted directed graph with loops (and its corresponding weighted adjacency matrix) and can by applied to many interesting matrices, including the various Laplacians, distance matrices, etc. (Received September 21, 2015)

1116-15-2416 **Gregory Taylor*** (gktaylor@email.wm.edu), 4634 Brook Highland Lane, Tuscaloosa, AL 35406, and **Chi-Kwong Li** and **Diane Pelejo**. *Polynomial Functions Over $\mathbb{Z}_n$.*

Polynomials play an important role in the theory of functions. It is known that all functions over a finite field can be written as a polynomial with entries from the field. In this talk, we study the case of polynomial functions over the ring of integers modulo some composite integer n. We take a matrix theoretic approach to establish results regarding the number of polynomial functions and determining whether a function can be represented as a polynomial. Computational techniques are emphasized in order to deliver meaningful calculations based on the theoretical results. (Received September 22, 2015)

1116-15-2687 **Justin D. Marks*** (jdmarks@wesleyan.edu). *Comparative Analysis of Matrix Manifold Means.*

Applications of geometric data analysis often involve producing collections of subspaces, such as illumination spaces for digital imagery. For a given collection of points, a natural task is to find the mean of the collection. A robust suite of algorithms has been developed to generate mean representatives for a collection of subspaces of fixed dimension, or equivalently, a collection of points on a particular Grassmann manifold. These representatives include the flag mean, the normal mean, the projection mean, and the Karcher mean. In this talk, we present comparative heuristics and visualizations to examine the suite of mean representatives. (Received September 23, 2015)

1116-15-2719 **Cailan Chun Chun Li** and **Man Cheung Kevin Tsui*** (mantsui@live.com), 9810 Taos Peak Way, Bakersfield, CA 93311. *On the images of multilinear maps of matrices over finite-dimensional division algebras.*

Let R be a central simple algebra finite-dimensional over its center $\mathbb{F}$ of characteristic 0. We will show that every element of reduced trace 0 in R can be expressed as $[a,[c,b]]+\lambda[c,[a,b]]$ for some $a,b,c \in R$ where $\lambda \neq 0,-1$. In addition, let $\mathcal{D}$ be a division algebra satisfying the conditions above. We will also show that the set of values of any nonzero multilinear polynomial of degree at most three, with coefficients from the center $\mathbb{F}$ of $\mathcal{D}$, evaluated on $M_k(\mathcal{D}), k \geq 2$, contains all matrices of reduced trace 0. (Received September 22, 2015)

1116-15-2730 **Justin Scott Goodwill*** (goodwil2@duq.edu), 6318 Oyster Bay Court, Bridgeville, PA 15017, and **Stacey Levine**. *Image Fusion Using SURE Guided Piecewise Linear Estimation.* Preliminary report.

In recent years, a number of image processing algorithms have employed the Gaussian mixture model (GMM) as a probabilistic patch-based paradigm for data classification and signal estimation achieving near state-of-the art results. Yu, Sapiro, and Mallat developed a general framework for solving inverse problems through the connection that the Weiner filter estimation of an image patch from a GMM is precisely equivalent to sparsely representing an image patch using a structured over-complete PCA dictionary. Wang and Morel expand upon this work by developing a piecewise linear estimation (S-PLE) using a flexible Bayesian Gaussian factor model and a SURE (Stein's unbiased risk estimator) guided statistical filter selection. In light of Wang and Morel's results for single image denoising, we show how the S-PLE formulation can be adapted for fusing multiple images that have been corrupted by additive Gaussian noise as well as linear degradations. (Received September 22, 2015)

16 ► Associative rings and algebras

1116-16-71 **Alexander Diaz-Lopez*** (adiaz4@nd.edu), 255 Hurley, Notre Dame, IN 46556, and **Matthew John Dyer** (dyer.1@nd.edu), 255 Hurley, Notre Dame, IN 46556. *Representations of Hecke Algebras on Quotients of Path Algebras.*

Given a Coxeter system (W,S), a W-graph is a graph, together with additional information, that encodes a representation (denoted τ representation) of the Hecke algebra associated to W. We generalize this work by defining W-graphs over non-commutative algebras, which give rise to new representations of Hecke algebras. The main examples to be discussed include several representations of Hecke algebras on quotients of path algebras (over suitable quivers). We discuss the relationship between these representations and the τ representations. The most interesting example comes from a quotient path algebra that is isomorphic to an important ideal of Lusztig's asymptotic Hecke algebra (when defined). (Received July 12, 2015)

1116-16-72 **Louis H Rowen*** (rowen@math.biu.ac.il), Mathematics Dept, Bar-Ilan University, 52900 Ramat Gan, Israel. *Evaluations of associative and Lie polynomials on matrices.* Preliminary report.

(Joint work with Kanel-Belov and Malev.) Kaplansky asked about the set S of possible images of a polynomial f in several noncommuting variables in the matrix algebra $M_n(F)$ over a field F. It follows from work of Herstein that the space spanned by S must either be scalar or contain sl_n. After a review of our earlier work for $n \leq 3$, when K is closed under quadratic extensions, we turn to the case of a Lie polynomial with constant term 0, and coefficients in an algebraically closed field K. We describe all the possible images of f in $M_2(K)$. An example is given of a polynomial f whose image is the set of trace zero matrices excluding nilpotent nonzero matrices, together with an arithmetic criterion for this case. Some Lie results are provided for $n = 3$, together with an indication of what remains open. (Received August 11, 2015)

1116-16-164 **John S. Kauta*** (jkauta@yahoo.com), School of Computing, Info. & Math. Sciences, The University of the South Pacific, Suva, Fiji Islands. *Crossed-product orders over valuation rings and the graphs of their cocycles.*

We will discuss certain crossed-product orders over valuation rings and the graphs their cocycles produce. Let F be a field with valuation ring V, K a finite tamely ramified and defectless Galois extension of F with group G, S the integral closure of V in K, and $f : G \times G \mapsto S \setminus \{0\}$ a normalized 2-cocycle (we do not require that the values of f should be units in the ring S). Then one can form the crossed-product V-order $A_f = \sum_{\sigma \in G} Sx_\sigma$.

Associated to f is a graph $\mathrm{Gr}(f)$. When V is indecomposed in K and the order A_f is (semi)hereditary, then $\mathrm{Gr}(f)$ is a chain.

There is a second graph associated to f and a maximal ideal M of S denoted by $\mathrm{Gr}(f^M)$ which may be considered as a generalization of $\mathrm{Gr}(f)$. When the order A_f is (semi)hereditary, then this graph is again a chain whether or not V decomposes in K.

Let f_M be the restriction of f to the decomposition group G^Z of M and set $A_{f_M} = \sum_{\sigma \in G^Z} S_M x_\sigma$. There is a natural graph monomorphism from $\mathrm{Gr}(f_M)$ to $\mathrm{Gr}(f^M)$. When it is an isomorphism, then A_f is (semi)hereditary (resp. a Dubrovin valuation ring) precisely when A_{f_M} has the same property. (Received August 10, 2015)

1116-16-500 **Najat Mohammed Muthana*** (nmuthana@kau.edu.sa), P.O.Box1859, Jeddah, 21441, Saudi Arabia. *On Rings with some kinds of centrally-extended maps.*

In 2015, Bell and Daif have introduced the notion of Centrally-extended derivation of a ring R. A centrally-extended derivation is a centrally additive and centrally multiplicative. In this paper we generalize this notation for some kinds of maps on ring and extend some given results for Bell and Daif. (Received September 04, 2015)

1116-16-511 **Kenneth R Goodearl***, Department of Mathematics, University of California, Santa Barbara, CA 93106. *Hopf algebra domains of Gelfand-Kirillov dimension two.* Preliminary report.

We will discuss progress in the classification of Hopf algebras as in the title, concentrating in particular on the non-affine case (Hopf algebras which are not finitely generated as algebras). This is joint work with James Zhang. (Received September 05, 2015)

1116-16-514 **Frauke M Bleher**, Department of Mathematics, University of Iowa, Iowa City, IA 52242, **Ted Chinburg**, Department of Mathematics, University of Pennsylvania, Philadelphia, PA 19104, and **Birge Huisgen-Zimmermann***, Department of Mathematics, University of California, Santa Barbara, CA 93106. *The geometry of algebras with zero radical square.*

We describe the geometry of the varieties parametrizing the finite dimensional representations of a basic finite dimensional algebra with vanishing radical square. In particular, we pin down the irreducible components of these varieties in terms of the algebra's Gabriel quiver and promote the generic structure theory of the modules encoded by the components to the level attained by Kac and Schofield in the hereditary case. (Received September 05, 2015)

1116-16-636 **Ojas Dave*** (ojasdave@my.unt.edu) and **J Matthew Douglass** (matthew.douglass@unt.edu). *Irreducible representations of Yokonuma-type Hecke algebras.* Preliminary report.

In this talk, I will describe the irreducible representations of a family of generic Hecke algebras that specialize to the complex reflection groups G(r,1,n) and to endomorphism rings of certain permutation characters of finite general linear groups. (Received September 09, 2015)

1116-16-674 **Paul Frank Baum*** (pxb6@psu.edu), Department of Mathematics, Penn State University, University Park, PA 16802. *Morita Equivalence Revisited.*

Let X be a complex affine variety and k its coordinate algebra. Equivalently, k is a unital algebra over the complex numbers which is commutative, finitely generated, and nilpotent-free. A k-algebra is an algebra A over the complex numbers $\mathbb{C}$ which is a k-module (with an evident compatibility between the algebra structure of A and the k-module structure of A). A is not required to have a unit. A k-algebra A is of finite type if as a k-module A is finitely generated. This talk will introduce — for finite type k-algebras —a weakening of Morita equivalence called geometric equivalence. The new equivalence relation preserves the primitive ideal space (i.e. the set of equivalence classes of irreducible A-modules) and the periodic cyclic homology of A. However, the new equivalence relation permits a tearing apart of strata in the primitive ideal space which is not allowed by Morita equivalence. The ABPS (Aubert-Baum-Plymen-Solleveld) conjecture asserts that if G is a connected split reductive p-adic group, then the finite type algebra which Bernstein assigns to any given Bernstein component is geometrically equivalent to the coordinate algebra of the associated extended quotient . (Received September 10, 2015)

1116-16-734 **Chelsea Walton*** (notlaw@temple.edu), 1805 N. Broad Street, Philadelphia, PA 19122. *Finite dimensional Hopf actions on Weyl algebras.*

We prove that any action of a finite dimensional Hopf algebra H on a Weyl algebra A over an algebraically closed field of characteristic zero factors through a group action. In other words, Weyl algebras do not admit genuine finite quantum symmetries. This is joint work with Juan Cuadra and Pavel Etingof.

Note: The title, abstract, and coauthors are subject to change. (Received September 11, 2015)

1116-16-846 **Jonathan Kujawa*** (kujawa@math.ou.edu), Dept. of Mathematics, University of Oklahoma, Norman, OK 73069, and **Benjiman Tharp** (btharp@math.ou.edu), Dept. of Mathematics, University of Oklahoma, Norman, OK 73069. *The Marked Brauer Algebra.*

We provided a diagrammatic description of the endomorphism algebras of the tensor powers of the natural representation for the type P Lie superalgebras. Our description naturally generalizes Brauer's classic work on the same question for the orthogonal and symplectic groups. It also provides transparent explanations and generalizations of earlier results of Moon. Furthermore, it naturally extends to a diagrammatic model category which combinatorially describes the full subcategory given by the tensor powers. (Received September 14, 2015)

1116-16-882 **S. Paul Smith*** (smith@math.washington.edu). *Positive entropy automorphisms and free subalgebras.*

Let X be a smooth projective surface defined over an uncountable algebraically closed field k, $k(X)$ its field of rational functions, and s be an automorphism of X. We show there is a non-negative integer n and elements $a, b \in k(X)$ such that the subalgebra of the skew Laurent extension $k(X)[t, t^{-1}; s]$ generated by at^n and bt^n is a free algebra if and only if the spectral radius for the action of s^* on the Neron-Severi group of X is > 1. Thus, when s is an automorphism of a smooth complex projective surface X, $\mathbb{C}(X)[t, t^{-1}; s]$ has a free subalgebra on > 1 variables if and only if the topological entropy of s is positive. Furthermore, if s is an automorphism of $k(X)$, then $k(X)[t, t^{-1}; s]$ contains a free subalgebra if and only if the dynamical degree of s is > 1; in this situation, s might not be induced by an automorphism of any smooth projective surface. These results are used to show that certain twisted homogeneous coordinate rings of smooth projective surfaces contain free subalgebras. (Received September 14, 2015)

1116-16-890 **Apoorva Khare*** (khare@stanford.edu) and **Akaki Tikaradze**. *BGG Category $\mathcal{O}$ over generalized Weyl algebras.*

Generalized Weyl algebras (GWAs), including down-up algebras and their quantum variants, have been the focus of much recent activity. In this talk, we first show that a large family of generalized down-up algebras, which are deformations of $U(\mathfrak{sl}_2)$, admit quantizations, which are deformations of $U_q(\mathfrak{sl}_2)$. Next, we study the BGG Category $\mathcal{O}$ over a "triangular GWA". More precisely, we study a block with finitely many simple objects, say n. We show that the endomorphism algebra of a projective generator of this block is finite-dimensional and graded Koszul. We also provide a presentation of this algebra, showing that it depends only on n. This shows that the blocks of $\mathcal{O}$ for any two triangular GWAs, with the same number of simple objects in each, are Morita equivalent. (Received September 14, 2015)

1116-16-1020 **Christine Uhl*** (christineuhl@my.unt.edu). *Parameter space of quantum Drinfeld Hecke algebras in low dimension.*

Finite groups act as graded automorphisms on quantum space giving rise to analogs of rational Cherednik algebras and symplectic reflection algebras for quantum/skew polynomial rings. The set of admissible parameters of these quantum Drinfeld Hecke algebras form a vector space. The dimension of the parameter space tells us about the degrees of freedom of nontrivial quantum Drinfeld Hecke algebras. We will pay special attention to mystic reflection groups, the infinite family of complex reflection groups and nonmonomial groups. (Received September 16, 2015)

1116-16-1289 **Lance W. Small*** (lwsmall@ucsd.edu), Department of Mathematics, UCSD, La Jolla, CA 92093. *Affine PI Algebras, Representability and the Hopfian Property.*

The following work in joint with Louis Rowen.

An algebra (over a field) is Hopfian if every onto algebra endomorphism is an automorphism; an affine algebra is a finitely generated PI; an algebra is representable if it can be embedded in matrices over a commutative algebra. We investigate the relationship between the Hopfian property and representability. For instance, a representable affine algebra is Hopfian though there are Hopfian affine PI algebras that are not representable. (Received September 18, 2015)

1116-16-1305 **Lauren Grimley**, **Cris Negron**, **Van C Nguyen** and **Sarah Witherspoon*** (sjw@math.tamu.edu). *The graded Lie structure of Hochschild cohomology.* Preliminary report.

The Hochschild cohomology of an algebra is a graded commutative algebra that encodes important information about the algebra and its representations. Its graded Lie structure is less well-known and harder to compute than is its associative algebra structure. This computational difficulty stems from its resistance to definition on complexes other than the bar complex where it was historically defined. Schwede gave an elegant topological definition of Lie brackets on Hochschild cohomology as loops on categories of extensions, yet this also has resisted an algebraic interpretation suitable for computational purposes. We present an alternative algebraic approach, defining the Lie bracket on choices of resolutions satisfying some properties, which for example Koszul resolutions of Koszul algebras do satisfy. We illustrate this approach on examples. (Received September 18, 2015)

1116-16-1352 **John E. Foster*** (john.foster@wallawalla.edu), Walla Walla University, 204 S College Ave, College Place, WA 99324. *Tame Representations of the Quantum Double.*

We will show that a good place to find representations of the quantum double $D(H)$ of a Hopf algebra H is in the $D(H)$-bimodule algebra $H \otimes C$, where C is dually paired to H. In the case $H = U_q(\mathfrak{sl}_2)$, where q is generic, a careful study of highest-weight bivectors shows that the locally finite part of $H \otimes C$ has a Peter-Weyl decomposition. We will see in this case that the algebra of highest-weight bivectors is of polynomial growth. (Received September 18, 2015)

1116-16-1365 **Richard Gene Chandler*** (richard.chandler@mavs.uta.edu) and **Michaela Vancliff** (vancliff@uta.edu). *Associating Geometry to the Hopf Algebra $\mathcal{U}_q(\mathfrak{sl}_2)$.* Preliminary report.

The Hopf algebra $\mathcal{U}_q(\mathfrak{sl}_2)$ is considered a quantum analog of the universal enveloping algebra of $\mathfrak{sl}_2$. In this talk, we will consider a certain graded algebra, $\mathcal{H}_q(\mathfrak{sl}_2)$, associated to $\mathcal{U}_q(\mathfrak{sl}_2)$ and study $\mathcal{H}_q(\mathfrak{sl}_2)$ via geometric techniques in the spirit of Artin, Tate and Van den Bergh. In particular, we will discuss the point and line schemes of $\mathcal{H}_q(\mathfrak{sl}_2)$ and relate them back to $\mathcal{U}_q(\mathfrak{sl}_2)$, including recognizing the quantum Casimir element as a distinguished element of $\mathcal{U}_q(\mathfrak{sl}_2)$. (Received September 18, 2015)

1116-16-1371 **Tim Hsu** (tim.hsu@sjsu.edu), **Hang Lu Su*** (hanglu.su@mail.mcgill.ca) and **Olga Zamoroueva** (olgazamorueva@yahoo.com). *Computation in the completion of the free group algebra.* Preliminary report.

It is known (e.g., due to independent results of Malcev and B.H. Neumann) that $\mathbf{Q}[F_n]$, the (rational) group algebra of the free group of rank n, can be embedded in a division algebra D. We consider the problem of making this embedding algorithmic.

More precisely, if D_0 is the smallest sub-division algebra of D containing $\mathbf{Q}[F_n]$, we consider the problem of representing elements of D_0 by a finite data structure with which the algebra operations (addition, multiplication, inversion) can be calculated algorithmically. We present a solution to this problem on a particular subalgebra of D_0, using noncommutative formal power series with recurrence relations, and discuss how to generalize this idea to all of D_0. We also discuss applications of our results to problems in algebraic topology. (Received September 22, 2015)

1116-16-1475 **Quanshui Wu*** (qswu@fudan.edu.cn), School of Mathematical Sciences, Fudan University, Shanghai, 200433, Peoples Rep of China. *Modular derivations for Poisson algebras.*

In the talk, I will give a definition of modular derivations for smooth Poisson algebras and for Frobenius Poisson algebras. By using the modular derivation, a twisted Poicare duality holds betwteen the Poisson cohomology and homology. (Received September 20, 2015)

1116-16-1493 **Xin Tang*** (xtang@uncfsu.edu), 1200 Murchison Roady, Fayetteville, NC 28301. *Endomorphisms of Quantized Weyl Algebras and Their Simple Localizations.* Preliminary report.

In this presentation, we discuss the symmetries of a quantized Weyl algebra and its simple localization in terms of their algebra endomorphisms and automorphisms. For the quantized Weyl algebra, we characterize its algebra endomorphisms, which happen to be algebra automorphisms. Then we prove that each algebra endomorphism of a certain simple localization of the quantized Weyl algebra is indeed an algebra automorphism, and determine the algebra automorphism group for this simple localization. Some applications will be discussed as well. (Received September 21, 2015)

1116-16-1604 **Siu-Hung Ng*** (rng@math.lsu.edu), Department of Mathematics, Louisiana State University, Baton Rouge, LA 70803. *On Frobenius-Schur indicators for nonsemisimple Hopf algebras.*

There are two different generalizations of higher Frobenius-Schur indicators for the regular representations of finite-dimensional pivotal Hopf algebras, which are not necessarily semisimple. Both of these generalizations are invariant under gauge transformations and they coincide when the underlying Hopf algebras are semisimple with the canonical pivotal structure. In this talk, we will discuss these two generalizations of indicators with some examples, which demonstrate their difference. (Received September 20, 2015)

1116-16-1654 **Zhaobing Fan**, **Yiqiang Li** and **Zongzhu Lin*** (zlin@math.ksu.edu), Department of Mathematics, Kansas State University, Manhattan, KS 66506. *Equivalence of representation categories of various quantum and super quantum groups.* Preliminary report.

Corresponding to a Cartan datum, which defines a Kac-Moody Lie algebra $\mathfrak{g}$, there are several versions of quantum enveloping algebras, including original quantum in the form of Lusztig, and quantum groups with many parameters, as well as their supervision. The main result of the talk is that, in the generic cases, the category $\mathcal{O}$'s for all these algebras including the super-algebras, have exactly the same decomposition matrices and character formulas, Similarly for modular representations, including the cases of at roots of unit cases, also have the same decomposition matrices and character formulas. Using the known results in original quantum groups at roots of 1, these decomposition numbers are determined by Kazhdan Lusztig polynomials. (Received September 21, 2015)

1116-16-1671 **Ashish Gupta*** (ashishg@iiserb.ac.in), Dept. of Mathematics, IISER Bhopal, Bhopal, 462066, India. *GK dimension of modules over noncommutative algebras.*

An approach to studying a given algebra is offered by the study of its representations or modules. An important and interesting invariant of finitely generated modules over affine algebras is the so-called Gelfand–Kirlllov dimension (GK dimension). We discuss this dimension for simple modules over various classes of non commutative affine algebras. (Received September 21, 2015)

1116-16-1912 **Susan Montgomery**, **Maria D. Vega*** (maria.vega@usma.edu) and **Sarah Witherspoon**. *Hopf automorphisms and twisted extensions.*

In this talk, I will describe some applications of a Hopf algebra constructed from a group acting on another Hopf algebra A as Hopf automorphisms, namely Molnar's smash coproduct Hopf algebra. I will also talk about connections between the exponent and Frobenius–Schur indicators of a smash coproduct and the twisted exponents and twisted Frobenius–Schur indicators of the original Hopf algebra A. (Received September 21, 2015)

1116-16-1948 **M Susan Montgomery*** (smontgom@usc.edu). *Values of Frobenius-Schur indicators for Hopf algebras.*

Frobenius-schur indicators are important for studying representations of semisimple Hopf algebra H, since they are invariants of the tensor category of representations of H. This talk is a survey of recent work on computing the values of the indicators for various Hopf algebras, such as the Drinfeld double of a group algebra. (Received September 21, 2015)

1116-16-1969 **Susan Elle*** (selle@ucsd.edu). *Iterated Ore extension of dimension 5.* Preliminary report.

We give a partial classification of iterated Ore extensions which are also Artin Schelter regular algebras of dimension 5 which are generated in degree 1. (Received September 21, 2015)

1116-16-2091 **Xinli Xiao*** (xiaoxinlixxl@gmail.com), 1600 Hillcrest Dr. Apt. 7, Manhattan, KS 66502. *The double of representations of Cohomological Hall algebras.*

Cohomological Hall algebra (COHA for short) for quivers was introduced by Kontsevich and Soibelman in the study of Motivic Donaldson-Thomas invariants and many other related topics. The definition of COHA is similar to the definition of conventional Hall algebra. By analogy with conventional Hall algebra of a quiver, which gives a quantization of the "positive" part of the corresponding Lie algebra, we studied the double of a certain type of COHA. First a series of geometric representations of COHA are constructed using an approach similar to the Nakajima's construction of infinite Heisenberg algebras. Then the double of the representations of COHA is constructed. From these representations, the double of COHA is discussed. (Received September 21, 2015)

1116-16-2201 **David C Meyer*** (meyerdc@missouri.edu), Department of Mathematics, University of Missouri, Columbia, MO 65201, and **Miodrag Iovanov**, **Gerard Koffi** and **Alex Sistko**. *Incidence-like algebras.* Preliminary report.

The representation theory of incidence algebras has been widely studied. Recently, modules for incidence algebras have been used in persistent homology in topological data analysis. In this talk, we discuss connections between incidence algebras and faithful distributive modules. If $(P, \leq)$ is a finite poset, the incidence algebra over a field K can be interpreted as the trivial element of the cohomology group $\mathrm{H}^2(P, K^*)$. Moreover, $\mathrm{H}^1(P, K^*)$ corresponds to isomorphism classes of faithful distributive modules for the incidence algebra. We demonstrate that under suitable hypotheses the existence of faithful distributive modules, in fact, characterizes incidence algebras. We then discuss generalizations of incidence algebras suggested by this characterization, and their connections to the cohomology of the poset. (Received September 22, 2015)

1116-16-2213 **Daniel Rogalski*** (drogalsk@math.ucsd.edu). *General noncommutative blowing up.* Preliminary report.

Van den Bergh has defined a notion of noncommutative blowing up which involves defining a Rees algebra in a category of functors. We show how to make the construction of this Rees algebra and its associated Proj category more explicit. As a consequence we see that the construction generalizes to define the blow up of a point in a noncommutative projective variety of any dimension. In addition, our generalization encompasses the Naive blowups we defined in earlier work with Keeler and Stafford. (Received September 22, 2015)

1116-16-2321 **Robert Muth*** (muth@uoregon.edu) and **Alexander Kleshchev**. *Representations of Khovanov-Lauda-Rouquier algebras of affine Lie type.*

The representation theory of KLR algebras of affine Lie type may be built up from the theory of semicuspidal representations associated to real and imaginary roots. We present an imaginary analogue of Howe duality which allows for the classification of irreducible imaginary semicuspidal representations via a connection to the classical Schur algebra. In affine ADE types, under a certain assumption on the characteristic of the ground field, the KLR algebra is properly stratified, and, given a balanced convex order, the stratum categories are Morita equivalent to certain positively-graded algebras which we describe explicitly. (Received September 22, 2015)

1116-16-2324 **Andrew B. Conner*** (abc12@stmarys-ca.edu). *Knörrer periodicity for noncommutative matrix factorizations.* Preliminary report.

Knörrer's periodicity theorem states that over an algebraically closed field of characteristic $\neq 2$ the stable category of maximal Cohen-Macaulay (MCM) modules over a complete hypersurface singularity of the form $S/(f)$ is equivalent to the stable category of MCM modules over $S[[u, v]]/(f + uv)$. This result provides a useful reduction tool in the classification of hypersurfaces of finite Cohen-Macaulay type. The proof relies on Eisenbud's correspondence between maximal Cohen-Macaulay modules over hypersurfaces and matrix factorizations.

Recently, Cassidy, Kirkman, Moore and the author proved a version of Eisenbud's correspondence for noncommutative graded hypersurfaces. In this talk we give a version of Knörrer's periodicity for algebras of the form $A/(f)$ where A is an Artin-Schelter regular algebra over an algebraically closed field of characteristic $\neq 2$ and f is a normal, regular, homogeneous element of even degree. (Received September 22, 2015)

1116-16-2364 **Calin Chindris** and **Daniel B Kline*** (dbkfz9@mail.missouri.edu), Columbia, MO 65202. *On locally semi-simple representations of quivers.*

We solve a problem raised by Victor Kac on locally semi-simple quiver representations. Specifically, we show that an acyclic quiver Q is of tame representation type if and only if every representation of Q with a semi-simple ring of endomorphisms is locally semi-simple. (Received September 22, 2015)

1116-16-2513 **Sam Mendelson*** (smendels@gmu.edu) and **Geir Agnarsson**. *Matrix Algebras: Equivalent Ring Relations and Special Presentations.*

A classic result in noncommutative ring theory states that a ring R is an $n \times n$ matrix ring if, and only if, R contains n^2 matrix units $\{e_{ij}\}_{1 \leq i,j \leq n}$. In this case $R \cong M_n(S)$ where S is a subring of R that can be described completely in terms of the matrix units. A lesser known result states that a ring R is an $(m+n) \times (m+n)$ matrix ring ($R \cong M_{m+n}(S)$ for some ring S) if and only if, R contains three elements a, b, and f satisfying the two relations $af^m + f^n b = 1$ and $f^{m+n} = 0$. In this talk, we investigate algebras over a commutative ring (or field) with elements c and f satisfying the two relations $c^i f^m + f^n c^j = 1$ and $f^{m+n} = 0$, where $m = n = 1$. We will discuss the structure of the underlying ring S for a general commutative ring A and investigate these algebras over the fields $\mathbb{Q}$ and $\mathbb{F}_p$, where p is prime. (Received September 22, 2015)

1116-16-2535 **Ethan J Gegner*** (ethan.gegner@gmail.com). *Zero Divisor Graphs of 2×2 Upper Triangular Matrix Rings over $\mathbb{Z}_n$.*

We explore the directed zero-divisor graphs of the rings of 2×2 upper triangular matrices modulo n, denoted by $\Gamma(T_2(n))$. For prime p, we give a complete characterization of the graph $\Gamma(T_2(p))$ by partitioning $T_2(p)$, and present several key corollaries of this approach. We establish additional properties of $\Gamma(T_2(n))$ for arbitrary n. We prove that $\Gamma(T_2(n))$ is Hamiltonian if and only if n is prime, and we give explicit formulas for the edge connectivity and clique number of $\Gamma(T_2(n))$ in terms of the prime factorization of n. (Received September 22, 2015)

1116-16-2598 **W. Frank Moore*** (moorewf@wfu.edu), **Jason Gaddis** and **Ellen Kirkman**. *Tools For Computing Discriminants.* Preliminary report.

Recent work of Ceken, Palmieri, Wang and Zhang as well as Chan, Young and Zhang have shown that the discriminant of the algebra extension $A/Z(A)$ can be used to compute the automorphism group of some skew polynomial rings and quantum Weyl algebras.

In this preliminary report, we provide some tools to compute the discriminant of certain Ore extensions, skew group rings, and rings of invariants. Many of the computations were made possible by the NCAlgebra package in Macaulay2, which will also be demonstrated. (Received September 22, 2015)

1116-16-2665 **David Julian Steinberg*** (dsteinbe@uoregon.edu), 1210 W 28th Avenue, Eugene, OR 97405. *Homomorphisms Between Standard Modules of KLR Algebras.*

Khovanov-Lauda-Rouquier algebras are a family of algebras which have been shown to categorify the quantized enveloping algebra of a semisimple Lie algebra. KLR algebras come with families of standard modules, which under this categorification correspond to PBW-bases of the positive part of the corresponding quantized enveloping algebra. These standard modules may be viewed as analogues of the Verma modules of semisimple Lie algebras, as they share many of their nice homological properties. A well known result on Verma modules states that every homomorphism between Verma modules is injective. In this talk, the speaker presents a more recent result of the speaker and his advisor, Alexander Kleshchev, in which they prove that there are no non-zero homomorphisms between distinct standard modules of KLR algebras of finite Lie type and that all non-zero endomorphisms of a standard module are injective. (Received September 22, 2015)

1116-16-2686 **Jesse S Levitt*** (jlevit3@lsu.edu) and **Milen Yakimov**. *Classifying connected Hopf algebras of finite GK-dimension via finite Drinfeld quantizations.*

The classification problem for Hopf Algebras of finite GK dimension has attracted a lot of interest in recent years. We will describe a new perspective to it via deformation theory. In 1983 Drinfeld constructed quantizations of all triangular r-matrices. We expand on work of Etingof and Gelaki showing that the ones that are finite define connected Hopf algebras of finite GK dimension. Hopf algebras constructed in this way are isomorphic, as algebras, to universal enveloping algebras. This construction recovers almost all of the known connected Hopf algebras of finite GK dimension, leads to many new examples from the general point of view of quasi-Frobenius Lie algebras, and enables preexisting Lie theoretic classification results to be brought to bear on the question at hand. (Received September 22, 2015)

1116-16-2701 **Shawn Baland*** (sbaland@math.washington.edu) and **Greg Stevenson** (gstevens@math.uni-bielefeld.de). *Relative stable categories and their prime ideal spectra.* Preliminary report.

In modular representation theory, one of the main objects of interest is the stable module category $\mathsf{stmod}(RG)$ of a group algebra RG. In particular, if R is a field, then it is well known that $\mathsf{stmod}(RG)$ is a triangulated category. In 2012, Benson, Iyengar and Krause defined a new exact structure on the module category $\mathsf{mod}(RG)$ for any commutative ring R in such a way that the resulting stable category is always triangulated. In this talk we'll discuss the support theoretic aspects of these new stable categories and some recent progress that has been made in computing the prime ideal spectrum (in the sense of Balmer) of $\mathsf{stmod}(RG)$ in the case where G is the cyclic group of order p and R is the commutative ring $\mathbb{Z}/p^n$. (Received September 22, 2015)

1116-16-2801 **Austin D Riedl**, **Hengzhou Liu** and **Dylan J Magnani*** (magnandj@uwec.edu), Dylan Magnani, Mathematics Department, University of Wisconsin-Eau Claire', Eau Claire, WI 54702-4004, and **Chris A Magyar**. *The Moduli Space of Complex* $1|3$*-dimensional algebras.*

Examples of $\mathbb{Z}_2$-graded associative algebras naturally arise in topology and physics, but finite dimensional examples are not well studied. The Fundamental Theorem of Finite Dimensional Algebras allows one to construct algebras as extensions of simple algebras by nilpotent algebras, using Wedderburn's Theorem which classifies the simple algebras, and knowledge of lower dimensional nilpotent algebras. These theorems have been extended to the case of $\mathbb{Z}_2$-graded algebras. We constructed the moduli space of $1|3$-dimensional complex associative algebras using this approach, and also determined the versal deformations of these algebras, leading to a stratification of the moduli space by projective orbifolds, which verifies a conjecture of Fialowski-Penkava for this moduli space. (Received September 22, 2015)

17 ► Nonassociative rings and algebras

1116-17-535 **Prakash Ghimire***, Mathematics/ Statistics Dept, Auburn University, 218 Parker Hall, auburn, AL 36849, and **Huajun Huang**. *Lie derivations and Lie triple derivations of dominant upper triangular ladder matrices.*

We explicitly describe Lie derivations and Lie triple derivations of the Lie algebra $M_L(F)$ associate with a dominant upper triangular ladder L over a field F with characteristics not equal to two. We also explicitly describe the derivation algebra of $[M_L(F), M_L(F)]$ when L is a strongly dominant upper triangular ladder and a field F is of characteristics not equal to $2, 3$. Some properties of these Lie algebras are discovered. (Received September 06, 2015)

1116-17-916 **Ismail Demir*** (idemir@ncsu.edu). *On Classification of Solvable Leibniz Algebras.*

Leibniz algebras are non-antisymmetric generalization of Lie algebras. Classification of all solvable Lie algebras is presently unsolved and is very difficult problem. Due to lack of antisymmetry in Leibniz algebras, the problem of classifying all solvable Leibniz algebras is more complicated. We give classification of solvable Leibniz algebras with one dimensional derived subalgebra. We use the canonical forms for the congruence classes of matrices of bilinear forms to obtain our result. (Received September 15, 2015)

1116-17-1656 **Zongzhu Lin*** (zlin@math.ksu.edu), Department of Mathematics, Kansas State University, Manhattan, KS 66506, and **Ke Ou**. *Geometry of the varieties of Borel subalgebras in Lie algebras of Cartan types.* Preliminary report.

For the Lie algebra of a semi-simple algebraic group, the set of all Borel subalgebras form the flag variety of the algebraic group. For a restricted Lie algebra of Cartan type Lie algebras, Borel subalgebras are no longer conjugate under the automorphism groups. In the cases of type W Lie algebras, the conjugacy classes Borel subalgebras. In this talk we will describe the geometry of the varieties of all Borel subalgebras and it relations with nilpotent variety. This is a joint work with Ke Ou. (Received September 21, 2015)

1116-17-1905 **Nina Yu*** (ninay@ucr.edu), Mathematics Department, University of California at Riverside, 900 University Avenue, Riverside, CA 92521. *Permutation Orbifolds.*

The permutation orbifolds study the permutations actions on the tensor products of vertex operator algebras. Namely, given a vertex operator algebra V , then tensor product of n-copies of V as a vector space naturally has a vertex operator algebras structure. Any element of the symmetric group S_n acts on V in the obvious way, and gives an automorphism of V of finite order. The fixed points set is a vertex operator subalgebra which is called a permutation orbifold model. In this talk, I will talk about 2-cycle permutation orbifold models of lattice vertex operator algebras. (Received September 21, 2015)

1116-17-1918 **Allison McAlister***, amcalist@highpoint.edu. *Leibniz Algebras and Vertex Algebras.*
The relationship between Leibniz algebras and vertex algebras is currently being explored. Some of these results are summarized. (Received September 21, 2015)

1116-17-2034 **Jonathan S Brown*** (jonathan.brown@oneonta.edu). *Shifted twisted Yangians and finite W-algebras.* Preliminary report.
Finite W-algebras are certain algebras used to help study the infinite dimensional representation theory of reductive complex Lie algebras. So far they are best understood in type A. This is because, apart from a few isolated cases, there are only presentations of finite W-algebras in type A. The key result in finding such presentations, due to Brundan and Kleshchev, is that in type A finite W-algebras are quotients of certain algebras called shifted Yangians, which are subalgebras of the Yangian for $\mathfrak{gl}_n$ defined in terms of the Yangian's Drinfeld presentation. For the other classical Lie algebras, the role of Yangians is played by twisted Yangians. In this talk I will review some of the representation theory of reductive Lie algebras, as well as the connection between Lie algebra representation theory and finite W-algebra representation theory. Then I will explain how I have defined a Drinfeld presentation for the twisted Yangian associated to $\mathfrak{so}_3$, from which I have defined the shifted twisted Yangian for $\mathfrak{so}_3$. This should lead to presentations of a large class of finite W-algebras. (Received September 21, 2015)

1116-17-2156 **Corina Calinescu**, **Antun Milas** and **Michael Penn***
(michael.penn@coloradocollege.edu), Colorado College, Dept. of Mathematics and Computer Science, 14 East Cache La Poudre St., Colorado Springs, CO 80903, and **Christopher Sadowski**. *Twisted Modules of affine Lie Algebras, Vertex Algebras, and Modular q-series.*
The vertex algebraic structure of principal subspaces of standard modules for affine Kac-Moody Lie algebras has been the source of much study in recent years. In the case of an untwisted Lie algebra of type A, D, or E and in the case of a twisted Lie algebra of type A_{2n} the characters of these modules are given by certain Nahm sums. Modularity has been proven in several subcases. In this talk, we explore the construction of characters via a system of q-difference equations. We finish by highlighting the difference in the characters which are Nahm sums and all other twisted cases. (Received September 21, 2015)

18 ► Category theory; homological algebra

1116-18-1036 **Ben Cooper*** (cooper.ben.j@gmail.com), 1020 Church St, Iowa City, IA 52245. *On formal contact categories.*
To each oriented surface S we associate a differential graded category. The homotopy category is a triangulated category which satisfies properties akin to those of the contact categories studied by K. Honda. These categories are related to the algebraic contact categories of Y. Tian and the bordered sutured categories of R. Zarev. (Received September 16, 2015)

1116-18-1282 **Radmila Sazdanovic*** (rsazdanovic@math.ncsu.edu), Department of Mathematics NCSU, SAS Hall 2311 Stinson drive, PO Box 8205, Raleigh, NC 27695, and **Mikhail Khovanov**. *Bernstein-Gelfand-Gelfand reciprocity property and categorification of the polynomial ring.* Preliminary report.
We develop a diagrammatic categorification of the polynomial ring Z[x], based on the geometrically defined graded algebra. This construction generalizes to categorification of some special functions, such as Chebyshev polynomials. Diagrammatic algebras featured in these categorifications lead to the first topological interpretations of the Bernstein-Gelfand-Gelfand reciprocity property. (Received September 18, 2015)

1116-18-1807 **Henry J. Tucker*** (htucker@usc.edu), 3620 S. Vermont Ave., KAP 104, Los Angeles, CA 90089. *Frobenius-Schur indicators for near group and Haagerup-Izumi fusion categories.*
Izumi's realization of the C^* fusion category associated to the Haagerup subfactor as a system of sectors on weak closures of Cuntz algebras began an ongoing program of studying fusion rules generalized from this example. New subfactors associated to these fusion rules have been found via this program, thus providing evidence that the Haagerup and other seemingly "exotic" subfactors are likely part of infinite families. The categorical Frobenius-Schur indicators are generalizations of the classical indicators for finite groups; they are an invariant of

pivotal fusion categories under monoidal equivalence, thus their values allow us to determine whether two fusion categories may appear in the same monoidal equivalence class. In some families, e.g. the Tambara-Yamagami categories, the indicators are sufficient to distinguish the monoidal equivalence classes associated to given fusion rules. Thus their values are useful for distinguishing newly constructed subfactors associated to a given fusion rule. We compute the values of the indicators for both near group and Haagerup-Izumi fusion categories, we show that one family of near groups are completely determined by the indicators, and we provide strong evidence that the same is true for Haagerup-Izumi fusion categories in general. (Received September 21, 2015)

1116-18-1881 **William Dietrich Hardesty*** (hardes1@uga.edu), University of Georgia, Department of Mathematics, 1023 DW Brooks Dr., Athens, GA 30602. *On Support Varieties and the Humphreys Conjecture in type A.*

Let G be a reductive algebraic group scheme defined over $\mathbb{F}_p$ and let G_1 denote the Frobenius kernel of G. To each finite-dimensional G module M, one can define the support variety $V_{G_1}(M)$, which can be regarded as a G-stable closed subvariety of the nilpotent cone. A G-module is called a tilting module if it has both good and Weyl filtrations. In 1997, it was conjectured by J.E. Humphreys that when $p \geq h$, the support varieties of the indecomposable tilting modules align with the nilpotent orbits given by the Lusztig bijection. We shall verify this conjecture when $G = SL_n$ and $p > n + 1$. (Received September 21, 2015)

1116-18-2004 **Jonathan Block** (blockj@math.upenn.edu), **Julian Holstein** (jvsh2@cam.ac.uk) and **Zhaoting Wei*** (zhaotwei@indiana.edu). *Twisted complexes and the homotopy limit of some cosimplicial dg-categories.* Preliminary report.

We give an explicit construction of the simplicial resolution of a dg-category and use it to show that the homotopy limits of some cosimplicial diagrams of dg-categories which arise in algebra and geometry are given by the so-called twisted complexes. In particular our construction works in the following two cases: (1) the complexes of sheaves on the Čech nerve of an open cover of a scheme; (2) the complexes of sheaves on the simplicial nerve of a group acting on a manifold. This result can be applied in the study of descent theory of dg-categories and equivariant dg-categories. (Received September 21, 2015)

1116-18-2888 **Michael N Crumley*** (crumley@findlay.edu), 1000 N. Main St., Findlay, OH 45840. *Ultraproducts of tannakian categories.*

We consider an ultraproduct of a collection of categories of finite dimensional representations of an algebraic group over a collection of fields of increasing positive characteristic. A certain subcategory of this is itself the category of finite dimensional representations of an affine group scheme over the ultraproduct of the fields (always of characteristic zero). We give a fairly tidy description of the underlying Hopf algebra of this group, and compute it in several examples. A possible application of this is to the study of generic cohomology of algebraic groups. (Received September 22, 2015)

1116-18-2965 **Nick J. Davidson*** (ndavidso@uoregon.edu), Department of Mathematics, Fenton Hall, University of Oregon, Eugene, OR 97403. *A Super Categorical View of Kashiwara's Rule for Tensor Products of Crystals.* Preliminary report.

I will discuss some results of Losev and Webster, which give a categorical view of Kashiwara's rule for tensor products of crystals. I have extended these results to super categorical actions. One application is to determine the crystal underlying the category O for the Lie superalgebra q(n). (Received September 23, 2015)

19 ► K-theory

1116-19-769 **Paul Frank Baum*** (pxb6@psu.edu), Mathematics Department, Penn State University, University Park, PA 16802. *Expanders and K-theory for group C* algebras.*

An expander is a sequence of finite graphs $X_1, X_2, X_3, \cdots$ which is efficiently connected. A discrete group G which contains an expander as a sub-graph of its Cayley graph is a counter-example to the Baum-Connes (BC) conjecture with coefficients.

The left side of BC with coefficients "sees" any group as if the group were exact. This talk will indicate how to make a change in the right side of BC with coefficients so that the right side also "sees" any group as if the group were exact. This corrected form of BC with coefficients uses the unique minimal exact and Morita-compatible intermediate crossed product. For exact groups (i.e. all groups except the Gromov groups and the more recent Osajda examples) there is no change in BC with coefficients.

In the corrected form of BC with coefficients any Gromov group or Osajda group acting on the coefficient algebra obtained from its expander is not a counter-example. Thus at the present time (September, 2015) there is no known counter-example to the corrected form of BC with coefficients. The above is joint work with E. Guentner and R. Willett. This work is based on — and inspired by — a result of R. Willett and G. Yu, and is closely connected to results in the thesis of M. Finn-Sell. (Received September 12, 2015)

20 ► Group theory and generalizations

1116-20-173 **Tuval Foguel*** (tfoguel@adelphi.edu), Adelphi University, Garden City, NY 11530.
Partition Numbers of Finite Groups.

A group partition is a group cover in which the elements have trivial pairwise intersection. Here we define the partition number of a group - the minimal number of subgroups necessary to form a partition - and examine some of its properties, including its relation to the covering number. (Received August 11, 2015)

1116-20-201 **Teerapong Suksumran*** (teerapong.suksumran@gmail.com), Department of Mathematics, North Dakota State University, Fargo, ND 58105. *Gyrogroup actions: A generalization of group actions.*

A gyrogroup is a group-like structure, introduced by Abraham A. Ungar in 1988. Gyrogroups share many algebraic properties with groups. In fact, any group may be viewed as a gyrogroup with trivial gyroautomorphisms. In this work we present the notion of gyrogroup actions, which is a natural generalization of the usual notion of group actions. In particular, we prove three celebrated theorems in group theory for gyrogroups: the orbit-stabilizer theorem, the Burnside lemma (or the Cauchy-Frobenius lemma), and the orbit decomposition theorem. We then prove that under a certain condition, a gyrogroup G acts transitively on the set G/H of left cosets of a subgyrogroup H in G by left gyroaddition. (Received August 17, 2015)

1116-20-328 **William L. Cocke*** (cocke@math.wisc.edu), Univ of Wisconsin, Madison, Dept of Math, 480 Lincoln Dr, Madison, WI 53706-1388, and **I. Marty Isaacs** and **D. Skabelund**. *On the number of elements that are not k-th powers in a group.*

Let k be a positive integer, and suppose that the number of elements of a group G that are not kth powers in G is nonzero but finite. If G is finite, we obtain an upper bound on $|G|$, and we present some conditions sufficient to guarantee that G actually is finite. (Received September 11, 2015)

1116-20-382 **Amanda A. Schaeffer Fry*** (aschaef6@msudenver.edu), MSU Denver Math & CS, Denver, CO 80217, and **C. Ryan Vinroot**, College of William and Mary, Williamsburg, VA. *Real classes of finite special unitary groups.*

If G is a group, an element $g \in G$ is said to be real in G if g is G-conjugate to g^{-1}, and is said to be strongly real in G if $hgh^{-1} = g^{-1}$ for some $h \in G$ such that $h^2 = 1$. We classify all conjugacy classes of the finite special unitary groups $SU_n(q)$ which are real and those which are strongly real. It was observed by Gow that there is a natural bijection between the real conjugacy classes of the finite general linear group $GL_n(q)$ and the finite unitary group $GU_n(q)$. Gill and Singh classified the real (and strongly real) conjugacy classes of the finite special linear group $SL_n(q)$, and showed that if n is not 2 mod 4 or q is not 3 mod 4, then a class in $SL_n(q)$ is real if and only if it is real in $GL_n(q)$, and otherwise a class in $SL_n(q)$ is real if and only if it is real in $GL_n(q)$ and has some elementary divisor of the form $f(t)^k$ where k is odd. Given the relationship between $GL_n(q)$ and $GU_n(q)$, one might hope for a parallel description of the real classes of $SU_n(q)$. Somewhat surprisingly, there is not in general. We show that there is a parallel description for real classes of $SU_n(q)$ unless n is divisible by 4 and q is 3 mod 4, in which case the description is somewhat complicated. (Received August 29, 2015)

1116-20-496 **Luise-Charlotte Kappe*** (menger@math.binghamton.edu), **Patrizia Longobardi** and **Mercede Maj**. *On autocommutators in infinite abelian groups.* Preliminary report.

It is well-known that the set of commutators does not necessarily form a subgroup in a group G. For $g \in G$ and $\varphi \in Aut(G)$, the automorphism group of G, we define the autocommutator of g and φ as $[g, \varphi] = g^{-1} \cdot g^{\varphi}$. We denote by $K^* = \{[g, \varphi]; g \in G,\ \varphi \in Aut(G)\}$, the set of all autocommutators of G, and write $G^* = \langle K^*(G)\rangle$ for the autocommutator subgroup of G.

There exists a group of order 64 of nilpotency class 2 in which the autocommutators do not form a subgroup and this group is of minimal order in this respect. It was also shown that the set of autocommutators in a finite abelian group always equals the autocommutator subgroup.

In this talk we will discuss the relationship between $K^*(G)$ and G^* in infinite abelian groups. In particular we have shown that in such groups we do not have necessarily $K^*(G) = G^*$. (Received September 04, 2015)

1116-20-558 **Matthew Zaremsky*** (zaremsky@math.binghamton.edu). *Finiteness properties of infinite groups, and examples in pure braid groups.*

An infinite group is, of course, not finite, but might still possess interesting "finiteness properties". For instance, it could be finitely generated, or even finitely presented. Sometimes it is surprisingly difficult to tell whether or not a group has these and other finiteness properties. One tool in this field is the so called *Bieri–Neumann–Strebel–Renz invariants* of a group, which reveal the finiteness properties of certain of its subgroups. I will discuss the (hard, open) problem of computing these invariants for the pure braid groups, for which I have some partial results, as do Koban-McCammond-Meier. In particular I will explain how these results reveal the finiteness properties of some interesting and natural subgroups of the pure braid groups. (Received September 07, 2015)

1116-20-576 **Kristen Pueschel*** (kpueschel@math.cornell.edu) and **Timothy Riley**. *Dehn functions of mapping tori of rank-3 right-angled Artin group automorphisms.*

The Dehn function of a finitely presented group G is at once both an algebraic and a geometric invariant. Algebraically, the Dehn function gives an upperbound on the time complexity of solving the word problem in G. Geometrically, it describes isoperimetry, the minimal area of discs spanning loops in a group's Cayley 2-complex as a function of perimeter length. In this talk, I will motivate and discuss a classification for the Dehn functions of groups of the form $G \rtimes_\phi \mathbb{Z}$, where G is a rank-3 right angled Artin group. (Received September 07, 2015)

1116-20-601 **Christopher M Drupieski*** (cdrupies@depaul.edu), Department of Mathematical Sciences, DePaul University, 2320 N Kenmove Ave, Chicago, IL 60614-3210, and **Jonathan R Kujawa** (kujawa@math.ou.edu), Department of Mathematics, University of Oklahoma, Norman, OK 73019-3103. *Support varieties for Lie superalgebras and graded group schemes.* Preliminary report.

Following the pioneering work of Quillen in the 1970s, Carlson, Avrunin and Scott, Friedlander and Parshall, Jantzen, and others made much progress in the 1980s studying the cohomology and representation theory of finite groups and restricted Lie algebras by way of their associated cohomological support varieties. Later, many of these methods and results were generalized first to infinitesimal group schemes by Suslin, Friedlander, and Bendel, and then to arbitrary finite group schemes by Friedlander and Pevtsova.

In this talk I will discuss some results and conjectures concerning how some of the aforementioned methods and results can be generalized to restricted (and non-restricted) Lie superalgebras and to certain finite graded group schemes. This is joint work with Jonathan Kujawa. (Received September 08, 2015)

1116-20-626 **Ilir Snopce*** (ilir@im.ufrj.br), Praia de Botafogo 22, Apt. 804, Rio de Janeiro, 22250-145, Brazil. *Asymptotic density of test elements in free groups and surface groups.*

Let G be a finitely generated group with a finite generating set X, d_X the word metric on G with respect to X and $B_X(r)$ the ball of radius $r \geq 0$ centered at the identity in the metric space (G, d_X). Given $S \subseteq G$, the *asymptotic density* of S in G with respect to X is defined as

$$\overline{\rho}_X(S) = \limsup_{k\to\infty} \frac{|S \cap B_X(k)|}{|B_X(k)|}.$$

An element g of a group G is called a test element if for any endomorphism φ of G , $\varphi(g) = g$ implies that φ is an automorphism. The first example of a test element was given by Nielsen in 1918, when he proved that every endomorphism of a free group of rank 2 that fixes the commutator $[x_1, x_2]$ of a pair of generators must be an automorphism.

Let G be a free group of finite rank, an orientable surface group of genus $n \geq 2$, or a non-orientable surface group of genus $n \geq 3$. Let $\mathcal{T}$ be the set of test elements of G. In this talk I will discuss the distribution of $\mathcal{T}$ in G. In particular, I will show that $\mathcal{T}$ has positive asymptotic density in G. This answers a question of Kapovich, Rivin, Schupp, and Shpilrain. This is a joint work with Slobodan Tanushevski. (Received September 09, 2015)

1116-20-629 **David M. Carroll*** (carroll@math.tamu.edu), Department of Mathematics, Mailstop 3368, Texas A&M University, TX 77843-3368, and **Benjamin Francisco** and **Zoran Sunic**. *Some computational complexity results for right-angled Artin groups.*

Right-angled Artin groups, also known as graph groups, are groups which can be presented in a simple way using a graph: each vertex is a generator, and two generators commute if and only if they are adjacent in the graph. Despite their apparent simplicity, in the last few decades right-angled Artin groups and their subgroups have been shown to exhibit surprisingly deep algebraic and geometric properties.

In this talk, we examine right-angled Artin groups from a computational complexity point of view. In particular, we discuss the problem of deciding if a right-angled Artin group, given by its defining graph, is free-by-cyclic or free-by-free; we show the former can be done in polynomial time but the latter is NP-complete. This is a joint work with Zoran Šunić and Benjamin Francisco. (Received September 09, 2015)

1116-20-632 **George Glauberman***, gg@math.uchicago.edu. *What's new about finite p-groups.*

I plan to discuss recent results and open problems about finite p-groups and some applications. (Received September 09, 2015)

1116-20-651 **Eric M. Friedlander*** (eric@math.northwestern.edu), Department of Mathematics, USC, 3620 S. Vermont Ave, Los Angeles, CA 90089. *Rational Cohomology and Supports for Unipotent Algebraic Groups.* Preliminary report.

Let G be an linear algebraic group of exponential type and M a rational G-module. We discuss the relationship between the support variety $V(G)_M$ defined in terms of 1-parameter subgroups and the support variety $V^{coh}(G)_M$ defined in terms of rational cohomology. As an interesting example, we consider the unipotent group U_N, improving previous computations of its rational cohomology. (Received September 10, 2015)

1116-20-681 **Jon F Carlson*** (jfc@math.uga.edu), Department of Mathematics, University of Georgia, Athens, GA 30602. *The relative stable category of a modular group algebra.* Preliminary report.

Let G be a finite group and k an algebraically closed field of characteristic $p > 0$. Let $\mathcal{H}$ be a collection of p-subgroups of G. We investigate the relative stable category $\mathbf{stmod}_{\mathcal{H}}(kG)$ of finitely generated modules modulo $\mathcal{H}$-projective modules. Triangles in this category correspond to $\mathcal{H}$-split sequences. Hence, compared to the ordinary stable category there are fewer triangles and more thick subcategories. Our interest is in the spectrum of this category and its relationship to the induction functor. (Received September 10, 2015)

1116-20-689 **Michael JJ Barry*** (mbarry@allegheny.edu). *Generators for Decompositions of Tensor Products of Modules associated with standard Jordan partitions.*

If K is a field of finite characteristic p, G is a cyclic group of order $q = p^\alpha$, U and W are indecomposable KG-modules with $\dim U = m$ and $\dim W = n$, and $\lambda(m, n, p)$ is a standard Jordan partition of mn, we describe how to find a generator for each of the indecomposable components of the KG-module $U \otimes W$. (Received September 10, 2015)

1116-20-713 **Dmytro M Savchuk*** (savchuk@usf.edu), Department of Mathematics and Statistics, University of South Florida, 4202 E Fowler ave., CMC 342, Tampa, FL 33620, and **Said N Sidki**, Departamneto de Matematica, Universidade de Brasilia, Brasilia-DF, 70910, Brazil. *Affine Automorphisms of Rooted Trees.* Preliminary report.

We introduce a class of automorphisms of rooted d-regular trees, arising from affine actions on their boundaries viewed as infinite dimensional vector spaces. This class includes, in particular, many examples of self-similar realizations of lamplighter groups. We show that for a regular binary tree this class coincides with the normalizer of the group of all spherically homogeneous automorphisms of this tree; automorphisms whose states coincide at all vertices of each level. We study in detail a nontrivial example of an automaton group that contains an index two subgroup with elements from this class and show that it is isomorphic to the index 2 extension of the rank 2 lamplighter group $\mathbb{Z}_2^2 \wr \mathbb{Z}$. (Received September 10, 2015)

1116-20-840 **Peter Loth*** (lothp@sacredheart.edu), Department of Mathematics, Sacred Heart University, 5151 Park Avenue, Fairfield, CT 06825. *Abelian groups with partial decomposition bases.* Preliminary report.

Warfield groups are defined to be abelian groups possessing a nice decomposition basis with simply presented cokernel. Generalizing the concept of decomposition basis, C. Jacoby developed the class of abelian groups with partial decomposition bases in order to extend Barwise and Eklof's classification of torsion groups in $L_{\infty\omega}$ to Warfield groups. In this talk, we study the class of groups with (partial) decomposition bases relative to Warfield groups. (Received September 14, 2015)

1116-20-844 **Christopher P. Bendel*** (bendelc@uwstout.edu), Math, Stats and CS Department, 231 Jarvis Hall Science Wing, University of Wisconsin-Stout, Menomonie, WI 54751, and **Daniel K. Nakano** and **Cornelius Pillen**. *Third cohomology for algebraic groups and Lie algebras.*

Let G be a simple, simply connected algebraic group over an algebraically closed field of prime characteristic p that is not too small. Let B be a Borel subgroup of G with unipotent radical U. We discuss recent computations of the third degree cohomology groups of B and its Frobenius kernels with coefficients in a one-dimensional module, as well as related computations of Frobenius kernels of G with coefficients in standard induced modules.

This work involves new computations of the ordinary Lie algebra cohomology of the Lie algebra of U. (Received September 14, 2015)

1116-20-845 **Mark Greer** (mgreer@una.edu) and **Lee Raney*** (lraney@una.edu), University of North Alabama, Florence, AL. *Constructions from Groups to Loops.*

Given a group G, we discuss some interesting modifications of the group operation in order to induce a loop $(G, \circ)$. Of particular interest is a remarkable construction known as the Baer Trick: Given a uniquely 2-divisible group G, define $x \oplus y = xy[y, x]^{1/2}$. We will examine the structure of these Baer trick loops $(G, \oplus)$ in general and survey a few known results. We will then discuss necessary and sufficient conditions that the group G should satisfy in order to guarantee a certain desirable loop structure on the corresponding Baer trick loop. (Received September 14, 2015)

1116-20-855 **Frederick R. Cohen** (conf@math.rochester.edu), Department of Mathematics, University of Rochester, Rochester, NY 14627, **David J. Hemmer** (dhemmer@math.buffalo.edu), Department of Mathematics, University of Buffalo, SUNY, Buffalo, NY 14260, and **Daniel K. Nakano*** (nakano@math.uga.edu), Department of Mathematics, University of Georgia, Athens, GA 30602. *The Lie Module and its Complexity.*

The complexity of a module is an important homological invariant that measures the polynomial rate of growth of its minimal projective resolution. For the symmetric group Σ_n, the Lie module $\mathsf{Lie}(n)$ has attracted a great deal of interest in recent years. In this talk, I will show that the complexity of $\mathsf{Lie}(n)$ in characteristic p is t where p^t is the largest power of p dividing n, thus proving a conjecture of Erdmann, Lim and Tan. The proof uses work of Arone and Kankaanrinta which describes the homology $\mathrm{H}^\bullet(\Sigma_n, \mathsf{Lie}(n))$ and earlier work of Hemmer and Nakano on complexity for modules over Σ_n that involves restriction to Young subgroups. (Received September 14, 2015)

1116-20-943 **Paul E Becker*** (peb8@psu.edu). *Automorphism groups of extremal codes.*

A linear binary code is a vector space consisting of binary vectors with a specified length. A code is error-correcting if the individual vectors are sufficiently far apart to allow correction of occasional substitution errors. Construction of codes with specified properties is an active area of research. In this talk, we will discuss a well-known error-correcting code, and explain how partial knowledge of its automorphism group is sufficient to construct the code. We will then discuss a sequence of papers by numerous authors which greatly restrict the automorphism group of a particular putative code. The existence of this code has been an open question for 40 years. (Received September 15, 2015)

1116-20-959 **Rachel K. Skipper*** (skipper@math.binghamton.edu), Department of Mathematical Sciences, Binghamton University, PO Box 6000, Binghamton, NY 13902-6000. *The congruence subgroup problem for branch groups.*

Branch groups form an important class of groups, as from this class many examples of groups with consequential algebraic properties arise.

With a branch group, G, just like with many types of infinite groups, one may ask what properties of G can be well understood by considering its finite quotients. This question can be addressed by considering the profinite completion of G, denoted $\hat{G}$, which G embeds into as branch groups are naturally residually finite. But a branch group also embeds into another profinite group whose structure is instead determined by its characteristic action on a tree, $\mathcal{T}$, namely its closure in $Aut(\mathcal{T})$ denoted $\bar{G}$. The congruence subgroup problem asks to compare these two profinite groups and in particular to quantitatively describe the congruence kernel, the kernel of the map $\hat{G} \to \bar{G}$.

In this talk, I will describe these profinite groups and discuss recent efforts towards solving the congruence subgroup problem for branch groups.

(Received September 15, 2015)

1116-20-964 **Michael A Rosas*** (marosas@buffalo.edu), 125 Glenhaven Drive Unit Right, Amherst, NY 14228. *Specht modules in the principal block of $F\Sigma_{3p}$.*

We discuss the radical structures of Specht modules lying in the principal block of $F\Sigma_{3p}$, where F is a field of characteristic $p \geq 5$. We see that the Loewy length of any Specht module in the block is at most four. Furthermore, we state precisely which Specht modules have Loewy length one, two, three, or four. We also see that the second radical layer of a Specht module in the block is determined by the Ext^1-quiver of the block.

Finally, we show that if a Specht module in the block has Loewy length three then its socle and third radical layer coincide. (Received September 15, 2015)

1116-20-1052 **Harald Ellers*** (hellers@allegheny.edu), Dept. of Mathematics, Allegheny College, 520 N. Main St., Meadville, PA 16335, and **Craig J. Dodge** (cdodge2@allegheny.edu), Dept. of Mathematics, Allegheny College. *Specht modules, simple modules, and a kernel intersection theorem for centralizer algebras of the symmetric group.* Preliminary report.

Let Σ_n be the symmetric group. For $l \leq n$, Σ_l is naturally identified as a subgroup of Σ_n. Let k be an algebraically closed field of characteristic p. The algebra $k\Sigma_n{}^{\Sigma_l}$ is the centralizer in the group algebra $k\Sigma_n$ of $k\Sigma_l$. The authors are engaged in a project to find all simple $k\Sigma_n{}^{\Sigma_l}$-modules.

In the 1970's, James produced a construction of all simple $k\Sigma_n$-modules. He associates to each partition λ of n a $k\Sigma_n$-permutation module M^λ. The Specht module S^λ is the intersection of the kernels of certain homomorphisms with domain M^λ, and $S^{\lambda^\perp}$ is the sum of the images of certain homomorphisms with codomain M^λ. The module $D^\lambda := S^\lambda/(S^\lambda \cap S^{\lambda^\perp})$ is 0 or simple.

We investigate an analogous construction for $k\Sigma_n{}^{\Sigma_l}$, with role of the permutation modules played by the $k\Sigma_n{}^{\Sigma_l}$-modules $\mathcal{M}^{\lambda,\mu} := \mathrm{Hom}_{\Sigma_l}(M^\mu, M^\lambda{}_{k\Sigma_l})$, where λ is a partition of n and μ is a partition of l. For some choices of n and l, the results look very much like the classical results. (Received September 16, 2015)

1116-20-1059 **Carl Mautner***, Mathematics Department, University of California, Riverside, 900 University Ave., Riverside, CA 92521, and **Simon Riche**. *Exotic sheaves, parity sheaves and the Mirković–Vilonen conjecture.*

Mirković and Vilonen conjectured a parity-vanishing property for stalks of perverse sheaves on the affine Grassmannian corresponding to Weyl modules under the geometric Satake equivalence. I will discuss the statement of this conjecture and its proof. Our proof involves a generalization to positive characteristic of an amazing equivalence due to Arkhipov–Bezrukavnikov–Ginzburg. The original equivalence has been useful in studying representations of quantum groups, and we suspect our generalization could play a similar role in the modular setting. (Received September 16, 2015)

1116-20-1215 **Jie Du**, **Brian Parshall** and **Leonard Scott*** (lls2l@virginia.edu). *Extending Hecke Endomorphism Algebras.*

The (Iwahori-)Hecke algebra in the title is a q-deformation $\mathcal{H}$ of the group algebra of a finite Weyl group W. The algebra $\mathcal{H}$ has a natural enlargement to an endomorphism algebra $\mathcal{A} = End_{\mathcal{H}}(\mathcal{T})$ where $\mathcal{T}$ is a q-permutation module. In type A_n (i.e., $W \cong \mathfrak{S}_{n+1}$), the algebra $\mathcal{A}$ is a q-Schur algebra which is quasi-hereditary and plays an important role in the modular representation of the finite groups of Lie type. In other types, $\mathcal{A}$ is not always quasi-hereditary, but the authors conjectured in 1998 that $\mathcal{T}$ can be enlarged to an $\mathcal{H}$-module $\mathcal{T}^+$ so that $\mathcal{A}^+ = End_{\mathcal{H}}(\mathcal{T}^+)$ is at least standardly stratified, a weaker condition than being quasi-hereditary, but with "strata" corresponding to Kazhdan-Lusztig two-sided cells.

The main result of this paper is a first step toward this conjecture, a "local" version in the equal parameter case, localizing at cyclotomic polynomials with some restrictions, and using the theory of rational Cherednik algebras. As time permits, I will try to place the result in a broader context. (Received September 17, 2015)

1116-20-1303 **Julia Pevtsova***, julia@math.washington.edu, and **Dave Benson**, **Srikanth Iyengar** and **Henning Krause**. *Localizing subcategories for modules of finite group schemes.*

I'll discuss a recent proof of the classification of the localizing tensor subcategories in the stable module category of a finite group scheme. (Received September 18, 2015)

1116-20-1355 **Justin Lynd*** (justin.lynd@mso.umt.edu). *Standard form problems for 2-fusion systems.*

A program of M. Aschbacher's for the classification of 2-fusion systems of component type is well underway. This program seeks to give a new proof of roughly half of the classification of finite simple groups by completing the bulk of the work in the category of 2-fusion systems. The last stage in this program involves solving the remaining so-called "standard form problems". I will explain what a standard form problem is, give a high-level description of how this last stage fits into the program, and survey the progress to date. (Received September 18, 2015)

1116-20-1394 **Michael P. Allocca*** (mallocca@muhlenberg.edu), 2400 Chew St., Allentown, PA 18104, and **Jason M. Graham**, **Candice R. Price**, **Shannon N. Talbott** and **Jennifer F. Vasquez**. *Symmetric Generating Sets for D_n and Word Length Perturbations.* Preliminary report.

The standard symmetric generating set of cardinality 2 for D_n is well-understood. We analyze symmetric generating sets for D_n of cardinality 3 and discuss the so-called "butterfly effect" on minimal word lengths using two measures of sensitivity that are of current interest in the computational biology literature. (Received September 19, 2015)

1116-20-1432 **Nham Vo Ngo*** (nhamngo@math.arizona.edu), University of Arizona, Department of Mathematics, Tucson, AZ 85721. *On nilpotent commuting varieties and cohomology of Frobenius kernels.*

In this talk, we present some results on commuting varieties of nilpotent r-tuples in a classical Lie algebra $\mathfrak{g}$ defined over an algebraically closed field k. These results are then used to obtain some information about the structure of the cohomology ring of Frobenius kernels G_r for each $r \geq 1$, where G is the simply connected, simple algebraic group such that $\mathrm{Lie}(G) = \mathfrak{g}$. (Received September 19, 2015)

1116-20-1549 **John Hutchens*** (jdhutchens@gmail.com) and **Nathaniel Schwartz** (nschwartz2@washcoll.edu). *Involutions of type G_2 over a field of characteristic 2.* Preliminary report.

Let C be an eight dimensional composition algebra, then $\mathrm{Aut}(C)$ is a group of type G_2. In this paper we establish a characterization of automorphisms of order 2 and their fixed point groups for groups of type G_2 over a field of characteristic 2. We do this by establishing a connection between the structure of the subalgebras of C, and the elements in $\mathrm{Aut}(C)$ that induce the inner automorphisms of order 2. (Received September 20, 2015)

1116-20-1577 **Jennifer Elder***, arwenu@mail.fresnostate.edu, Fresno, CA 93720. *Generalizations of The Futurama Theorem.* Preliminary report.

What if there was a machine that could switch the brains of two people, but couldn't swap them back? Ken Keeler created this puzzle specifically for the TV show Futurama, and solved it using Abstract Algebra. In this talk, we will present a new proof for Keeler's Theorem, as well as a generalized solution to the problem involving a machine that swaps k people at a time. (Received September 20, 2015)

1116-20-1640 **Paul Sobaje*** (psobaje@yahoo.com). *Projective indecomposable $G_{(r)}$-modules.*

Let G be simple algebraic group over an algebraically closed field of positive characteristic, and let $G_{(r)}$ be the r-th Frobenius kernel of G. Various conjectures deal with the existence and possible structures over G of the projective indecomposable $G_{(r)}$-modules. These conjectures are known to hold when p is large enough, but remain open in smaller characteristic. We will discuss recent work on this problem, including new techniques which have been developed in an effort to solve it. (Received September 20, 2015)

1116-20-1652 **Joel Kamnitzer**, **Peter Tingley**, **Ben Webster**, **Alex Weekes** and **Oded Yacobi*** (oded.yacobi@sydney.edu.au). *Lusztig slices and truncated shifted Yangians.*

Lusztig slices are transverse slices to affine Schubert varieties in the affine Grassmannian of a reductive group G, which arise naturally in representation theory via the geometric Satake correspondence. We will discuss algebras called truncated shifted Yangians, which are quantizations of these slices. In particular we will describe the highest weight theory of these algebras using Nakajima's monomial crystal. This leads to conjectures about categorical g^L-action (Langlands dual Lie algebra) on representation categories of truncated shifted Yangians. (Received September 20, 2015)

1116-20-1837 **Stephen M Gagola, Jr*** (gagola@math.kent.edu), Department of Mathematics, 1300 University Esplanade, Kent State University, Kent, OH 44242. *Linear group actions on related algebras.* Preliminary report.

Let G be a finite linear group in characteristic 0. It is well known that this action by G on the vector space induces related actions by G on other linear spaces, most notably the homogeneous components of the symmetric algebra of the original space, as well as the graded components of this algebra modulo homogeneous invariants of positive degree (the 'coinvariant' algebra). We explore this theme when the algebra is selected in a way adapted to the group. (Received September 21, 2015)

1116-20-1862 **Tsunekazu Nishinaka*** (nishinaka@econ.u-hyogo.ac.jp), University of Hyogo, 8-2-1, Gakuen-Nishimachi, Nishi-Ku, Kobe, Hyogo 651-2197, Japan. *Uncountable locally free groups and their group algebras.*

A group is called locally free if all of its finitely generated subgroups are free. It is known that there exist locally free groups which are not free. Clearly, a locally free group G whose cardinality is countable has always a countably infinite subgroup which is free. In this talk, we extend this fact to the result for general cardinality:

Theorem 1 If G is a locally free group, then G has a free subgroup whose cardinality is the same as that of G itself.

Now, a ring R is (right) primitive if it has a faithful irreducible (right) R module. In [1], the present author showed that the group algebra KG of a group G over a field K is primitive provided G is a non-abelian locally free group which has a free subgroup whose cardinality is the same as that of G. We can improve this result by Theorem 1:

Theorem 2 If G is a non-abelian locally free group, then the group algebra KG is primitive for any field K.

References

[1] Nishinaka, T. *Group rings of countable non-abelian locally free groups are primitive,* Int. J. algebra and computation, **21**, (2011), 409-431.

(Received September 21, 2015)

1116-20-1920 **Thomas W Tucker*** (ttucker@colgate.edu), Math Dept, Colgate University, Hamilton, NY 13346, and **Marston D.E. Conder** (m.conder@auckland.ac.nz) and **Mark E Watkins** (mewatkin@syr.edu). *Graphical Frobenius Representations with even complements.* Preliminary report.

A Frobenius group is a transitive, but not regular, permutation group G such that the only element fixing two points is the identity. By a theorem of Frobenius, we can write $G = HK$ where H is a point stabilizer and K is a normal, regular subgroup; K is called the *kernel* and H the *complement*. When $|H|$ is even, then K is abelian of odd order.. A graphical Frobenius representation for $G = HK$ is a Cayley graph for K with point stabilizer H. Determining which Frobenius groups have a GFR is a natural generalization of the classical graphical regular representation (GRR) problem. We are interested in the case where $|H|$ is even and at least 4. (Received September 21, 2015)

1116-20-1981 **Anton Lukyanenko*** (lukyanen@umich.edu) and **Joseph Vandehey**. *Carnot vs Siegel: Diophantine approximation in the Heisenberg group.*

In 1966, W. Schmidt used a game theory argument to prove that the set of badly approximable real numbers has full Hausdorff dimension, despite having measure zero. The argument was extended in 2010 by McMullen to the set of points D(G) in the boundary of a hyperbolic space that are occluded by a collection of horoballs associated to a non-uniform lattice G.

Interpreting McMullen's result for the Heisenberg group H^1 (a boundary of the complex hyperbolic plane), we show that the set of badly approximable points in the Siegel model of H^1 has full Hausdorff dimension. We then compare Diophantine approximation in the Carnot and Siegel models of H^n, finding a difference in both the critical Diophantine exponent and the structure of badly approximable points (the latter via a Schmidt games result).

In particular, we obtain a correspondence between the set D(G) (for G the Picard modular group), the set of points with bounded continued fraction digits, and set of badly approximable points in the Siegel model of H^1. This provides the first strong link between Heisenberg continued fractions and complex hyperbolic geometry. (Received September 21, 2015)

1116-20-2037 **Keith M Jones*** (keith.jones@oneonta.edu), Department of Mathematics, Computer Science, and Statistics, SUNY College at Oneonta, 108 Ravine Parkway, Oneonta, NY 13820, and **Gregory Kelsey**. *The Horofunction Boundary of the Lamplighter Group.*

While many groups do not enjoy the same geometric properties that hyperbolic or CAT(0) groups enjoy, we can use the horofunction boundary, first introduced by Gromov, to provide any group with a "boundary at infinity" once a generating set has been chosen. This boundary is dependent on generating set, but it provides a topological space on which the group acts, which is metrizable and compact when the group is finitely generated.

In this talk I will describe the structure of the horofunction boundary of the lamplighter group L_2 with the generating set corresponding to the Diestel-Leader graph, in an update to work with my colleague Gregory Kelsey. (Received September 21, 2015)

1116-20-2055 **Bir Kafle*** (bkafle@pnc.edu), 1401 S. U.S. 421, Westville, IN 46391, and **Robert Perlis**. *Local Conjugacy in Nilpotent Groups.* Preliminary report.

Two subgroups H, H' of a finite group G are said to be Gassmann equivalent if each conjugacy class of G intersects H and H' in the same number of elements. Gassmann equivalent subgroups are also locally conjugate in G. In this talk, we will disscuss the local conjugacy in nilpotent groups. We will also present a construction of a finite group with locally conjugate subgroups which are pairwise non-conjugate. (Received September 21, 2015)

1116-20-2122 **Atish J Mitra*** (atish.mitra@gmail.com). *Infinite Groups and Absolute Extensors.*

M. Gromov introduced the concept of asymptotic dimension of a metric space as a large scale analog of classical topological dimension and as a coarse invariant of metric spaces. This and related large scale dimensions turn out to be an important tool in understanding some properties of finitely generated groups viewed as metric spaces.

In this talk we introduce the new concept of large scale absolute extensors of a metric space and study its relations to various aspects of coarse geometry. We characterize this concept in several ways, and relate it with asymptotic dimension of groups. We use this concept to study asymptotic properties of finitely generated groups. (Received September 21, 2015)

1116-20-2126 **Nate Harman*** (nharman@mit.edu). *Periodicity phenomena in the modular representation theory of symmetric and general linear groups.*

In characteristic zero there are a number of representation theoretic quantities for symmetric groups S_n and general linear groups GL_n which stabilize in an appropriate sense as n tends to infinity. We investigate what happens to these when we pass to the positive characteristic and quantum cases. In positive characteristic we have a notion categorical periodicity which is actually stronger than what happens in characteristic zero, but the periods involved are unbounded. In the quantum case we get a weaker numerical periodicity similar to the semisimple case, but with bounded period. (Received September 21, 2015)

1116-20-2192 **George Glauberman** and **Justin Lynd*** (justin.lynd@mso.umt.edu). *Centric linking systems and control of fixed points.*

Andrew Chermak has recently shown that each saturated fusion system has a unique associated centric linking system, thereby giving a new proof of the Martino-Priddy conjecture concerning the p-completed classifying spaces of finite groups. In the case of a fusion system of a finite group, the centric linking system provides a "link" to, and a combinatorial model of, the p-completed classifying space. In the case of an arbitrary saturated fusion system, perhaps arising from no ambient finite group, a centric linking system for it allows one to associate with the fusion system a classifying space. Concurrently with Chermak's result, Oliver gave a version of Chermak's proof that involved showing that a certain representation of the p-orbit category has vanishing cohomology in degrees at least 2 (and is acyclic if p is odd). Both Chermak's and Oliver's proofs appeal to the classification of finite simple groups to handle a residual case in an inductive context. On the other hand, a 1971 result of Glauberman sheds additional light on the nature of the vanishing of low-dimensional cohomology of this representation and allows for a classification-free proof of Chermak's Theorem. (Received September 22, 2015)

1116-20-2413 **Martha Lee Kilpack*** (mlhkilpack@mathematics.byu.edu) and **Arturo Magidin** (magidin@member.ams.org). *For what groups would the lattice of closure operators which act on the subgroup lattice also form a subgroup lattice?*

If L is a lattice, the collection of all closure operators on L forms a lattice from a natural partial order. A standard example of a lattice a subgrps(G), the lattice of subgroups of a given group G. We will determine all the finite groups G for which the lattice of closure operators on subgrps(G) give a lattice that is isomorphic to subgrps(H) for some group H. (Received September 22, 2015)

1116-20-2480 **Madeleine Burkhart** and **David C. Vella*** (dvella@skidmore.edu), Dept. Mathematics & Computer Science, Skidmore College, 815 N. Broadway, Saratoga Springs, NY 12866. *Nilpotent Orbits for Borel Subgroups of Modality Zero.* Preliminary report.

Let G be a simple algebraic group with Lie algebra Lie(G) and B a Borel subgroup of G with Lie algebra Lie(B). Let $\mathfrak{n}$ denote the nilradical of Lie(B). Then B acts on $\mathfrak{n}$ via the Adjoint action. The orbits of this action are called the nilpotent orbits of B. In 1990 it was shown that there are finitely many nilpotent orbits (if this happens, B is said to have 'modality zero') in exactly five cases. Since then, much of the literature has been focused on generalizing this result to studying the modality of parabolic subgroups. In this paper, we stick to Borel subgroups in the five cases of modality zero. In these cases, we determine the defining equations of each orbit and use this information to find the dimension of each orbit as well as the closure ordering on the orbits. (Received September 22, 2015)

1116-20-2483 **Andrei Minchenko*** (an.minchenko@gmail.com), Faculty of Mathematics and Computer Science, Weizmann Institute of Science, 234 Herzl St, 7610001 Rehovot, Israel. *Calculating parameterized Picard-Vessiot group.*

One of the most important problems of differential Galois theory is description of the Galois group of a linear differential equation with parameters. Moreover, one wants to know an algorithm that finds the defining equations of this group. There have been many results providing solution for special cases but in general the problem is still unsolved. I will try to sum up what is known and explain a possible general approach. (Received September 22, 2015)

1116-20-2594 **Corey F Lyons*** (clyons3@kent.edu). *Induced Characters with Equal Degree Constituents.* Preliminary report.

We investigate the situation where each of the nonprincipal irreducible characters of a subgroup H, of a finite group G, induce to G as a sum of irreducible characters, all of equal degree. When this situation occurs either H is contained in G' or G' is contained in H. It has been conjectured further that H is subnormal in G. We present a partial result and a related family of examples. (Received September 22, 2015)

1116-20-2652 **Marijo Sracic*** (msracic@kent.edu). *A Review of Thompson's Fixed-Point-Free Automorphism Theorem.*

In the early 1900s, Frobenius conjectured that if a group G admits a fixed-point-free automorphism ϕ, then G must be solvable. During the next half-century mathematicians struggled to find a completely group theoretic proof of Frobenius' Conjecture.

In this presentation, we will consider Thompson's group theoretic proof of the restricted Frobenius Conjecture:

Theorem: Let G be a group admitting a fixed-point-free automorphism of prime order. Then G is nilpotent. (Received September 22, 2015)

1116-20-2824 **Jason Saied*** (saiedj@lafayette.edu), Math Dept, Lafayette College, Easton, PA 18042, and **Dantong Zhu**. *Outer Automorphisms of S_6 Acting on Combinatorial Structures.* Preliminary report.

S_6 is the only symmetric group with outer automorphisms. These curious objects have gotten a lot of attention recently, with researchers trying to understand their structure and how they act on various objects. We will look at the action of the outer automorphisms on combinatorial objects, including finite geometry and root systems. (Received September 22, 2015)

22 ► Topological groups, Lie groups

1116-22-44 **David Vogan*** (dav@math.mit.edu), Department of Mathematics, E18-442, MIT, 77 Massachusetts Avenue, Cambridge, MA 02139. *Conjugacy classes and group representations.* Preliminary report.

The conjugacy classes in a group carry a lot of nice information in an easy-to-understand package: conjugacy classes of permutations are classified by their cycle decomposition, and conjugacy classes of matrices by (more or less!) their eigenvalues. The sizes of conjugacy classes measure how noncommutative the group is.

The representations of a group offer much more information, but in less agreeable packaging: it is not so easy to say even what the representations of a permutation group are, for example.

An idea of Kirillov and Kostant from the 1960s seeks to describe (abstract and mysterious) representations in terms of (concrete and geometric) conjugacy classes. I'll recall what their idea looks like; some of its classical successes; and some ways that it fits into modern mathematics. (Received June 18, 2015)

1116-22-676 **Paul Frank Baum*** (pxb6@psu.edu), Department of Mathematics, Penn State University, University Park, PA 16802. *Geometric Structure in Smooth Dual.*

Let G be a connected split reductive p-adic group. Examples are $GL(n, F), SL(n, F), SO(n, F)$, and $Sp(2n, F)$ where n can be any positive integer and F can be any finite extension of the field Q_p of p-adic numbers. The smooth (or admissible) dual of G is the set of equivalence classes of smooth irreducible representations of G. The smooth dual of G is the disjoint union of subsets known as the Bernstein components.

The talk will explain the ABPS (Aubert-Baum-Plymen-Solleveld) conjecture which states that each Bernstein component is a complex affine variety. Each of these complex affine varieties is explicitly identified as the extended quotient associated to the given Bernstein component.

The ABPS conjecture has been proved for $GL(n, F), SL(n, F), SO(n, F)$, and $Sp(2n, F)$. The above is joint work with Anne-Marie Aubert, Roger Plymen, and Maarten Solleveld. (Received September 10, 2015)

1116-22-743 **Robert W. Benim*** (rbenim@gmail.com), Forest Grove, OR, and **Mark Hunnell** and **Amanda K. Sutherland**. *Isomorphy Classes of Finite Order Automorphisms of SL(2,k).*

In this paper, we consider the order m k-automorphisms of SL(2,k). We first characterize the forms that order m k-automorphisms of SL(2,k) take and then we find simple conditions on matrices A and B, involving eigenvalues and the field that the entries of A and B lie in, that are equivalent to isomorphy between the order m k-automorphisms Inn_A and Inn_B. We examine the number of isomorphy classes and conclude with examples for selected fields. (Received September 11, 2015)

1116-22-1624 **Firas Y Hindeleh*** (hindelef@gvsu.edu), 1 Campus Dr, Allendale, MI 49401, and **Christopher Mattoon** (mattoonc@mail.gvsu.edu), 547 Crosby St. NW, Grand Rapids, MI 49504. *Classification of Seven-Dimensional Lie Algebras with $H \oplus \mathbb{R}^3$ Niradical.* Preliminary report.

Low dimensional solvable Lie algebra classification started back in 1963 by Mubarakzyanov. Solvable Lie algebras were completely classified up to dimension six. A general theorem asserts that if $\mathfrak{g}$ is a solvable Lie algebra of dimension n, then the dimension of the nilradical is at least $\frac{n}{2}$. For the seven- dimensional algebras, the nilradical's dimension could be $4, 5, 6$ or 7. The four and seven dimensional nilradical cases were classified. We examine the six-dimensional niradical case, and depending on the structure of this nilradical there are 32 classes. In this project we focus on the class where the nilradical is to a direct sum of a three-dimensional Heisenberg and a three-dimensional abelian algebras ($H \oplus \mathbb{R}^3$). (Received September 20, 2015)

1116-22-2332 **Laura J Rider*** (laurajoy@mit.edu) and **Pramod Achar**. *Parity sheaves on the affine Grassmannian and the Langlands dual Springer resolution.*

Through geometric Satake, the local intersection cohomology on the affine Grassmannian encodes the weight multiplicities of corresponding representations of the Langlands dual group over any field. Several such derived versions of geometric Satake have been proven in characteristic 0 in work of Bezrukavnikov–Finkelberg and Arkhipov–Bezrukavnikov–Ginzburg. I'll discuss these equivalences and recent progress on modular versions of these theorems. This is joint work with Pramod Achar. (Received September 22, 2015)

1116-22-2948 **William Graham** and **Wenjing Li*** (wli@simpsonu.edu). *The Bruhat order, the lookup conjecture and spiral Schubert Varieties of type $\tilde{A}_2$.*

Although the Bruhat order on a Weyl group is closely related to the singularities of the Schubert varieties for the corresponding Kač-Moody group, it can be difficult to use this information to prove general theorems. This paper uses the action of the affine Weyl group of type $\tilde{A}_2$ on a Euclidean space $V \cong \mathbb{R}^2$ to study the Bruhat order on W. We believe that these methods can be used to study the Bruhat order on arbitrary affine Weyl groups. Our motivation for this study was to extend the lookup conjecture (which is a conjectural simplification of the Carrell-Peterson criterion for rational smoothness) to type $\tilde{A}_2$. Computational evidence suggests that the only Schubert varieties in type $\tilde{A}_2$ where the "nontrivial" case of the lookup conjecture occurs are the spiral Schubert varieties, and as a step towards the lookup conjecture, we prove it for a spiral Schubert variety $X(w)$ of type $\tilde{A}_2$. The proof uses descriptions we obtain of the elements $x \leq w$ and of the rationally smooth locus of $X(w)$ in terms of the W-action on V. (Received September 23, 2015)

26 ► Real functions

1116-26-1382 **DoYong Kwon*** (doyong@jnu.ac.kr), Department of Mathematics, Chonnam National University, Gwangju, 500-757, South Korea. *Discrete measures with dense jumps induced by Sturmian Dirichlet series.*

Let $(s_\alpha(n))_{n\geq 1}$ be the lexicographically greatest Sturmian word of slope $\alpha > 0$. For a fixed $\sigma > 1$, we consider Dirichlet series of the form $\nu_\sigma(\alpha) := \sum_{n=1}^{\infty} s_\alpha(n)n^{-\sigma}$. In this talk, we study the singular properties of the real function ν_σ, and the Lebesgue-Stieltjes measure whose distribution is given by ν_σ. (Received September 19, 2015)

1116-26-2653 **Udita N Katugampola*** (udita@udel.edu), Department of Mathematical Sciences, University of Delaware, Newark, DE 19716. *Can we generalize the limit-definition of the derivative?* Preliminary report.

Let $f : D \to \mathbb{R}$ and $x \in (a, b) \subset D$. Let $g : E \to \mathbb{R}$ such that $x + \epsilon g(\xi) \in D$ for $\xi \in E$ and some $\epsilon > 0$. We consider the derivative given by

$$\mathcal{D}_{g(\xi)}(f)(x) = \lim_{\epsilon\to 0} \frac{f(x + \epsilon g(\xi)) - f(x)}{\epsilon}$$

relative to the function g and prove that it obeys the familiar properties such as product rule, quotient rule, power rule, chain rule, Mean Value Theorems, Rolle's Theorem and several other properties that a standard derivative satisfies. It can be seen that the function g acts as a `catalyst` and controls the convergence rate. We also discuss the relation between this derivative and two other existing derivatives, namely the Fréchet and Gâutaux derivatives. According to the literature, it is interesting to note that the case of $g(x) = x^{1-\alpha}$, is now known as the *Katugampola fractional derivative.* Finally, we also point out that the definition can easily be extended to include the complex-valued functions. (Received September 23, 2015)

28 ► Measure and integration

1116-28-411 **Matthew Badger*** (matthew.badger@uconn.edu). *Rectifiable and purely unrectifable measures in the absence of absolute continuity.*

This talk will survey recent progress by the speaker and R. Schul on the problem of identifying necessary and sufficient conditions for a Radon measure μ on $\mathbb{R}^n$ to be m-rectifiable ($1 \leq m \leq n-1$) or purely m-unrectifiable in the sense of Federer. The interesting aspect of this program is to study the rectifiability of μ without assuming an *a priori* relationship between μ and the m-dimensional Hausdorff measure as has been done in the past. (Received August 31, 2015)

1116-28-440 **Xiao-Xiong Gan*** (xiao-xiong.gan@morgan.edu), Department of Mathematics, Morgan State University, Baltimore, MD 21251. *Minkowski's Inequality with One-Form.*

The classical Minkowski's inequality has two different forms based on the values of the positive number p:

Part 1. If $1 \leq p < \infty$, then

$$\|f + g\|_p \leq \|f\|_p + \|g\|_p;$$

Part 2. If $0 < p < 1$, then

$$\|f + g\|_p \geq \|f\|_p + \|g\|_p$$

where $\|f\|_p = (\int |f|^p)^{1/p}$.

We provide a one-form Minkowski's inequality for all $p > 0$. A non-conjugate Hölder's inequality is also introduced. Some applications of the one-form Minkowski's inequality and non-conjugate Hölder's inequality are introduced too (Received September 01, 2015)

1116-28-1130 **Bruce Kleiner***, Courant Institute of Mathematical Sciences, 251 Mercer Street, New York, NY 10012. *New examples of spaces satisfying Poincare inequalities.*

I will discuss some new examples of spaces satisfying Poincare inequalities that exhibit novel structure. (Received September 17, 2015)

1116-28-1235 **Michel L. Lapidus**, **Goran Radunović*** (goran.radunovic@fer.hr) and **Darko Žubrinić**. *Fractal tube formulas for relative fractal drums in arbitrary Euclidean spaces via Lapidus zeta functions.*

Relative fractal drums generalize the notion of fractal sets in Euclidean spaces of arbitrary dimension. We establish pointwise and distributional fractal tube formulas for a large class of relative fractal drums. These fractal tube formulas are expressed as sums of residues of suitable meromorphic functions over the complex dimensions of the relative fractal drum under consideration (i.e., over the poles of its distance or tube zeta function which generalizes the well-known zeta function for fractal strings). These results generalize to higher dimensions the corresponding ones previously obtained for fractal strings by M. L. Lapidus and M. van Frankenhuijsen. We illustrate our results by several interesting examples and apply them to obtain a new Minkowski measurability criterion. We also reflect on the notion of h-Minkowski measurability (where h is an appropriate gauge function), which is connected to the existence of principal complex dimensions of higher order (i.e., multiplicity). (Received September 18, 2015)

1116-28-1253 **Guy C. David*** (guydavid@math.nyu.edu) and **Raanan Schul**. *Analyst's Traveling Salesman theorems in limits of metric graphs.* Preliminary report.

The "Analyst's Traveling Salesman Theorem" of Peter Jones characterizes subsets of rectifiable curves in the plane. There has been much recent work extending this result to more general spaces. In this talk, we will discuss an analog of this theorem in a class of highly non-Euclidean spaces with interesting analytic properties introduced by Laakso and Cheeger-Kleiner, which can be viewed as limits of metric graphs. (Received September 18, 2015)

1116-28-1350 **Joshua Kaminski**, **Alexander Panchenko*** (anpanchenko@gmail.com) and **Kevin Vixie**. *L^∞-Transport and Data-Driven Partitions.* Preliminary report.

The main question addressed in the talk is as follows. Given a set of N data points in the unit cube of a finite-dimensional Euclidean space, partition the cube into the union of non-overlapping sets satisfying the following requirements: (i) every set contains exactly one data point; (ii) the Lebesgue measures of the sets are equal; (iii) there is an upper bound on the diameter of the sets which converges to zero as N approaches infinity. We show that the necessary and sufficient conditions for existence of such a partition is weak-* convergence of the empirical measures associated with the data set to the Lebesgue measure. (Received September 18, 2015)

1116-28-1416 **Sarah Dumnich*** (src210@lehigh.edu), Christmas Saucon Hall, 14 E. Packer Ave, Bethlehem, PA 18015, and **Robert Neel** (robert.neel@lehigh.edu). *Weak Convergence to a Solution of the Dilation Equation for Measures.*

A multiresolution analysis is a tool used in the construction of orthogonal wavelets. The dilation equation is an equation that arises naturally when using an MRA to construct a wavelet basis. One way to understand the dilation equation is through a measure theoretic approach. By constructing a solution to the dilation equation for measures, we are able to uniquely determine a corresponding wavelet basis. In this talk, I will define a sequence of discrete measures μ_n, and show that this sequence weakly converges to a solution of the dilation equation for measures. (Received September 19, 2015)

1116-28-1588 **Vasileios Chousionis*** (vasileios.chousionis@uconn.edu), Department of Mathematics, University of Connecticut, 196 Auditorium Road U-3009, Storrs, CT 06269-3009. *Densities and uniformly distributed measures in the Heisenberg group.*

We prove Marstrand's density theorem in the Heisenberg group $\mathbb{H}^n$ with respect to the Korányi metric d_H. The proof relies on an analysis of uniformly distributed measures on $(\mathbb{H}^n, d_H)$. We provide a number of examples of such measures, illustrating both the similarities and the differences of this sub-Riemannian setting from its Euclidean counterpart. We will also discuss uniform measures in the first Heisenberg group. Based on joint works with Jeremy T. Tyson and V. Magnani. (Received September 20, 2015)

1116-28-2216 **Shuang Shen*** (sshen@math.cuhk.edu.hk), Room 233, Lady Shaw Building, The Chinese University of Hong Kong, Shatin, N. T., Hong Kong, Hong Kong. *On the "degree of emptiness of empty sets": An interpretation of "latent dimension".* Preliminary report.

A set assigned to a negative fractal dimension is by convention an empty set, while B. B. Mandelbrot in 1980s claimed that simply neglecting this dimension "is a waste of valuable information". In this talk, a class of inhomogeneous multinomial measures is to be introduced and used as a direct and simple example to give an interpretation of the latent dimension. Such a measure μ is constructed to satisfy an extended multifractal formalism in the sense that, for a certain range of α, the Hausdorff dimension and packing dimension of the α-level set of the local Hölder exponent of μ, taking the entropy-like form, are respectively given by the values of the Legendre transforms of two distinct energy functions (Olsen's B and b functions) at α. When α is chosen outside its domain, it may happen that the Hausdorff dimension is negative whereas the packing dimension is positive. Following Mandelbrot's suggestion, we tackle the problem on both geometric and statistical aspects. Methodologically we begin with the computation of the corresponding upper and lower large deviations spectra. (Received September 22, 2015)

1116-28-2425 **Marianna Csornyei*** (csornyei@math.uchicago.edu). *Projection theorem in infinite dimensional spaces.*

A fundamental theorem in geometric measure theory is the Besicovitch-Federer projection theorem which characterizes pure unrectifiability in terms of projections. The projection theorem states that in an Euclidean space, for any set of finite 1-dimensional measure, the projection in almost every direction has measure zero if and only if the set is purely unrectifiable.

In this talk we study projection theorem in infinite dimensional spaces. This is a joint work with D. Bate and B. Wilson. (Received September 22, 2015)

30 ► Functions of a complex variable

1116-30-28 **Mikhail Tyaglov*** (tyaglov@sjtu.edu.cn), Shanghai, Peoples Rep of China, **Olga Katkova**, Boston, MA, **Anna Vishnyakova**, Kharkov, Ukraine, and **Jiacheng Xia**, Shanghai, Peoples Rep of China. *Zeros of finite differences of polynomials and entire functions.*

We study the classes of finite differences that preserve roots of univariate polynomials on lines or in strips and half-planes of the complex plane. In particular, we describe the classes of finite differences that preserve the hyperbolicity of polynomials and prove a finite difference analogue of the Hermite-Pauline theorem. As well, we study finite differences of polynomials with minimal mesh (minimal distance between roots). Corresponding results for entire functions will be presented. (Received June 03, 2015)

1116-30-112 **Rosihan M Ali*** (rosihan@usm.my), School of Mathematical Sciences, 11800 Penang, Malaysia, and **Roger W Barnard** and **Alexander Yu. Solynin**. *The Bohr radius for power series and analytic functions into wedge domains.*

The Bohr radius is obtained for certain power series in the unit disk. The Bohr radius is also established for analytic functions mapping the unit disk into a concave-wedge domain. (Received July 29, 2015)

1116-30-475 **Sarah Koch***, kochsc@umich.edu. *Postcritical sets in moduli space.*

Consider the moduli space $\mathcal{M}_{0,n}$ of curves of genus 0 with n marked points. Call a point $x \in \mathcal{M}_{0,n}$ *postcritically special* if there is a postcritically finite rational map $F : \mathbb{P}^1 \to \mathbb{P}^1$ whose postcritical set P is a representative of the point x in moduli space.

In an email conversation, L. DeMarco posed the following question: in $\mathcal{M}_{0,n}$, what does the locus of postcritically special points look like? We prove that this locus is dense in $\mathcal{M}_{0,n}$, with respect to the complex-analytic topology. (Received September 03, 2015)

1116-30-554 **See Keong Lee*** (sklee@usm.my), School of Mathematical Sciences, Universiti Sains Malaysia, 11800 USM, Malaysia, and **Rosihan M. Ali**. *Some Properties for the Generalized Struve Functions.* Preliminary report.

In this talk, a generalization of the classical Struve functions will be given. It is shown that this generalized Struve function is a solution of a differential equation of certain order. Some properties of this function, such as monotonicity and log-convexity properties, will be investigated too. (Received September 07, 2015)

1116-30-597 **Robert D. Bates*** (rdbates@math.hawaii.edu), Department of Mathematics, 874 Dillingham Blvd, Honolulu, HI 96817. *Operator Diagonalizations of Multiplier Sequences.*

We consider hyperbolicity preserving operators with respect to a new linear operator representation on $\mathbb{R}[x]$. In essence, we demonstrate that every Hermite and Laguerre multiplier sequence can be diagonalized into a sum of hyperbolicity preserving operators, where each of the summands forms a classical multiplier sequence. Interestingly, this does not work for other orthogonal bases; for example, this property fails for the Legendre basis. We establish many new formulas concerning the Q_k's of Peetre's 1959 differential representation for linear operators in the specific case of Hermite and Laguerre diagonal differential operators. Additionally, we provide a new algebraic characterization of the Hermite multiplier sequences and also extend a recent result of T. Forgács and A. Piotrowski on hyperbolicity properties of the polynomial coefficients in hyperbolicity preserving Hermite diagonal differential operators. (Received September 08, 2015)

1116-30-765 **Vyron S Vellis*** (vyron.v.vellis@jyu.fi) and **Pekka Pankka**. *Quasiconformal non-parametrizability of almost smooth spheres.*

We show that, for each $n \geq 3$, there exists a smooth Riemannian metric g on a punctured sphere $\mathbb{S}^n \setminus \{x_0\}$ for which the associated length metric extends to a length metric d of $\mathbb{S}^n$ with the following properties: the metric sphere $(\mathbb{S}^n, d)$ is Ahlfors n-regular and linearly locally contractible but there is no quasiconformal homeomorphism $(\mathbb{S}^n, d) \to \mathbb{S}^n$. (Received September 12, 2015)

1116-30-780 **David Alan Cardon*** (cardon@math.byu.edu), Department of Mathematics, Brigham Young University, Provo, UT 84602. *Complex zero strip decreasing operators.*

Let $\phi(z)$ be a function in the Laguerre-Pólya class. Write $\phi(z) = e^{-\alpha z^2}\phi_1(z)$ where $\alpha \geq 0$ and where $\phi_1(z)$ is a real entire function of genus 0 or 1. Let $f(z)$ be any real entire function of the form $f(z) = e^{-\gamma z^2} f_1(z)$ such that $\gamma \geq 0$ and $f_1(z)$ is a real entire function of genus 0 or 1 having all of its zeros in the strip $S(r) = \{z \in \mathbb{C}\colon -r \leq \operatorname{Im} z \leq r\}$ for $r > 0$. If $\alpha\gamma < 1/4$, the linear differential operator $\phi(D)f(z)$, where D denotes differentiation, converges to a real entire function whose zeros also belong the strip $S(r)$. We discuss necessary and sufficient conditions on $\phi(z)$ such that all zeros of $\phi(D)f(z)$ belong to a smaller strip $S(r_1) = \{z \in \mathbb{C}\colon -r_1 \leq \operatorname{Im} z \leq r_1\}$ where $0 \leq r_1 < r$ and r_1 depends on $\phi(z)$ but is independent of $f(z)$. A linear operator having this property is called a *complex zero strip decreasing operator*. (Received September 12, 2015)

1116-30-819 **Rajesh Pereira*** (pereirar@uoguelph.ca), Department of Mathematics and Statistics, University of Guelph, 50 Stone Road E., Guelph, Ontario N1H 2W1, Canada. *Majorization and the Zeros of Entire Functions.* Preliminary report.

The majorization and log-majorization partial orders have proved very useful in the theory of inequalities. We describe a natural connection between Jensen's formula and weak log-majorization relations on the zero sets of entire functions. Connections to Mahler measure, Lehmer's conjecture and other inequalities are also explored. (Received September 13, 2015)

1116-30-852 **Stephanie Edwards*** (sedwards@hope.edu), **Sarah Hilsman** and **Anna Snyder**. *Level curves of real algebraic functions and theorem of Pólya.* Preliminary report.

We consider an old theorem of G. Pólya's which looks at the level curves of real algebraic functions and the intersection of such curves with lines of positive slope. We modify Pólya's theorem, relaxing conditions on the functions and also considering intersections with lines of negative slope. We look at some specific examples for lower degree polynomial functions. (Received September 14, 2015)

1116-30-948 **Khang D Tran*** (khangt@csufresno.edu), Department of Mathematics, California State University, Fresno, 5245 North Backer Avenue M/S PB108, Fresno, CA 93740. *Zero distribution of sequences of polynomials.*

We discuss an approach which shows that the zeros of various sequences of polynomials lie on fixed curves on the complex plane. In one application of this approach, we provide a linear operator T which preserves zeros of real polynomials on the negative real ray. Special forms of this operator transform real polynomials whose zeros lie on an open sector of the complex plane to polynomials whose zeros lie on $(-\infty, 0)$. In another application of this approach, we study the zeros of sequences of polynomials with complex coefficients generated by rational generating functions. For example, given any two polynomials $A(z)$ and $B(z)$ with complex coefficients, the zeros of the large degree polynomials, generated by the reciprocal of $1 + B(z)t + A(z)t^n$ by expanding it as a series in t, lie on an explicit curve whose equation is defined by $A(z)$ and $B(z)$. We also study other rational generating functions where the method may apply. (Received September 15, 2015)

1116-30-989 **Pritha Chakraborty*** (pritha.chakraborty@ttu.edu) and **Alexander Solynin**. *Non-Linear Extremal Problems in Bergman Spaces.*

The Bergman space $\mathcal{A}^2(\mathbb{D})$ is the set of square integrable analytic functions in the unit disc $\mathbb{D} = \{z \in \mathbb{C} :\ |z| < 1\}$. Boris Korenblum conjectured in 1991 and Walter Hayman proved in 1992 that for $f,\ g \in \mathcal{A}^2(\mathbb{D})$, there is a constant c, $0 < c < 1$, such that if $|f(z)| \leq |g(z)|$ for all z in $c \leq |z| < 1$, then $\|f\|_2 \leq \|g\|_2$. The largest possible value of such c is called the Korenblum's constant. The exact value of this constant, which is denoted by κ, remains unknown. I will discuss some non-linear extremal problems in Bergman space and prove some results which will shed some light on the Korenblum's problem. (Received September 15, 2015)

1116-30-990 **Nageswari Shanmugalingam*** (shanmun@uc.edu), Department of Mathematical Sciences, P.O.Box 210025, University of Cincinnati, Cincinnati, OH 45221, and **Panu Lahti**. *Fine properties of BV functions-analogs of quasicontinuity.*

It is now well-known that Sobolev functions are quasicontinuous – that is, we can find open sets of small capacity so that the restriction of a (good representative of a) Sobolev function to the complement of the open set is continuous. This property fails for functions of bounded variation. In this talk we will give an analog of quasicontinuity for functions of bounded variation. (Received September 15, 2015)

1116-30-1032 **Javad Mashreghi*** (javad.mashreghi@mat.ulaval.ca), Department of Mathematics and Statistics, Laval University, Quebec, QC G1V 0A6, Canada. *An application of finite Blaschke products in operator theory.*

Let T be an operator on a Hilbert space H with numerical radius $w(T) \leq 1$. According to a theorem of Berger and Stampfli, if f is a function in the disk algebra such that $f(0) = 0$, then $w(f(T)) \leq \|f\|_\infty$. We give a new and elementary proof of this result using finite Blaschke products.

A well-known result relating numerical radius and norm says $\|T\| \leq 2w(T)$. We obtain a local improvement of this estimate, namely, if $w(T) \leq 1$ then

$$\|Tx\|^2 \leq 2 + 2\sqrt{1 - |\langle Tx, x\rangle|^2} \qquad (x \in H,\ \|x\| \leq 1).$$

Using this refinement, we give a simplified proof of Drury's teardrop theorem, which extends the Berger–Stampfli theorem to the case $f(0) \neq 0$.

Joint work with H. Klaja and T. Ransford. (Received September 16, 2015)

1116-30-1270 **Kevin Wildrick*** (kevin.wildrick@montana.edu). *Quasiconformal mappings via iterated function systems.* Preliminary report.

The family of quasiconformal mappings in the plane is very rich, as attested to by the measurable Riemann mapping theorem. However, in higher dimensions, the richness of this family is still unclear. The situation in the sub-Riemannian Heisenberg group is even less clear; while it is homeomorphic to three-dimensional space, its quasiconformal geometry is strongly influenced by the two-dimensional horizontal distribution. We will discuss the construction of quasiconformal mappings using iterated function systems, and show that this method can produce mappings that substantially distort the dimension of many subsets in these settings. This reports on joint work with Zoltán Balogh and Jeremy Tyson. (Received September 18, 2015)

1116-30-1412 **Pietro Poggi-Corradini*** (pietro@math.ksu.edu). *Theory and applications of p-modulus of families of walks on networks.* Preliminary report.

I will review the theory of p-modulus for families of walks on networks and discuss a couple of numerical implementations. Then I will show through examples how the flexibility and generality of p-modulus makes it a suitable tool for applications to the study and modeling of epidemic spreading. (Received September 19, 2015)

1116-30-1542 **Yuji Kodama*** (kodama.1@osu.edu), Department of Mathematics, The Ohio State University, 231 West 18th Ave, Columbus, OH 43210. *Confluence of generalized hypergeometric functions and integrable hydrodynamic type equations.* Preliminary report.

We start with a brief introduction of the Gelfand hypergeometric (GHG) functions and their confluences by means of the action of the centralizers of regular elements. The confluence then implies that the GHG functions are now defined in a degenerate cell of the Grassmannian. We construct integrable hydrodynamic type systems defined on such cells. This is a joint work with Boris Konopelchenko. (Received September 20, 2015)

1116-30-1764 **Olivia Isabella Orrantia-Kotowski*** (olivia.orrantia@ttu.edu), 1336 James Kelley, El Paso, TX 79936, and **George Brock Williams**. *Circle Packing Random Triangulations.*

The deep connection between conformal maps and discrete maps from one circle packing to another have been an object of study since Thurston's pioneering work in the 1980's. Far less well understood is the nature of maps from a random triangulation to a circle packing for that triangulation. We expect there to be a normal distribution of point relations as they move from a random triangulation to a circle packing. Our research will serve to help validate our current hypothesis. (Received September 21, 2015)

1116-30-1860 **Mario Bonk*** (mbonk@math.ucla.edu), Dept. of Mathematics, UCLA, Los Angeles, CA 90095. *The quasiconformal geometry of continuum trees.*

Continuum trees appear in various contexts: in probabilistic models, as Julia sets of polynomials, or as attractors of iterated function systems. Accordingly, one wants to gain a good understanding of the topology and geometry of these objects, but often faces difficult problems. For example, it was not known until recently whether two independent samples of the CRT (continuum random tree) are almost surely homeomorphic. Even more difficult questions arise if one investigates the quasiconformal geometry of continuum trees, and more specifically, if one wants to characterize a given tree up to quasisymmetric equivalence. In my talk I will present some recent developments in this area. This is joint work with Huy Tran. (Received September 21, 2015)

1116-30-1888 **Thomas Craven*** (tom@math.hawaii.edu). *Recent progress on the question of whether rapidly decreasing sequences are complex zero decreasing sequences.* Preliminary report.

A sequence of nonnegative real numbers $\Gamma = \{\gamma_k\},\ k = 0, 1, 2, 3, \ldots$ is said to be a complex zero decreasing sequence if for any real polynomial $p(x) = \sum_{k=0}^{n} a_k x^k$, the polynomial $\Gamma[p(x)] = \sum_{k=0}^{n} \gamma_k a_k x^k$ has no more nonreal zeros than $p(x)$. These sequences have been completely characterized if they do not decrease more rapidly than can be interpolated by an entire function in the Laguerre-Pólya class. In particular, the sequences satisfying $\gamma_k^2 \geq 4\gamma_{k-1}\gamma_{k+1}$, know as rapidly decreasing sequences, still pose an open problem. They are known to work if $p(x)$ has only real zeros. We will discuss known results, experiments and a possible approach to a proof. (Received September 21, 2015)

1116-30-2159 **Alexandre Eremenko** and **Erik Lundberg*** (elundber@fau.edu). *The classification problem for arclength null-quadrature domains.*

A null-quadrature domain is a domain for which integration of any function in the domain's Bergman space vanishes. M Sakai classified (planar) null-quadrature domains in 1981. Considering the Smirnov space of the domain instead of the Bergman space leads to the notion of an arclength null-quadrature domain. The corresponding classification problem remains open. We discuss recent progress and useful unexpected connections to fluid dynamics (hollow vortex equilibria) and minimal surfaces. (Received September 22, 2015)

1116-30-2227 **Lukasz Grabarek*** (lgrabarek@matsu.alaska.edu), P.O. Box 2889, Palmer, AK 99645. *On stability preserving properties of coefficient-wise transformations.* Preliminary report.

The Laguerre-Pólya class of entire functions consists of precisely those functions that can be approximated, uniformly on compacta, by real polynomials all of whose zeros are real. Necessary and sufficient conditions for membership in the Laguerre-Pólya class are of particular interest.

The non-linear, coefficient-wise transformation $a_k \mapsto a_k^2 - a_{k-1}a_{k+1}$, maps polynomials with real and negative zeros to polynomials of the same kind. This transformation extends to transcendental entire functions, enjoys stability preserving properties, is the building block of a class of coefficient-wise transformations, and thus characterizes a class of necessary conditions for membership in the Laguerre-Pólya class. A joint work with M. Chasse and M. Visontai extends the stability preserving properties of $a_k \mapsto a_k^2 - a_{k-1}a_{k+1}$ to certain sequences of polynomials, i.e., the polynomial $P_{k+1}^2 - P_kP_{k+2}$ will be (weakly) Hurwitz stable provided the sequence $\{P_k\}_{k=0}^{\infty}$ of simple polynomials satisfies certain first-order differential recurrences.

This talk is a survey of results concerning non-linear, coefficient-wise transformations, analogous transformations on sequences of polynomials, and their stability preserving properties. (Received September 22, 2015)

1116-30-2460 **Michael Dorff** (mdorff@mathematics.byu.edu), Department of Mathematics, Brigham Young University, Provo, UT 84604, **Samaneh G. Hamidi*** (s.hamidi@mathematics.byu.edu), Department of Mathematics, Brigham Young University, Provo, UT 84604, **Bo-Yong Long** (longboyong@ahu.edu.cn), School of Mathematical Sciences, Anhui University, Hefei, Peoples Rep of China, and **Jay M. Jahangiri** (jjahangi@kent.edu), Department of Mathematics, Kent State University, Burton, OH 44021. *Convolution of A Harmonic Square Map Preserving Directional Convexity.*

Previously, M. Dorff proved that the harmonic convolution of a normalized right half-plane mapping with either another normalized right half-plane mapping or a normalized vertical strip mapping is convex in the direction of the real axis, provided that it is locally univalent. This result has formed the basis of many current research papers. In this talk, we prove a similar result but this time for the harmonic convolution of a normalized square mapping with a normalized polygonal mapping or a normalized half strip mapping is convex in the direction of the real axis, provided that it is locally univalent. (Received September 22, 2015)

1116-30-2554 **Stacey Muir***, The University of Scranton, Mathematics Department, Scranton, PA 18510. *Convex Combinations of Planar Harmonic Mappings Realized through Convolutions with Half-strip Mappings.* Preliminary report.

Recent investigations into what geometric properties are preserved under the convolution of two planar harmonic mappings on the open unit disk $\mathbb{D}$ have often involved half-plane and strip mappings. We introduce a family of half-strip mappings on $\mathbb{D}$ and consider the convolution of members of this family with other harmonic mappings. We will show this convolution decomposes into a convex combination of two planar harmonic mappings and use this decomposition to produce interesting families of convex harmonic mappings. (Received September 22, 2015)

1116-30-2654 **Debendra Banjade**, **Hyun Kwon** and **Todd Neal*** (taneal@crimson.ua.edu). *A Refinement of Wolff's Theorem on the Multiplier Algebra of the Dirichlet Space.* Preliminary report.

Some recent progress in solving Corona type problems on the multiplier algebra of the Dirichlet space will be presented. Insight into the techniques used to solve such problems will be given. (Received September 22, 2015)

1116-30-2819 **Matthew Chasse**, **Tamás Forgács** and **Andrzej Piotrowski*** (apiotrowski@uas.alaska.edu). *Multiplier Sequences for the Legendre Polynomial Basis.* Preliminary report.

We investigate the hyperbolicity preserving properties of linear operators $T : \mathbb{R}[x] \to \mathbb{R}[x]$ of the form $T[P_n(x)] = p(n)P_n(x)$ where P_n denotes the nth Legendre polynomial and p is a given real polynomial. Following the ideas of P. Brändén and E. Ottergren, we apply the classical multiplier sequence $\{1, 0, 0, 0, \dots\}$ to the symbol $G_T(x, y) = \sum(-1)^n T(x^n)y^n/n!$. This leads to conditions which must be satisfied by the coefficients of the interpolating polynomial p in the case where the corresponding operator T is hyperbolicity preserving. As an application of our results, we demonstrate that a large number of classical multiplier sequences are not multiplier sequences for the Legendre basis. (Received September 22, 2015)

1116-30-2839 **Kourosh Tavakoli*** (ktavakoli@okcu.edu). *Arbitrary Compositions of Infinitely Many Analytic Complex Functions.*

In this talk we study the compositions of infinitely many analytic complex functions from a domain in the plane into a subdomain. In particular we are interested in the behavior of the limit functions. The geometry of a domain and its subdomain can be an important factor in determining the type of the limit functions. We also study some interesting examples to see the wide range of possibilities of the limit functions. We also discuss the new extensions of the existing results. Finally we pose some questions for further research. (Received September 22, 2015)

1116-30-2874 **Mohammed A. Qazi*** (maqazi@mytu.tuskegee.edu), Dept of Mathematics, Tuskegee, AL 36088. *An L^2 Inequality for Polynomials.*

Let $\mathcal{M}_2(g\,;\,\rho)$ denote the L^2 mean of g on the circle $|z| = \rho$. We prove that for any polynomial $f(z) := \sum_{k=0}^n a_k z^k$ of degree at most n, with $|a_{n-k}| = |a_k|$ for $k = 0, 1, \dots, n$, the ratio $\mathcal{M}_2(f'\,;\,\rho)/\mathcal{M}_2(f\,;\,1)$ is maximized by $f(z) := 1 + z^n$ for all $\rho \in [2^{-1/n}\,, \infty)$. At least in the case where n is even, the restriction on ρ cannot be relaxed. (Received September 22, 2015)

31 ► Potential theory

1116-31-572 **Jonas Azzam*** (jazzam@mat.uab.cat), Universitat Autònoma de Barcelona, Departament de Matemàtiques, Edifici C, Faculta de Ciències, Bellaterra,, Spain, and **Steve Hofmann**, **José María Martell**, **Svitlana Mayboroda**, **Mihalis Mourgoglou**, **Xavier Tolsa** and **Alexander Volberg**. *Rectifiability of Harmonic Measure.*

The local F. and M. Riesz theorem of Bishop and Jones says that, for a simply connected planar domain, harmonic measure is absolutely continuous with respect to 1-dimensional Hausdorff measure on the intersection of the boundary with any rectifiable curve. We will survey some recent generalizations of this theorem under certain geometric restrictions on the domain. Surprisingly, the converse holds in even more generality than the original theorem: absolute continuity of harmonic measure on any domain implies rectifiability of the boundary. This is based on joint work with Steve Hofmann, José María Martell, Svitlana Mayboroda, Mihalis Mourgoglou, Xavier Tolsa, and Alexander Volberg. (Received September 07, 2015)

1116-31-2755 **Lucio M.G. Prado*** (lprado@gradcenter.cuny.edu), Department of Mathematics, BMCC, The City University of New York, New York, NY - 10007, New York, NY 10007. ***Poisson Equation for p-Laplacian on Infinite Graphs and Existence of Solution.***

The aim of this talk is to present concepts and techniques from p-potential theory on Riemannian manifolds adapted to*infinite graphs*. We investigated p-Laplacian Poisson equation on a connected locally finite simplicial graph G with vertex set V. The principal tool will be p-capacity that allow us to classify the infinite graphs regarding p-hyperbolicity/p-parabolicity, under determined condition in terms of p. With p-hyperbolicity/p-parabolicity, we examine the conditions under which the existence of solution of the Poisson equation on p-Dirichlet space can be determined. Finally, if time permits, examples will be presented.
(Received September 22, 2015)

32 ► Several complex variables and analytic spaces

1116-32-204 **James Sunkes*** (sunkes@math.utk.edu), Department of Mathematics, University of Tennessee, Knoxville, TN 37996, and **Stefan Richter**. *Hankel Operators, Invariant Subspaces, and Cyclic Vectors in the Drury-Arveson Space.*

In this talk, I will sketch the proof that every nonzero invariant subspace of the d-shift on the Drury-Arveson space H^2_d is an intersection of kernels of Hankel operators. I will then use this result to show that if f and $1/f \in H^2_d$, then f is cyclic in H^2_d. This talk is based upon a joint paper with my advisor, Stefan Richter, entitled "Hankel operators, invariant subspaces, and cyclic vectors in the Drury-Arveson space." (Received September 17, 2015)

1116-32-410 **severine biard*** (biards@math.tamu.edu), Department of Mathematics, Mailstop 3368, Texas A&M University, College Station, TX 77843-3368. *Nonexistence of smooth Levi-flat hypersurface with positive normal bundle in compact Kähler manifolds of dimension ≥ 3.*

Among results of nonexistence of Levi-flat hypersurfaces in $\mathbb{CP}^n$, $n \geq 2$, conjectured by D. Cerveau in 1993, there are some generalizations to compact Kähler manifolds, particularly the conjecture given by Marco Brunella in 2008: there is no smooth Levi-flat hypersurface such that the normal bundle to the Levi foliation is positive along the leaves in compact Kähler manifolds of dimension ≥ 3. In a joint work with Andrei Iordan, we obtained a positive answer to this conjecture by using L^2-weighted estimates for $\bar{\partial}$. (Received August 31, 2015)

1116-32-420 **Liwei Chen***, chen.1690@osu.edu. *Regularity of the weighted Bergman projection on the Hartogs triangle.*

We study the L^p and L^p-Sobolev regularity of the weighted Bergman projection on the Hartogs triangle, where the weight is any real power of the distance away from the singularity. We also introduce the exponential weight, which can be considered as the limiting case. (Received August 31, 2015)

1116-32-489 **Zeljko Cuckovic** (zeljko.cuckovic@utoledo.edu), Toledo, OH 43606, and **Sonmez Sahutoglu*** (sonmez.sahutoglu@utoledo.edu), Toledo, OH 43606. *Essential norm estimates for the $\overline{\partial}$-Neumann operator.*

Essential norm of an operator is its distance to compact operators. In this talk we give a lower estimate for the essential norm of the $\overline{\partial}$-Neumann operator on convex domains and on worm domains. This is joint work with Zeljko Cuckovic. (Received September 03, 2015)

1116-32-672 **R. Michael Range*** (range@albany.edu). *A pointwise a-priori estimate for the $\overline{\partial}-$Neumann problem on weakly pseudoconvex domains.*

We discuss *pointwise* a-priori estimates for the $\overline{\partial}-$Neumann problem on an *arbitrary* weakly pseudoconvex domain D in $\mathbb{C}^n$. Such estimates provide an analogon of the classical basic estimate in the L^2 theory that has been the starting point for all major work in this area involving L^2 and Sobolev norm estimates for the complex Neumann and related operators. In particular, it is shown that for $(0,q)$ forms f in the domain of the adjoint $\overline{\partial}^*$ of $\overline{\partial}$, for any coefficient f_J of f the pointwise growth of $\overline{\partial} f_J$ is controlled by the sum of the suprema of f, $\overline{\partial} f$, and $\overline{\partial}^* f$ over D multiplied with $dist(z, bD)^{-1+\delta}$, for any $\delta < 1/2$. These results generalize known estimates from the *strictly* pseudoconvex case to general weakly pseudoconvex domains. The proofs utilize the new non-holomorphic Cauchy-Fantappié kernels recently introduced by the author (Math. Ann. **356** (2013), 793–808) that reflect the complex geometry of the boundary of D. (Received September 10, 2015)

1116-32-727 **Andrew Zimmer*** (aazimmer@uchicago.edu). *Negative curvature in several complex variables.*

Any complex manifold has several intrinsic (but possibly degenerate) metrics: for instance the Kobayashi and Carathéodory metrics. In this talk we will describe when these metrics have negative curvature like behavior. Finding and exploiting this behavior leads to a number of new results including: a new characterization of polynomial domains via their automorphism group, the Greene-Krantz conjecture in the case of uniform non-tangential convergence, a new Denjoy-Wolff theorem, and new results about continuous extensions of bi-holomorphisms and complex geodesics. (Received September 11, 2015)

1116-32-767 **Luke D. Edholm*** (edholm.1@osu.edu). *The Bergman theory of generalized Hartogs triangles: L^p-Sobolev boundedness.*

The Bergman theory of domains which generalize the Hartogs triangle is explored. For each $\gamma \in \mathbb{Z}^+$, we give an explicit formula for the Bergman kernel of the domain $\Omega_\gamma = \{|z_1|^\gamma < |z_2| < 1\}$. Using this formula we explore the action of the Bergman projection of Ω_γ on the associated Lebesgue and Sobolev function spaces.

We also mention how these results change in the cases when γ is a non-integer rational or an irrational number.
(Received September 12, 2015)

1116-32-861 **Dincer Guler*** (dincer.guler@park.edu), 8700 NW River Park Drive, Parkville, MO 64152. *Positive eigenvalues of curvatures of line bundles that lie on the boundary of the Kahler cone.* Preliminary report.

In this talk we will describe how to compute the maximum number of positive eigenvalues of curvatures of special line bundles on compact Kahler manifolds and how the result generalizes the Andreotti-Grauert vanishing theorem. (Received September 21, 2015)

1116-32-1017 **Dusty Grundmeier*** (deg@math.harvard.edu), Dept. of Mathematics, Harvard University, 1 Oxford Street, Cambridge, MA 02138. *Compressed Sensing and CR Mappings.* Preliminary report.

In this talk we will show how techniques from compressed sensing can be used to compute the minimal embedding dimension for certain CR manifolds into spheres. (Received September 16, 2015)

1116-32-1075 **Loredana Lanzani*** (llanzani@syr.edu), Mathematics Department, 215 Carnegie Bldg, Syracuse, NY 13244, and **Elias M. Stein**. *On Cauchy Integrals and the Szegő projection.* Preliminary report.

I will present joint work with E. M. Stein concerning various examples and counter-examples that aim to complement our recent joint work on the L^p-regularity of the Szegő projection and other singular integral operators in the context of domains with minimal boundary regularity. (Received September 16, 2015)

1116-32-1161 **Phillip S Harrington*** (psharrin@uark.edu), SCEN 309, 1 University of Arkansas, Fayetteville, AR 72701. *Bounded Plurisubharmonic Exhaustion Functions in $\mathbb{CP}^n$.* Preliminary report.

It is frequently helpful in the study of pseudoconvex domains to have a defining function r with the property that $-(-r)^s$ is plurisubharmonic for some $s > 0$. In Stein manifolds, Diederich and Fornaess showed that this is always possible on bounded pseudoconvex domains with C^2 boundaries. Ohsawa and Sibony proved the corresponding result in $\mathbb{CP}^n$, using a result of Takeuchi to substitute for the lack of a global strictly plurisubharmonic function. In this talk, we will examine the possibility of extending the Ohsawa-Sibony result to domains with Lipschitz boundaries. (Received September 17, 2015)

1116-32-1378 **Zhenghui Huo*** (huo3@illinois.edu). *The Bergman kernel on some Hartogs domains.*

We introduce a technique for finding the Bergman kernel on certain Hartogs domains. Let $\Omega \subseteq \mathbb{C}^{n+m}$ be Hartogs and star shaped in first n variables. Let $\mathcal{U} \subseteq \mathbb{C}^{n+m+k}$ be a domain constructed in a certain way by Ω. We obtain the Bergman kernel $B_{\mathcal{U}}$ by applying a k-th order differential operator to B_Ω. Using our formula and some admissible approach regions, we analyze the boundary behaviors of $B_{\mathcal{U}}$. In our setting, some $\mathcal{U}$'s have non-smooth boundaries. (Received September 19, 2015)

1116-32-1610 **David E. Barrett** (barrett@umich.edu) and **Purvi Gupta*** (pgupta45@uwo.ca). *Super-level sets of the Bergman kernel on tube domains.* Preliminary report.

We will give estimates that relate the super-level sets of the diagonal Bergman kernel on a pseudoconvex tube domain with the so-called floating bodies of its convex base. For a given convex domain, the floating bodies are generally easier to construct and this comparison can prove useful for estimating the Bergman kernel. If time permits, we will demonstrate this with some examples. (Received September 20, 2015)

1116-32-2149 **Muhamed A Alan*** (malan@syr.edu). *Supports of Continuous Solutions to complex Monge-Ampère equation and Pluriregularity.* Preliminary report.

We will discuss the support of Supports of complex Monge-Ampère measures, Pluriregularity and Plurithinness. We will also present two counterexamples. (Received September 21, 2015)

1116-32-2220 **Ilya Kossovskiy*** (ilya.kossovskiy@univie.ac.at). *Sphericity of a Real Hypersurface via Projective Geometry.*

Identifying the 3-sphere among real hypersurfaces in 2-dimensional complex space is a problem which attracted a lot of attention of experts in CR-geometry since the work of Cartan and Chern-Moser. It is well known that the sphericity of a real hypersurface amounts to vanishing of its special - CR - curvature. However, the latter is extremely hard to compute explicitly, and even more difficult to identify geometrically. In connection with that, we have recently discovered an amusing (unknown) fact on a very simple geometric identification of sphericity. It employs the Segre family of a real hypersurface, as introduced by Webster. We prove that a real-analytic hypersurface in 2-dimensional complex space is spherical if and only if its Segre family satisfies one of the configuration theorems of Projective Geometry: the Desargues theorem. Such a characterizations is important in that it does not presume any conditions on a real hypersurface (e.g. existence of additional symmetries), neither it requires any special choice of coordinates to characterize the sphericity. In this talk, we will show an elegant proof of the above described Segre-Desargues theorem. (Received September 22, 2015)

1116-32-2279 **Fiammetta Battaglia** and **Dan J. Zaffran*** (dzaffran@fit.edu). *Foliations modeling nonrational toric varieties.*

It is well known that to any rational fan (a convex geometric object), one can associate a toric variety (a complex geometric object) whose Betti numbers and cohomology ring reflect the fan combinatorics.

We show how "vector configurations" (a convex geometric object) and so-called "LVMB-manifolds" (a complex geometric object) provide a way to drop the rationality condition. In particular, toric varieties become part of a larger, continuous family of geometric objects.

LVMB-manifolds are known non-Kähler complex manifolds that come with a holomorphic foliation. The toric varieties' Betti numbers are replaced with the foliation's "basic Betti numbers", that we compute. We also show how to apply the hard Lefschetz theorem in the nonrational context. These results give evidence that the rich interplay between convex and complex geometries embodied by toric varieties carries over to our nonrational construction. (Received September 22, 2015)

1116-32-2659 **Jerry R. Muir, Jr.*** (jerry.muir@scranton.edu), Department of Mathematics, The University of Scranton, Scranton, PA 18510. *Vector-Valued Kernels of Bergman Type.* Preliminary report.

Two classes of vector-valued kernels are provided that reproduce holomorphic mappings $f\colon \mathbb{B} \to \mathbb{C}^n$ when integrated against a scalar-valued transform of the mappings with respect to weighted Lebesgue measure on the open unit ball $\mathbb{B} \subseteq \mathbb{C}^n$. The spaces of mappings that are reproduced in this manner properly contain weighted vector-valued Bergman spaces when $n \geq 2$ and are characterized. (Received September 22, 2015)

33 ► Special functions

1116-33-114 **Jae-Ho Lee*** (jhlee@ims.is.tohoku.ac.jp), 6-3-09 Aramaki-Aza-Aoba, Aoba-ku, Sendai, 980-8579, Japan. *Nonsymmetric Askey-Wilson polynomials and Q-polynomial distance-regular graphs.*

Nonsymmetric Askey-Wilson polynomials are defined as eigenfunctions of Cherednik-Dunkl operator and form a linear basis of the vector space of the Laurent polynomials in one-variable. It is known that nonsymmetric Askey-Wilson polynomials are orthogonal with respect to a certain bilinear form. In this paper we define certain nonsymmetic Laurent polynomials in one-variable, using a Q-polynomial distance-regular graph that contains a Delsarte clique. We discuss how these polynomials are related to the nonsymmetric Askey-Wilson polynomials. Furthermore, using the above Q-polynomial distance-regular graph we define another bilinear form with respect to which the nonsymmetric Askey-Wilson polynomials are orthogonal. (Received July 29, 2015)

1116-33-273 **Jin Liang*** (jinliang@sjtu.edu.cn), Department of Mathematics, Shanghai Jiao Tong University, Shanghai, Shanghai 200240, Peoples Rep of China. *Relations among weighted power means functions.*

We investigate the basic properties of weighted power means functions and their applications. Our main purpose is to find new relations among some weighted power means associated to different sequences of weights. A general comparison theorem is presented. Moreover, we apply the abstract result to the theory of operator inequalities and give some new operator inequalities. (Received August 19, 2015)

1116-33-274 **Ti-Jun Xiao*** (tjxiao@fudan.edu.cn), School of Mathematical Sciences, Fudan University, Shanghai, Shanghai 200433, Peoples Rep of China. *Decay rates of energy functions for a system with memory.*

We study decay rates of energy functions associated with a system of coupled second order semilinear evolution equations with memory in Hilbert spaces. We present a new approach for obtaining optimal rates of uniform decay of the energy functions for the system. The same rate is also obtained for energy functions of the single second order evolution equations with memory. Moreover, applications to some partial differential equations are given. (Received August 19, 2015)

1116-33-426 **S Ole Warnaar*** (o.warnaar@maths.uq.edu.au). *Discrete Macdonald–Mehta integrals.*
In 1982 Macdonald conjectured a Mehta-type integral for every finite reflection group. This was later proved by Opdam in the crystallographic case using hypergeometric shift operators, and by Garvan in the remaining exceptional cases H_3 and H_4 using computer algebra. In this talk I will discuss discrete analogues of the Macdonald–Mehta integrals for the reflection groups A_{r-1}, B_r and D_r, and how these are related to the enumeration of tableaux and non-intersecting lattice paths in combinatorics. (Received August 31, 2015)

1116-33-454 **Richard Beals*** (richard.beals@yale.edu). *Understanding Meijer G-functions.*
As originally introduced by Meijer in 1936, G-functions seem to be both arbitrary and complicated. The aim of this talk is to demonstrate that, in fact, these functions are both extremely natural and easily understood. (Received September 02, 2015)

1116-33-571 **George E Andrews*** (gea1@psu.edu), Department of Mathematics, Pennsylvania State University, 306 McAllister Bldg., University Park, PA 16802. *Partitions associated with the mock theta functions $\omega(q)$ and $\nu(q)$.*
This is a report on joint work with Atul Dixit and Ae Ja Yee. We study the generating function for partitions with repeated (resp. distinct) parts such that each odd part is less than twice the smallest part. Surprisingly, the generating function turns out to be $\omega(q)q$ (resp. $\nu(-q)$, where $\omega(q)$ and $\nu(q)$ are two of the third order mock theta functions of Ramanujan. We also consider associated smallest parts functions. Here our work has overlap with that of Garvan and Jennings-Shaffer. (Received September 07, 2015)

1116-33-582 **Dan Dai***, Department of Mathematics, City University of Hong Kong, Hong Kong. *Uniform asymptotics of orthogonal polynomials arising from coherent states.*
In this paper, we study a family of orthogonal polynomials $\{\phi_n(z)\}$ arising from nonlinear coherent states in quantum optics. Based on the three-term recurrence relation only, we obtain a uniform asymptotic expansion of $\phi_n(z)$ as the polynomial degree n tends to infinity. Our asymptotic results suggest that the weight function associated with the polynomials has an unusual singularity, which has never appeared for orthogonal polynomials in the Askey scheme. Our main technique is the Wang and Wong's difference equation method. In addition, the limiting zero distribution of the polynomials $\phi_n(z)$ is provided.

This is a joint work with Weiying Hu and and Xiang-Sheng Wang (Received September 08, 2015)

1116-33-642 **Mourad E. H. Ismail*** (mourad.eh.ismail@gmail.com), Department of Mathematics, University of Central Florida, Orlando, FL 32816, and **Ruiming Zhang**, College of Science, Northwest A&F University, Yangling, Shaanxi 712100, Peoples Rep of China. *Classes of bivariate orthogonal polynomials.*
We introduce a class of orthogonal polynomials in two variables which generalizes the disc polynomials and the 2-D Hermite polynomials. We identify certain interesting members of this class including a one variable generalization of the 2-D Hermite polynomials and a two variable extension of the Zernike or disc polynomials. We also give q-analogues of all these extensions.

In each case in addition to generating functions and three term recursions we provide raising and lowering operators and show that the polynomials are eigenfunctions of record order partial differential or q-difference operators. (Received September 09, 2015)

1116-33-646 **Bruce C Berndt*** (berndt@illinois.edu). *Some Integrals of S. Ramanujan and S. Chowla.*
In his third notebook, Ramanujan claimed to have proved the identity

$$\int_0^\infty \frac{\cos(nx)}{x^2+1}\log x\,dx + \frac{\pi}{2}\int_0^\infty \frac{\sin(nx)}{x^2+1}dx = 0$$

by contour integration. In the new, clearer edition of Ramanujan's notebooks published in 2012, a further result of this type, unintelligible in the first edition, was indicated by Ramanujan. In joint work with Armin Straub, we prove these two identities as well as more general theorems.

In the second part of our lecture, several integrals, mostly containing $\cos x + \cosh x$ in the denominators of the integrands, are examined. Some were considered by Ramanujan, and later also by Chowla. One is the weight function associated with a system of orthogonal polynomials arising in work of M. E. H. Ismail and G. Valent. (Received September 09, 2015)

1116-33-717 **Richard Askey*** (askey@math.wisc.edu), 2105 Regent St, Madison, WI 53726. *Some work of Mizan Rahman.* Preliminary report.

In addition to the very important book by George Gasper and Mizan Rahman, there are many interesting and important papers written by Mizan Rahman. Some of these will be described, and some related open problems will be mentioned. (Received September 11, 2015)

1116-33-766 **Harish Nagar*** (drharishngr@gmail.com), 2-A-16, Nagar Villa, Bapu Nagar, Bhilwara, 311001, India, and **Alka Tank** (drsunitangr@gmail.com), Mewar University, Chittorgarh, India. *Integral Representations and Composition of Generalized Mittag-Leffler Function.*

In the present paper new results for Classical Generalized Mittag – Leffler function E^{α} (z), $\mathrm{E}_{(\alpha,\beta)}$ (z) and $\mathrm{E}^{(\eta,\delta)}_{(\alpha,\beta)}$ (z) are established. Here we have established three integral formulas for the Mittag-Leffler functions of one and several variables. In the first integral we have considered the Mittag-Leffler function and in last two we have considered generalized Mittag – Leffler function. The integrals evaluated here in terms of confluent Hypergeometric function of n-variables. (Received September 12, 2015)

1116-33-838 **Wolter Groenevelt*** (w.g.m.groenevelt@tudelft.nl), Delft Institute of Applied Mathematics, Technische Universiteit Delft, Mekelweg 4, 2628 CD Delft, Netherlands. *Orthogonal polynomials related to a ${}_2\psi_2$-summation formula.*

We consider orthogonal polynomials corresponding to a q-integral on $\mathbb{R}$. The q-integral can be written as a sum of two bilateral q-hypergeometric ${}_2\psi_2$-series, for which an evaluation formula is known due to Slater. The corresponding orthogonal polynomials, which are (limit cases of) big q-Jacobi polynomials, do not form a basis for the corresponding L^2-spaces. A set of functions that complements the orthogonal polynomials to an orthogonal basis can be obtained using spectral analysis of q-difference operators. These polynomials and their complementing function arise naturally in representation theory of quantum groups. (Received September 14, 2015)

1116-33-847 **Tom H Koornwinder*** (t.h.koornwinder@uva.nl). *Transmutation operators acting on solutions of the system of pde's for Appell's hypergeometric F_2.* Preliminary report.

Analogous to work done by the speaker for Gauss hypergeometric functions (see [1]), fractional integral type and Stieltjes type transform formulas will be presented which act as parameter changing transmutation operators on solutions of the system of pde's for Appell's hypergeometric function F_2 (see solutions given in [2]). Specializations of these double integral transforms give Euler type double integral representations for the mentioned solutions. The research presented here is inspired by work in progress by Enno Diekema, and may include some of his results.

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[2] P. O. M. Olsson, On the integration of the differential equations of five-parametric double-hypergeometric functions of second order, *J. Math. Phys.* **18** (1977), 1285–1294.

(Received September 21, 2015)

1116-33-947 **Vincent X Genest** and **Luc Vinet*** (vinet@crm.umontreal.ca), Centre de Recherches Mathématiques, Université de Montréal, C.P. 6128, Succursale Centre-ville, Montréal, Québec H3C 3J7, Canada, and **Alexei Zhedanov**. *Fractional Revival in Spin Chains and Orthogonal Polynomials.*

The couplings and magnetic fields of XX spin chains with nearest neighbor interactions correspond to the recurrence coefficients of orthogonal polynomials. Fractional revival (FR) occurs in a quantum system when an initial wave packet evolves into small clones that recur with periodicities in a localized fashion. This phenomenon can be observed in spin chains and put to use to perform tasks such as quantum information transfer or the generation of entangled states. The special case where the wave packet is reproduced at only one site is referred to as perfect state transfer (PST). There are two basic ways to engineer chains with FR and the connection in each case to orthogonal polynomials will be discussed. The first method naturally brings in the para Krawtchouk polynomials that are orthogonal on linear bi-lattices. The second mechanism involves performing an isospectral transformation of the persymmetric Jacobi matrix associated to chains with PST and leads to polynomials that also have interesting properties. (Received September 15, 2015)

1116-33-1083 **Vincent X. Genest*** (vxgenest@mit.edu), **Luc Vinet** and **Alexei Zhedanov**. *The non-symmetric Wilson polynomials are the Bannai-Ito polynomials.*

In this talk, I will explain that the non-symmetric Wilson polynomials coincide with the Bannai–Ito polynomials. I will show explicitly the isomorphism between the degenerate double affine Hecke algebra of type $(C_1^\vee, C_1)$ associated to the non-symmetric Wilson polynomials and the Bannai-Ito algebra. The Bannai-Ito polynomials will be seen to satisfy an orthogonality relation with respect to a positive-definite, continuous measure on the real line and a non-compact form of the Bannai-Ito algebra will be presented. (Received September 16, 2015)

1116-33-1108 **Roderick Sue Cheun Wong*** (mawong@cityu.edu.hk) and **Xiang-Sheng Wang**. *Asymptotics of Racah polynomials.* Preliminary report.

Within the Askey scheme of hypergeometric orthogonal polynomials, Racah polynomials stay on the top of the hierarchy and they generalize all of the discrete hypergeometric orthogonal polynomials. In this talk, we investigate asymptotic behaviors of Racah polynomials with varying parameters when the polynomial degree tends to infinity. Using the difference equation technique developed in our earlier papers, we obtain an asymptotic formula in the outer region via ratio asymptotics and then derive asymptotic formulas in the oscillatory region via a matching method. Our asymptotic formulas are explicitly given in terms of the polynomial degree, variable and parameters, using elementary functions such as logarithmic, exponential and rational functions. By taking limits, our results also yield asymptotic formulas for orthogonal polynomials in the lower hierarchy of the Askey scheme such as Hahn polynomials and Krawtchouk polynomials. (Received September 17, 2015)

1116-33-1228 **Gaurav Bhatnagar*** (bhatnagarg@gmail.com), Indian Statistical Institute, 7, S. J. S. Sansalwal Marg, New Delhi, 110016, India. *A_n to A_m transformation formulas using Heine's method.*

We study Andrews' generalization of Heine's transformation for ${}_2\phi_1$ series, and related identities that are closely related to many q-series identities due to Ramanujan. We generalize Andrews' identities to the setting of multivariable series related to the root system A_n. Our formulas transform an A_n series into a multiple of an A_m series, somewhat like the results of Kajihara (2004). However, our identities are more closely related to multivariable q-binomial identities due to Gustafson and Krattenthaler (1997), Milne (1997), and Milne and Lilly (1995). (Received September 18, 2015)

1116-33-1594 **Dominic Lanphier***, Department of Mathematics, 1906 College Heights Blvd., Bowling Green, KY 42101. *Integral Formulas and Generating Functions of Jacobi Polynomials.*

We give two integral formulas with applications to orthogonal polynomials. The first is a general integral formula for generating functions of Jacobi polynomials. As an application we give a new arithmetic generating function for these polynomials. The proof relies on a generalization of Cauchy's beta integral. The second integral formula is an interpolation formula derived from Ramanujan's master theorem. (Received September 20, 2015)

1116-33-1641 **Mohammad Salmassi*** (msalmassi@framingham.edu), Department of Mathematics, Framingham State University, Framingham, MA 01602, and **Ed Merkes**, Department of Mathematics, University of Cincinnati, Cincinnati, OH 45221. *Univalent solutions of a second order differential equation.* Preliminary report.

We discuss univalence of special solutions of the differential equation y"+w(z)y = 0 in complex domain. This permits us to establish in a new way the radius of univalence of the Airy function Ai(z). In an earlier paper which appeared in the journal Complex Variables, we used the infinite product representation of Ai(z) to prove that the radius of univalence of Ai(z) is the distance of the nearest zero of Ai'(z) to the origin. (Received September 20, 2015)

1116-33-1992 **Michael J Schlosser*** (michael.schlosser@univie.ac.at), University of Vienna, Faculty of Mathematics, Oskar-Morgenstern-Platz 1, 1090 Vienna, Austria. *New multivariate generalizations of Ramanujan's ${}_1\psi_1$ summation formula.*

We derive several explicit summations for multivariable basic hypergeometric series. The series we are dealing with are characterized by having a special determinant as a factor in the summand and can be associated to the root system A_n. Among our results are new multivariate extensions of Ramanujan's ${}_1\psi_1$ summation formula. We compare these to existing results in the literature such as a closely related multivariate ${}_1\psi_1$ summation by Aomoto, and a similar ${}_1\psi_1$ summation recently given by Warnaar (which is contained in one of our formulae as a special case). Already the one-variable ${}_1\psi_1$ summation was described by Hardy as "a remarkable formula with many parameters". Our multivariate extensions of this identity have even more parameters. This work is dedicated to the memory of Mizan Rahman who felt perfectly comfortable with and enjoyed formulae with many parameters. (Received September 21, 2015)

1116-33-2241 **Neil M Bickford*** (techie314@gmail.com), 4509 Thistle Drive, San Jose, CA 95136, and **Ralph William Gosper** (billgosper@gmail.com), 12625 La Cresta Drive, Los Altos Hills, CA 94022. *Special and limiting values of the Weber function and Dedekind η.*

We present a new method for computing exact values of the Dedekind eta function and the closely related Weber function. Specifically, by working with ratios of Dedekind eta functions, we're able to compute $\eta(2\tau)$, $\eta(-2/\tau)$, and $\eta(\tau+2)$ from $\eta(\tau)$. This allows us to compute $f(\tau)$ for dyadic complex numbers in the upper half-plane. We also extend this method to compute values of the Weber function for a wide class of imaginary quadratic surds, such as $\frac{\eta(\frac{7+\sqrt{-15}}{8})}{\eta(\frac{7+\sqrt{-15}}{4})} = \frac{\sqrt[12]{-33+11\sqrt{5}-i\left(9\sqrt{15}-15\sqrt{3}\right)}}{\sqrt[6]{2}}$ Finally, we find an asymptotic formula for the behavior of η close to the real line, as well as a few other special values using PSLQ and other empirical methods. (Received September 22, 2015)

1116-33-2304 **Oksana Bihun*** (obihun@uccs.edu). *Properties of the Zeros of the Generalized Basic Hypergeometric Polynomials.* Preliminary report.

We define the generalized basic hypergeometric polynomial of degree N in terms of the generalized basic hypergeometric function, by choosing one of its parameters to allow the termination of the series after a finite number of summands. We consider a Differential q-Difference Equation (DqDE) whose solutions are polynomials with time-dependent coefficients and whose time-independent equilibrium solutions are generalized basic hypergeometric polynomials. The time-dependent zeros of the polynomial solutions of the DqDE satisfy a nonlinear system of ODEs. From the equations for the equilibria of the latter system, we obtain a set of nonlinear algebraic equations satisfied by the zeros of the generalized basic hypergeometric polynomials. By linearizing the system about its equilibria, we obtain a remarkable $N \times N$ matrix M defined in terms of the zeros of the polynomial. The eigenvalues of the matrix M are given by neat expressions that depend only on some of the parameters of the polynomial; that is, the matrix M is *isospectral*. Moreover, in case the parameters that appear in the expressions for the eigenvalues of M are rational, the matrix M has rational eigenvalues, a *Diophantine property.* (Received September 22, 2015)

1116-33-2587 **Jessica Stewart Kelly*** (jessica.kelly@cnu.edu). *Spectral Analysis of the Exceptional Hermite Polynomials.* Preliminary report.

As Bochner's well-known classification theorem indicates, the only orthogonal polynomial systems arising from Sturm-Liouville type problems having polynomial solutions of every degree are the classical orthogonal polynomials of Hermite, Jacobi, and Laguerre. This result has been generalized with the introduction of the *exceptional* orthogonal polynomials. Exceptional orthogonal polynomial systems occur when we study Sturm-Liouville type problems but allow for a finite number of degrees to be missing from the sequence of eigenpolynomials. Our main results concern the spectral theory associated with exceptional Hermite differential expression. In particular, the self-adjoint operator associated with the Hermite differential expression may be studied using the classical Glazman, Krein, Naimark theory for ordinary differential operators. We will also discuss related results, such as completeness and the location of the zeros (Kuijlaars and Milson, 2014) for the exceptional Hermite polynomials. (Received September 22, 2015)

34 ► Ordinary differential equations

1116-34-316 **Bhuvaneswari Sambandham***, Department of Mathematics, University of Louisiana at Lafayette, Lafayette, LA 70504, and **Aghalaya S. Vatsala**. *Numerical Results for Linear Caputo Fractional Differential Equations with Variable Coefficients and Applications.* Preliminary report.

Recently, we published results which includes the symbolic representation for the linear Caputo fractional differential equations in the journal "Mathematics." Also, we obtained numerical results by iterative methods. In this paper, we derive numerical results by direct numerical method using the symbolic representation we have obtained earlier. This direct numerical method is useful in developing monotone method and quasilinearization method for nonlinear problems. As an application of this result, we have obtained the numerical solution for a special Ricatti, type of differential equation which blows up in finite time. (Received August 24, 2015)

1116-34-366 **Zhivko S. Athanassov*** (zhivko@math.bas.bg), G. Bonchev Str. 8, 1113 Sofia, Bulgaria. *Remarks on Almost Periodic Differential Equations.* Preliminary report.

In a number of papers on almost periodic differential equations the restrictive requirement of continuity with respect to time is made. A theory of generalized almost periodic functions is applied to avoid such a requirement.

Non-autonomous dynamical systems are obtained for such equations. A mathematical meaning for almost periodic discontinuous functions is given. The behavior of solutions near critical points and periodic orbits are studied by methods of topological dynamics. (Received August 28, 2015)

1116-34-400 **Sougata Dhar*** (sougata_dhar@ymail.com), 810 Kimberly Dr., Apt 212, DeKalb, IL 60115, and **Qingkai Kong**. *The Lyapunov-type inequality for third order and odd-order equations and application to the boundary value problems.*

We obtain new Lyapunov-type inequalities for the third-order linear differential equation. Our work provides the sharpest results in the literature. Based on the above, we further establish new Lyapunov-type inequalities for more general third-order linear differential equations. We also extend our results to any odd order linear differential equations. Furthermore, by combining these inequalities with the "uniqueness implies existence" theorems by several authors, we establish the uniqueness and hence existence-uniqueness for several classes of boundary value problems for third-order linear equations as well as odd order linear equations. (Received August 30, 2015)

1116-34-434 **Kbenesh W. Blayneh*** (kbenesh.blayneh@famu.edu), 1617 Martin Luther King Blvd, Jackson Davis 316, Tallahassee, FM 32307. *The effects of extreme climate conditions on vertically transmitted vector-borne diseases.* Preliminary report.

The transmission dynamics of vector-borne diseases which are vertically transmitted in the vector and the host populations are studied. The contributions of extreme climate changes, personal protection, vertical transmission and mosquito control on the dynamics of the disease are assessed using analytical and numerical approaches. Results include the effects of key model parameters on the likelihood of disease prevalence, direction of bifurcation and the global stability of disease-free equilibrium points. (Received September 01, 2015)

1116-34-587 **Ngoc Do*** (dothanh@math.tamu.edu) and **Peter Kuchment**. *Quantum graph model of a graphyne and graphyne nanotubes.*

Graphynes, which are non-honeycomb monolayers of carbon allotropes, are expected to be sometimes even better than graphene in terms of electronics properties. Nanotube, although appeared much earlier than graphene, can be viewed as sheets of graphene rolled onto a cylinder. It is thus natural to look at the nanotubes obtained by folding a sheet of a graphyne. In this talk, we will present a study of spectra of Schrödinger operator on a particular graphyne structure and its nanotubes. (Received September 08, 2015)

1116-34-622 **T.Mihiri M. De silva*** (mihiri.de-silva@ttu.edu), Department of Mathematics and Statistics, Broadway and Boston, Lubbock, TX 79409-1042, and **Sophia R.J. Jang** (sophia.jang@ttu.edu), Department of Mathematics and Statistics, Broadway and Boston, Lubbock, TX 79409-1042. ***Dynamics of phytoplankton-zooplankton interactions with toxin producing phytoplankton and mutual interference of zooplankton.***

We propose a system of the interacting populations with non-toxic phytoplankton (NTP), toxin producing phytoplankton (TPP) and zooplankton in which mutual interference between zooplankton and avoidance of toxin producing phytoplankton by zooplankton is considered. It is assumed that NTP and TPP populations follow the Lotka-Vollterra competition interaction. We investigate the global stability of the positive equilibrium of NTP and zooplankton predator-prey subsystem and derive conditions of Hopf bifurcations. It is proved that the uniform persistence of NTP and zooplankton system holds. Moreover, using the concept of uniform persistence, we establish coexistence of NTP, TPP and zooplankton under certain parameter restrictions. Numerical simulations are performed to illustrate the complexity of the population interactions. (Received September 09, 2015)

1116-34-624 **G. Edgar Parker*** (parkerge@jmu.edu), 1106 Foxfire Drive, Greensboro, NC 27410. *Some Algebraic Considerations for P.*

P, the set of real analytic functions each of which is the solution to a differential equation with a polynomial (possibly on Rn) generator and containing 0 in its domain, is a proper subset of the real analytic functions and elements of P are numerically accessible in very robust ways. In addition, if one is willing to ignore "the domain issue", P is closed under function addition, function multiplication, and, when it makes sense, composition. In this talk, we present a representation that provides an isomorphism of + and *, and a structure preserving map for composition. The representation involves equivalence classes and the question of identifying members of the same equivalence class by algebraic, rather than analytic, means is posed. Also, the structure identified by The Intersecting Coset Theorem will be discussed in purely algebraic terms. Progress on either of these problems would promise analytic, and consequently, computational, payoffs. (Received September 09, 2015)

1116-34-968 **Charles Nelms Jr.*** (charles_nelms@baylor.edu), Department of Mathematics, Baylor University, Waco, TX 76798-7328. *Comparison of smallest eigenvalues for certain fifth order boundary value problems.*

The theory of u_0-positive operators is applied to a class of boundary value problems for some fifth order linear problems to establish some comparisons between smallest positive eigenvalues. (Received September 15, 2015)

1116-34-1085 **Dimplekumar N Chalishajar*** (dipu17370@gmail.com), 1227 Landon Dr, Harrisonburg, VA 22801. *Trajectory Controllability of Nonlinear systems-An analytical and a Numerical Approach.*

New notion of control theory called Trajectory Controllability of first and second order nonlinear systems are studied using monotone operator theory and the techniques of functional analysis. Results are proved in finite and infinite dimension spaces. Examples are given to illustrate the theory. Finally numerical estimations are given to compare with analytical results. (Received September 16, 2015)

1116-34-1266 **Dongmei Xiao***, 800 Dongchuan Road, Dept of Math, Shanghai Jiao Tong University, Shanghai, Shanghai 200240, Peoples Rep of China, **Yilei Tang**, Shanghai, Shanghai 200240, Peoples Rep of China, **Weinian Zhang**, Chengdu, SiChuan 610064, Peoples Rep of China, and **Di Zhu**, Shanghai, Shanghai 200240, Peoples Rep of China. *Dynamics of epidemic models with asymptomatic infection and seasonal succession.* Preliminary report.

In this talk, we will introduce a compartmental SIRS epidemic model with asymptomatic infection and seasonal succession, which describes the impact of the asymptomatic infective and season factors on the spread of disease. By defining the basic reproduction number R_0, we study the threshold dynamics of this epidemic model. The basic reproduction number R_0 is closely related to the asymptomatic infective and season factors. This reveals that classical SIRS epidemic model may underestimate or overestimate infection risks on the disease transmission. (Received September 18, 2015)

1116-34-1271 **Taoufik Meklachi*** (tmeklachi@gmail.com), 4822 Regent st. 3rd fl, Philadelphia, PA , and **Daniel Onofrei**. *Vibration Cloaking and suppression model.*

In an effort to understand active and passive SONAR acoustic cloaking, we study the vibration suppression questions in the context of a 1D coupled spring-mass system. The longitudinal motion of the latter is considered to be a discretization of acoustic systems, where the stiffness of the springs represents the compressibility and the masses represent the density of the medium. We study systems, with and without damping, of an arbitrary number of masses N. We propose discrete models for Active as well as Passive SONAR and describe explicitly the necessary controls for the desired cloaking effects. (Received September 18, 2015)

1116-34-1294 **Anand Pillay*** (apillay@nd.edu), Department of Mathematics, University of Notre Dame, Notre Dame, IN 46556. *Differential Galois extensions.*

This is a report on joint work with Moshe Kamensky. Given a differential field K with field of constants C_K, and a linear DE (more generally "logarithmic DE") over K, we give sufficient conditions on C_K for the existence of a Picard-Vessiot (strongly normal) extension L of K for the equation such that C_K is existentially closed in L (as fields). Our results subsume those of Crespo, Hajto and van der Put, among others. (Received September 18, 2015)

1116-34-1364 **Hamid Semiyari*** (hamid.semiyari@gmail.com), 10301 Grosvenoor Pl, North Bethesda, MD 20852. *Approximating Solutions of Boundary Value Problems.*

We present a new algorithm for approximating solutions of two-point boundary value problems and prove theorems that give conditions under which the solution must exist and the algorithm generate approximations that converge to it. We show how to make the algorithm computationally efficient and demonstrate how the full method works both when guaranteed to do so and more broadly. We also prove a theorem on existence of solutions of certain multi-dimensional Volterra integral equations and use it to show that the Parker-Sochacki method of introducing auxiliary variables, used to make the new algorithm computationally efficient, can be effectively applied to these Volterra integral equations in order to approximate their solutions by means of a Picard iteration scheme. (Received September 18, 2015)

1116-34-1374 **Vishal Vasan*** (vishal.vasan@icts.res.in), International Centre for Theoretical Sciences, TIFR Centre Building, IISc Campus, Subedarpalya, Malleshwaram, Bangalore, Karnataka 560012, India. *Gradient descent with nonlinear constraints: a dynamical systems approach.* Preliminary report.

One of the oldest and simplest algorithms for smooth optimisation problems is gradient descent. Our goal is to develop a method for constrained optimisation that follows the original spirit of unconstrained gradient descent, i.e. simply following a vector field pointing towards the optimal point. In this setup we view nonlinear constraints as defining a manifold and hence we construct a vector field that exhibits first integrals of motion which are precisely the constraints and simultaneously minimises the cost function. This is achieved by using a generalisation of Hamiltonian dynamical systems. This talk will present some preliminary work in this direction. (Received September 19, 2015)

1116-34-1457 **Alex P Farrell***, alex.farrell@asu.edu, and **H Thieme**, hthieme@asu.edu. *Infectious diseases can eradicate host species.*

Amphibian decline and disappearance has rekindled interest in whether infectious diseases alone (without Allee effects or reservoirs, e.g.) have the potential to drive their host species into extinction. A negative answer has been given for tiger salamanders because frequency-dependence incidence has found to be a bad fit in infection experiments. We show that that frequency-dependent incidence is not the only type of incidence that can cause host extinction, but that incidences that are quite close to those found to be good fits as well. (Received September 19, 2015)

1116-34-1630 **Faina S Berezovskaya*** (fsberezo@hotmail.com), fsberezo@hotmail.com, and **Georgiy P Karev**. *Inhomogeneous logistic equation and the Newton diagram.* Preliminary report.

The inhomogeneous logistic equation presents a simplest conceptual model for Darwinian Struggle for Existence. It can be proven that under fixed Malthusian growth rate only the individuals having maximal carrying capacity survive in the population; it means "the survival of the fittest". In contrast, under fixed carrying capacity all individuals that were present initially in the population survive in course of time; it means "survival of every-body". Achleh et.al., (Discrete &Continuous Dynamical systems 2005) considered an inhomogeneous logistic equation in the form of birth-and-death equation. Both the clone per capita birth and death rates, b and d correspondingly, were assumed to be distributed. It was proven that only "the fittest", i.e. those individuals which have the largest value of b/d survive in population. It may happen that there are many fittest individuals in the population. Reducing initial multidimensional model to a single non-autonomic equation for "key-stone" variable (Karev, J. Math. Biology 2010), transforming it to two-dimensional ODE in the power form and applying the Newton diagram method (Berezovskaya, Proceeding AMS 2014) we are able to find the limit distribution between the fittest individuals. (Received September 21, 2015)

1116-34-1666 **Gal Binyamini*** (galbin@gmail.com). *Two Bezout-type theorems for differential equations.*

I will discuss recent results on two counting problems related to systems of differential equations:

(1) For a given system of algebraic differential conditions on an n-tuple of functions and their first l derivatives, estimate the number of solutions assuming that this number is finite.

(2) For a fixed solution of a system of algebraic ODEs, estimate the number of intersections between the graph of the solution and an algebraic hypersurface of degree d as a function of d.

I will also describe some applications of these problems to diophantine counting problems on algebraic and transcendental varieties. (Received September 21, 2015)

1116-34-1740 **Duane Chin-Quee*** (dchinque@irsc.edu), 3209 Virginia Ave, Ft. Pierce, FL 32908, and **G.T. Bhaskar** (gtenali@fit.edu), 150 W. University Blvd., Melbourne, FL 32901. *Solutions of First Order Functional Differential Equations with Linear Delay and Advance Arguments, with Boundary Conditions, Using the Continuation Method.*

We consider functional differential equations with linear delay and advance arguments. Boundary conditions are prescribed to coincide with the arguments. Existence results will be presented by using the continuation method. (Received September 21, 2015)

1116-34-1779 **Elena Dimitrova*** (edimit@clemson.edu), O-303 Martin Hall, Clemson University, Clemson, SC 29634, and **Sherli Koshy**. *Long-term survival and chaotic dynamics in population models.* Preliminary report.

In 1996, Cushing et al. announced the first discovery of a real population (the flour beetle *tribolium*) that exhibits chaotic dynamics. Since then others have observed chaotic behavior in populations of species but little is know about the significance of such behavior. We study the connection between chaotic dynamics and long-term survival of populations in ecological context using models differential equations. Many criteria have been used to define the notion of long-term survival of each species in a system of interacting populations. We focus on perhaps the most widely accepted criterion, permanence, which roughly speaking requires that any asymptotic behavior of orbits should be allowed as long as the orbits come too close to the boundary. (Received September 21, 2015)

1116-34-1854 **Shelby R. Stanhope*** (srs114@pitt.edu), **David Swigon** (swigon@pitt.edu) and **Jonathan Rubin** (jonrubin@pitt.edu). *Existence and uniqueness of solutions to the inverse problem for linear dynamical systems with uncertain data.* Preliminary report.

I will analyze the problem of estimating the parameters of a dynamical system model from discrete data, i.e., the inverse problem for dynamical systems. In the case of a linear model, I will present necessary and sufficient conditions for the data to yield a unique matrix of parameters. Contrary to our expectations, we find that the existence of model parameters corresponding to given data is guaranteed only for a subset of potential data sets and that there is only a narrow range of data that yields a unique set of parameters. A key practical issue of estimating how much uncertainty in data can be tolerated without compromising the existence and uniqueness of inverse problem solutions will be addressed. Analytical and numerical estimates of the largest allowable error in the data that still yields a unique parameter matrix will be presented. In addition, I will also examine connections between perturbations in the data and the stability of the equilibrium of the system. (Received September 21, 2015)

1116-34-1887 **David Lipshutz*** (david_lipshutz@brown.edu), 182 George Street, Providence, RI 02912, and **Ruth J. Williams**. *Oscillatory behavior of a genetic circuit with delayed negative feedback.*

Dynamical system models with delayed feedback, non-negativity constraints and small noise arise in the study of simple genetic circuit. Under certain conditions oscillatory behavior has been observed. Here we consider prototypical diffusion (second-order) approximation for such a system — a one-dimensional stochastic delay differential equation with a non-negativity constraint — along with its deterministic analogue. We establish conditions for existence, uniqueness and stability of "slowly oscillating" periodic solutions to the deterministic equation and show that solutions to the small noise stochastic equation remain close to these periodic solutions from the perspective of large deviations. This is joint work with Ruth Williams. (Received September 21, 2015)

1116-34-1907 **Ratna Khatri*** (rkhatri3@masonlive.gmu.edu) and **Matt Holzer**. *Consensus vs. fragmentation in a model of opinion dynamics.* Preliminary report.

We consider a continuous version of the Krause model of opinion dynamics. Interaction between agents either leads to a state of consensus, where agents starting out with random initial opinions converge to a single opinion as time evolves, or to a fragmented state with multiple opinions. We linearize the system about a uniform density solution and predict consensus or fragmentation based upon the most unstable mode of the dispersion relation. Analytical predictions are then compared to numerical simulations. (Received September 21, 2015)

1116-34-2175 **Carlos E Cruz*** (ccruz14@lion.lmu.edu), **Matthew Baca**, **Armando Salinas** and **Carlos Agrinsoni**. *Modeling the Interaction Dynamics between Honeybees and Food Availability.* Preliminary report.

The success of honeybee colonies is critical to the United States agriculture with 35% of American diets dependent on honeybee pollination. There are various complex factors that contribute to a colony's failure. Nutritional stressors primarily pertain to food scarcity, lack in diversity of food, and the availability of food with low nutritional value. Previous mathematical models have examined the impact of nutrition and the early recruitment on honeybee population dynamics. In this work, we use a mathematical model to investigate the impact of food scarcity and limited storage space on colony viability, early recruitment rates of workers into foragers, and the influence of these rates on the growth of a colony. We found conditions for the stable coexistence of a honeybee population and food supply as well as conditions for periodic behavior. Through sensitivity analysis we find that a honeybee colony is most sensitive to changes in the rate at which a worker bee encounters food and the rate food is entering the food supply. There are no qualitative differences between using a Holling Type I or Type II functional response in honeybee population persistence when modeling the interaction between a honeybee colony and the availability of food. (Received September 22, 2015)

1116-34-2284 **Dylan P O'Connell*** (doconnel@haverford.edu), 161 Waban Hill Rd N, Newton, MA 02467, and **Joe Chen**, **Fan Ny Shum**, **Rajeshwari Majumdar**, **Lance Ford**, **Derek Kielty** and **Heather McCain**. *Stochastic Stabilization of Complex Multivariable Systems.*

A polynomial complex-valued Ordinary Differential Equation (ODE) contains trajectories blowing up in finite time (which we will refer to as *explosions*). Past research has shown that by adding a suitable complex-valued Brownian motion to the equation, the trajectories from any initial condition in $\mathbb{C}$ will converge toward the stable fixed point with probability 1.

Much less is understood about the analogous stochastic stabilization problem in higher dimensions. To that end, we investigate a prototype multivariable system of ODEs in $\mathbb{C}^2$, which admits explosive solutions. The goal is to stabilize the system by introducing a suitable Brownian noise. We found that by performing a coordinate transformation, the system can be reduced to a quasi-1-dimensional ODE similar to the polynomial form. This modification enables us to identify necessary and sufficient conditions for the Brownian noise to stabilize. These conditions have been verified numerically, and rigorous proofs are forthcoming. (Received September 22, 2015)

1116-34-2349 **Olivia Bennett**, **Daniel Brumley**, **Britney Hopkins**, **Kristi Karber** and **Thomas Milligan***, 100 N. University Dr, Dept. of Mathematics and Statistics, University of Central Oklahoma, Edmond, OK 73034. *The Multiplicity of Solutions for a Class of Fourth Order Differential Equations.*

Making use of the Guo-Krasnosel'skii Fixed Point Theorem, we establish the existence of multiple solutions for the fourth order differential equation, $u^{(4)} = \lambda h(t, u(t), u'(t), u''(t), u'''(t))$, for $t \in (0,1)$ with right focal boundary conditions $u(0) = u''(0) = 0$, $u'(1) = a$, and $u'''(1) = -b$, where $h : [0,1] \times [0,\infty)^2 \times (-\infty, 0]^2 \to [0,\infty)$, $a, b, \lambda \geq 0$, and $a + b > 0$. Our technique involves examining an analogous system of second order differential equations satisfying homogeneous boundary conditions prior to applying the aforementioned fixed point theorem. (Received September 22, 2015)

1116-34-2356 **Yinlin Dai*** (daiy@southwestern.edu) and **Emma Kathryn Groves** (grovese@southwestern.edu). *Math Modeling in the Time of Cholera.*

Cholera is an infectious disease that has been a global health issue, particularly for South Asia and Africa. We present several models. First, we create a simulation model specifically on Haiti, predicting how Cholera incidence rates will change in the near future. The predictions are based on Cholera data gathered from South American countries. Then we implement an SIR model with reservoir, which is a system of differential equations describing susceptible, infected, and recovered human populations as well as bacterial concentration in the water supply. (Received September 22, 2015)

1116-34-2569 **Inbo Sim*** (ibsim@ulsan.ac.kr), 93 Daehak-ro, Nam-gu, Ulsan, 44610, South Korea. *Multiplicity of positive solutions for one-dimensional p-Laplacian with weight functions.*

In this talk, I will establish the results of exact two positive solutions and at least three positive solutions for one-dimensional p-Laplacian with weight functions based on Kolodner-Coffman method and bifurcation theory, respectively. This is a joint work with Satoshi Tanaka. (Received September 22, 2015)

1116-34-2886 **Lianwen Wang*** (lwang@ucmo.edu). *On Monotonic Solutions of Systems of Nonlinear Differential Equations.*

In this talk we consider bounded and monotonic solutions for a system of nonlinear differential equations. Necessary and sufficient conditions for the boundedness of all solutions are established. Moreover, all monotonic solutions of the system are classified into categories, and necessary and sufficient condition for the existence of each category is provided. (Received September 22, 2015)

1116-34-2914 **Velinda R. Calvert*** (vcalvert@math.msstate.edu) and **Moshen Razzaghi**. *Solving problems on the semi-infinite domain using rational Bernoulli functions.*

In this talk, a numerical method for solving nonlinear ordinary differential equations on the semi-infinite domain is presented. The method is based upon the modified rational Bernoulli functions, these functions are first introduced. Operational matrices of derivative and product of modified rational Bernoulli functions are then given and are utilized to reduce the solution of these equations to a system of algebraic equations. Illustrative examples are included to demonstrate the validity and applicability of the technique. (Received September 23, 2015)

1116-34-2927 **Calistus N. Ngonghala*** (calistus_ngonghala@hms.harvard.edu), Harvard Medical School, 641 Huntington Avenue, Boston, MA 02115, and **Giuleo de Leo**, **Mercedes Pascual**, **Donald C. Keenan**, **Andrew Dobson** and **Matthew H. Bonds**. *General mathematical models for ecological drivers of poverty.*

The livelihoods of the rural poor are nested within ecological communities. The poor rely heavily on their immediate natural environment for subsistence and suffer high morbidity and mortality due to infectious diseases. We show how the dynamics of poverty can be modeled, focusing on four exemplar drivers: infectious diseases, renewable resources, land-use change and population growth. Interactions between these ecological processes and economics can create reinforcing feedbacks associated with persistent poverty, characterized by a stable, low level, equilibrium; or poverty traps characterized by multiple stable equilibria in ecological-economic space. The inherent complexity of these relationships, combined with the spatial/temporal scales at which they occur in the real world, create empirical challenges for estimating parameters and validating the models. We use numerical methods to evaluate the parameter spaces for various combinations of these coupled systems. We find that 6-20% of the feasible parameter space generate bistable outcomes, or poverty traps, and identify key parameters that are most influential to the outcomes of the systems. Combined, these models provide a general framework for deeper theoretical and empirical explorations of ecological drivers of poverty. (Received September 23, 2015)

35 ► Partial differential equations

1116-35-38 **Wolfgang F. Ellermeier*** (ellermeier@fkp.tu-darmstadt.de), TU Darmstadt, Fachbereich Physik, Institut für Festkörperphysik, 64285 Darmstadt, Germany. *Diffusive Nonlinear Electrodynamics.*

A theory of electromagnetic wave propagation is presented for the low frequency regime in dissipative reactive matter. Nonlinear Ohmic, heat conductive , Debye and quadrupole dissipation is modeled by using Extended Irreversible Thermodynamics. The resulting nonlinear hyperbolic reaction diffusion equations are solved by perturbation techniques exhibiting shock structures, modulational instabilities and pattern formation. (Received June 10, 2015)

1116-35-70 **Marta Lewicka***, lewicka@pitt.edu. *Prestrained elasticity: curvature constraints and differential geometry with low regularity.*

This lecture is concerned with the analysis of thin elastic films exhibiting residual stress at free equilibria. Examples of such structures and their actuations include: plastically strained sheets; specifically engineered swelling or shrinking gels; growing tissues; atomically thin graphene layers, etc. These and other phenomena can be studied through a variational model, pertaining to the non-Euclidean version of nonlinear elasticity, which postulates formation of a target Riemannian metric, resulting in the morphogenesis of the tissue which attains an orientation-preserving configuration closest to being the metric's isometric immersion.

In this context, analysis of scaling of the energy minimizers in terms of the film's thickness leads to the rigorous derivation of a hierarchy of limiting theories, differentiated by the embeddability properties of the target metrics and, a-posteriori, by the emergence of isometry constraints with low regularity. This leads to questions of rigidity and flexibility of solutions to the weak formulations of the related PDEs, including the Monge-Ampere equation. In particular, we observe that the set of $C^{1,\alpha}$ solutions to the Monge-Ampere equation is dense in C^0 provided that $\alpha < 1/7$, whereas rigidity holds when $\alpha > 2/3$. (Received July 11, 2015)

1116-35-87 **Ugur Abdulla** and **Curtis Earl*** (cearl2013@my.fit.edu), 2920 Emory st., Melbourne, FL 32901, and **Chelsey Hoff**, **Jim Jones**, **Bruno Poggi** and **Ryan Stees**. *State Constrained Optimal Control of the Stefan Type Free Boundary Problems.*

We consider an inverse free boundary problem, the inverse Stefan problem (ISP), for the general second order linear parabolic PDE

$$(a(x,t)u_x)_x + b(x,t)u_x + c(x,t)u - u_t = f(x,t)$$

where u is the temperature, f is the density of heat sources, and a, b, and c reflect non-homogeneity of the media. The ISP arises when considering a phase transition process with unknown temperature function, phase transition boundary, source term and boundary heat flux. We follow a variational formulation developed in *U. G. Abdulla, Inverse Problems and Imaging, 7,2(2013),307-340*. We pursue the same formulation with additional state constraint $u(x,t) \leq u_*$. We reformulate the ISP as an optimal control problem, with the source term, flux, and free boundary as controls, which minimizes L_2 declinations of traces of a state vector and a penalty term

$$\int_0^T \int_0^{s(t)} |\max(u(x,t) - u_*; 0)|^2 dxdt.$$

We use a Sobolev spaces framework and prove that the penalty functional is continuous in a weak topology in the space of weakly differentiable functions, implying existence of the optimal control. We pursue discretization and prove convergence of the sequence of discrete optimal control problems to the continuous problem. (Received July 20, 2015)

1116-35-90 **Dylanger S Pittman*** (dsp1@williams.edu), 1436 Paresky Center, Williamstown, MA 01267, **Jessica Pillow** (pilja-16@rhodes.edu), 979 Belton Rd, Ripley, TN 38063, **Ugur Abdulla** (abdulla@fit.edu), Mathematical Sciences, 150 West University Blvd, Melbourne, FL 32901, **Jim Jones** (jim@fit.edu), Mathematical Sciences, 150 West University Blvd, Melbourne, FL 32901, and **Jonathan Goldfarb** (jgoldfar@gmail.com), Mathematical Sciences, 150 West University Blvd, Melbourne, FL 32901. *Frechet Differentiability in Optimal Control of Free Boundary Problems for the Second Order Parabolic PDE.*

We consider an optimal control of the Stefan type free boundary problem for the following general second order linear parabolic PDE:

$$(a(x,t)u_x)_x + b(x,t)u_x + c(x,t)u - u_t = f(x,t)$$

where $u(x,t)$ is the temperature function. The density of heat sources f, unknown free boundary, and boundary heat flux are components of the control vector, and cost functional consists of the L_2-declination of the trace of the temperature at the final moment, temperature at the fixed boundary and final position of the free boundary from available measurements. We follow a new variational formulation developed in *U. G. Abdulla, Inverse Problems and Imaging, 7,2(2013),307-340.*

In this project we prove Frechet differentiability of the cost functional in Hilbert space framework. Extension of the differentiable calculus to the infinite-dimensional setting is the major mathematical challenge in this context. We apply the idea of decomposition of the domain, and analyse carefully effect of boundary integrals on the derivation of the first variation of the cost functional. With the delicate use of sharp embedding theorems in fractional Sobolev-Besov spaces we prove Frechet differentiability, and derive the formula for the Frechet gradient. (Received July 21, 2015)

1116-35-101 **Ugur G. Abdulla**, **Luke Thomas Andrejek**, **Christie M. Campbell*** (camp744@msu.edu), **Jian Du**, **Jonathon Goldfarb** and **Adam L. Prinkey**. *Evolution of Free Boundaries for the Nonlinear Fokker-Planck Equation.*

We investigate the problem on short-time behavior of interfaces and local solutions near it in the following Cauchy problem for the nonlinear diffusion equation with convection, the so called nonlinear Fokker-Planck equation: $u_t = (u^m)_{xx} + b(u^\gamma)_x, x \in \mathbb{R}, t > 0; u|_{t=0} = C(-x)_+^\alpha (1)$ where $m > 1, \gamma > 0$. The equation (1) arises in many applications, such as water infiltration in a porous medium, transport of energy in plasma, etc. Full classification of the short-time behavior of interfaces and local solutions for the reaction-diffusion equation are given in [Abdulla and King, SIAM J. Math. Anal., 32, 2(2000), 235-260] and [Abdulla, Nonlinear Analysis, 50, 4(2002), 541-560]. The goal of this research is to apply the methods of these papers, i.e. rescaling, construction of super- and subsolutions, and special comparison theorems in irregular domain to solve the open problem for the diffusion-convection equation (1). The behavior of the interface for $b > 0$ depends on the competition between diffusion and convection. We identify regions of the (α, γ)-parameter space where one dominates over the other and prove explicit formulae for the interface and local solution, with precise estimates. A WENO scheme is applied and supports our estimates. (Received July 23, 2015)

1116-35-102 **Ugur G Abdulla**, **Jian Du**, **Chloe L Ondracek**, **Suneil Parimoo*** (parimoos@sas.upenn.edu) and **Adam L Prinkey**. *Analysis of Interfaces for the Nonlinear Double-Degenerate Reaction-Diffusion Equation.*

We consider the problem of interface development and local behavior of solutions near the interface in the following Cauchy problem for the nonlinear double-degenerate parabolic PDE with reaction: $u_t = (|(u^m)_x|^{p-1}(u^m)_x) - bu^\beta, x \in \mathbb{R}, t > 0; u(x,0) = C(-x)_+^\alpha$. The problem arises in applications such as heat radiation in plasma, spatial spread of populations, and chemical diffusion through groundwater. The structure of the PDE implies that interface behavior is determined by the competition between diffusion and reaction. The full solution for the reaction-diffusion equation ($p = 1$) was given in 2000 [Abdulla and King, SIAM J. Math. Anal., 32, 2(2000), 235-260] and 2002 [Abdulla, Nonlinear Analysis, 50, 4(2002), 541-560]. Our aim is to apply the methods of these papers to solve the open problem for double-degenerate reaction-diffusion equations ($p > 1, mp > 1$). First we apply the nonlinear scaling method to identify which term dominates in various regions of the (α, β)-parameter space. We then construct super/subsolutions and apply special comparison theorems in irregular domains to prove explicit formulae for the interface and local solution, with precise estimations up to constant coefficients. A WENO scheme is applied and supports our estimates. (Received July 23, 2015)

1116-35-186 **Xiaoxia Xie*** (xxie12@iit.edu), Department of Applied Mathematics, Illinois Institute of Technology, Chicago, IL 60616, **Wenxian Shen** (wenxish@mail.auburn.edu), Department of Mathematics, Auburn University, Auburn, AL 36849, **Jinqiao Duan** (duan@iit.edu), Department of Applied Mathematics, Illinois Institute of Technology, Chicago, IL 60616, and **Xiaofan Li** (lix@iit.edu), Department of Applied Mathematics, Illinois Institute of Technology, Chicago, IL 60616. *Two Types of Nonlocal Diffusions and the Convergence to the Random/Normal Diffusion.*

This talk is concerned with the study of different types of diffusions: the random/normal diffusion and two types of nonlocal diffusions. The random/normal diffusion is the classical Laplace operator, while one type of nonlocal diffusions is an integral operator with a smooth kernel, and the other one is called the anomalous diffusion generated by the fractional Laplace operation.

Regarding the nonlocal dispersal operator with a smooth kernel, we first study its principal spectral theory and asymptotic dynamics. Secondly, we consider its convergence to the random dispersal operator from three points of view.

About the anomalous diffusion, we are interested in the Fokker-Plank equation, when the noise in the system is an α-stable Lévy motion. We investigate the existence, uniqueness, and regularity of solutions to the corresponding Fokker-Plank equation in two prototypical stochastic systems. (Received August 11, 2015)

1116-35-214 **Alexey Cheskidov** and **Mimi Dai*** (mdai@uic.edu). *Regularity criteria for the 3D Navier-Stokes and MHD equations.*

We prove that a solution to the 3D Navier-Stokes or MHD equations does not blow up at $t = T$ provided $\limsup_{q\to\infty} \int_{\mathcal{T}_q}^{T} \|\Delta_q(\nabla \times u)\|_\infty \, dt$ is small enough, where u is the velocity, Δ_q is the Littlewood-Paley projection, and $\mathcal{T}_q$ is a certain sequence such that $\mathcal{T}_q \to T$ as $q \to \infty$. This improves many existing regularity criteria. (Received August 14, 2015)

1116-35-220 **Jin Woo Jang*** (jangjinw@math.upenn.edu), University of Pennsylvania, David Rittenhouse Lab, 209 S. 33rd St, Ofc 4w1, Philadelphia, PA 19104. *Global Classical Solutions to the Relativistic Boltzmann Equation without Angular Cut-off.*

We prove the unique existence and exponential decay of global in time classical solutions to the special relativistic Boltzmann equation without any angular cut-off assumptions with initial perturbations in some weighted Sobolev spaces. We consider perturbations of the relativistic Maxwellian equilibrium states. We work in the case of spatially periodic box. We consider the general conditions on the collision kernel from Dudyński and Ekiel-Jeżewska (Commun Math Phys 115(4):607–629, 1985). Additionally, we prove sharp constructive upper and coercive lower bounds for the linearized relativistic Boltzmann collision operator in terms of a geometric fractional Sobolev norm; this shows a spectral gap exists and this behavior is similar to that of non-relativistic case as shown by Gressman and Strain(Journal of AMS 24(3), 771–847, 2011). This is the first global stability result for relativistic Boltzmann equation without angular cutoff and this resolves the open question of perturbative global existence for the relativistic kinetic theory without the Grad's angular cut-off assumption. (Received September 16, 2015)

1116-35-258 **Matthew D Blair*** (blair@math.unm.edu). *L^p norms of eigenfunctions and Kakeya-Nikodym averages.*

We consider the problem of determining optimal upper bounds on the growth of L^p norms of eigenfunctions of the Laplacian on a compact Riemannian manifold in the high frequency limit. After an introduction to the problem, we will discuss recent works relating such upper bounds to mass concentration in frequency dependent tubes about geodesic segments. When the manifold has nonpositive sectional curvatures, it can be shown that the criteria developed here yields improved L^p bounds on the eigenfunctions. These are results in joint works with C. Sogge and S. Zelditch. (Received August 18, 2015)

1116-35-259 **Justin Trulen*** (jgtrulen@uwm.edu), Department of Mathematical Sciences, University of Wisconsin - Milwaukee, Milwaukee, WI 53211. *Strichartz Estimate for the Cauchy Problem of Dispersive Equations on α-Modulation Space.* Preliminary report.

Abstract: Recently, asymptotic estimates for the unimodular Fourier multipliers $e^{i\mu(D)}$ have been studied for the function space α-modulation space. In this talk, using the almost orthogonality of projections and some techniques on oscillating integrals, we obtain asymptotic estimates for the unimodular Fourier multipliers $e^{it|\Delta|^{\frac{\alpha_O}{2}}}$ on the α-modulation space. As applications, we give the Strichartz estimate of the solutions for the Cauchy problem for the free Schrödinger equation, the wave equation, and the Airy equation with initial data in a α-modulation space. We also obtain a quantitative form about the solution to the Cauchy problem of the nonlinear dispersive equations. (Received August 18, 2015)

1116-35-319 **Michael Oyesola Okelola*** (okelola@ukzn.ac.za), University of KwaZulu-Natal, School of Mathematics, Statistics & Computer, Private Bag X5400, Durban, KwaZulu-Na 4000, South Africa, and **K S Govinder**, University of KwaZulu-Natal, School of Mathematics, Statistics & Computer, Private Bag X5400, Durban, KwaZulu-Na 4000, South Africa. *Analytical solutions to the partial hedging of the HJB model in a stochastic volatility environment.* Preliminary report.

We look at the problem of hedging a portfolio, modeled as a nonlinear Hamilton Jacobi Bellman equation, in a stochastic volatility environment. Previous studies have either dealt with the physically non-relevant cases of constant and time dependent volatility or of obtaining numerical solutions to the stochastic volatility case.

The problem which is a partial differential equation with four independent variables is addressed via the Lie group approach. We obtain an analytical solution for the problem in a stochastic volatility environment and also show the physical implications of our result by using a simulated portfolio form. (Received August 25, 2015)

1116-35-346 **Zachary Bradshaw*** (zbradshaw@math.ubc.ca) and **Zoran Grujic**. *Regularity criteria for the Navier-Stokes equations.*

Two *dynamically opposing conditions* are identified for Leray-Hopf weak solutions involving only peripherally high or low Littlewood-Paley modes. Both conditions are shown to prevent singularity formation at an initial possible blow-up time. A refined Ladyzhenskaya-Prodi-Serrin-type regularity criterion is also established and has the novel feature of considering only Littlewood-Paley blocks above a time-dependent threshold which is diverging to $+\infty$ at an initial blow-up time – i.e. *the window of relevant frequencies is vanishing*. (Received August 26, 2015)

1116-35-358 **Tristan Buckmaster*** (buckmaster@cims.nyu.edu). *Onsager's Conjecture.*

In 1949, Lars Onsager in his famous note on statistical hydrodynamics conjectured that weak solutions to the Euler equation belonging to Hölder spaces with Hölder exponent greater than 1/3 conserve energy; conversely, he conjectured the existence of solutions belonging to any Hölder space with exponent less than 1/3 which dissipate energy.

The first part of this conjecture has since been confirmed (cf. Eyink 1994, Constantin, E and Titi 1994). During this talk we will discuss recent work by Camillo De Lellis, László Székelyhidi Jr., Philip Isett and myself related to resolving the second component of Onsager's conjecture. (Received August 27, 2015)

1116-35-381 **Ugur G. Abdulla*** (abdulla@fit.edu), Department of Mathematical Sciences, Florida Institute of Technology, Melbourne, FL 32901. *The Wiener Test for the Removability of the Logarithmic Singularity for the Elliptic PDEs with Measurable Coefficients and Its Consequences.*

We introduce a notion of *log*-regularity (or *log*-irregularity) of the boundary point ζ (possibly $\zeta = \infty$) of arbitrary open subset Ω of the Greenian deleted neigborhood of ζ in R^2 concerning second order uniformly elliptic equations with bounded and measurable coefficients, according as whether the *log*-harmonic measure of ζ is null (or positive). A necessary and sufficient condition for the removability of the logarithmic singularity, that is to say for existence of a unique solution to the Dirichlet problem in Ω in a class $O(\log|\cdot - \zeta|)$ is established in terms of the Wiener test for the *log*-regularity of ζ. From the topological point of view, the Wiener test at ζ presents minimal thinness criteria of sets near ζ in minimal fine topology. Precisely, the open set Ω is a deleted neigborhood of ζ in minimal fine topology if and only if ζ is *log*-irregular. From the probabilistic point of view Wiener test presents asymptotic law for the *log*-Brownian motion near ζ conditioned on the logarithmic kernel with pole at ζ. (Received August 29, 2015)

1116-35-428 **Andrew Lawrie*** (alawrie@math.berkeley.edu). *Wave maps with large data.*

We begin with a survey of some recent results on energy critical wave maps from Minkowski space emphasizing the effect of the geometry of the target manifold on dynamics and the special role played by finite energy harmonic maps. Then we consider equivariant wave maps from the hyperbolic plane into rotationally symmetric targets and discuss new phenomena that arise in this model problem due to the hyperbolic geometry of the domain. This is joint work with Sung-Jin Oh and Sohrab Shahshahani. (Received August 31, 2015)

1116-35-466 **Jiahong Wu*** (jiahong.wu@okstate.edu), Department of Mathematics, 401 Mathematical Sciences, Stillwater, OK 74078. *The 2D magnetohydrodynamic (MHD) equations with partial dissipation.*

The magnetohydrodynamic (MHD) equations model electrically conducting fluids in the presence of a magnetic field such as plasmas and liquid metals. They are a combination of the Navier-Stokes equations (with Lorentz force) and the electromagnetic equations. The global (in time) regularity problem concerning the MHD equations have garnered considerable interest recently. This talk focuses on recent developments on the 2D MHD equations with partial dissipation. When there is only partial dissipation, the global regularity problem can be extremely difficult. We report very recent global regularity results for two partial dissipation cases: the MHD equations with no magnetic diffusion and the MHD equations with no velocity dissipation. (Received September 02, 2015)

1116-35-499 **Avner Peleg*** (avpeleg@gmail.com), Racah Institute of Physics, The Hebrew University of Jerusalem, 91904 Jerusalem, Israel, and **Quan M Nguyen** and **Toan T Huynh**. *On the relation between collision dynamics of soliton sequences of coupled-NLS equations and population dynamics in Lotka-Volterra models.*

We use model reduction along with collision-rate calculations to show that collision dynamics of N sequences of solitons of perturbed systems of coupled nonlinear Schrödinger (NLS) equations can be described by N-dimensional Lotka-Volterra (LV) models, where the form of the LV model depends on the nature of the perturbation term. We employ stability and bifurcation analysis of the equilibrium points of the LV models to stabilize soliton-sequence propagation and to achieve on-off and off-on transmission switching. We demonstrate the relation in the case where the perturbations are due to a Ginzburg-Landau gain-loss profile and Raman scattering. In this case, numerical simulations with a system of N coupled nonlinear Schrödinger equations with $2 \leq N \leq 4$ show excellent agreement with the predator-prey model's predictions. Moreover, stable on-off and off-on switching of multiple soliton sequences and stable multiple transmission switching events are demonstrated by the simulations. We discuss the reasons for the robustness and scalability of transmission stabilization and switching in this case. (Received September 04, 2015)

1116-35-505 **Pei Pei*** (peipe@earlham.edu), **Mohammad Rammaha** and **Daniel Toundykov**. *Weak solutions and blow-up for wave equations of p-Laplacian type with supercritical sources.*

This paper investigates a quasilinear wave equation with Kelvin-Voigt damping, $u_{tt} - \Delta_p u - \Delta u_t = f(u)$, in a bounded domain $\Omega \subset \mathbb{R}^3$ and subject to Dirichlét boundary conditions. The operator Δ_p, $2 < p < 3$, denotes the classical p-Laplacian. The nonlinear term $f(u)$ is a source feedback that is allowed to have a *supercritical* exponent, in the sense that the associated Nemytskii operator is not locally Lipschitz from $\mathrm{W}_0^{1,p}(\Omega)$ into $L^2(\Omega)$. Under suitable assumptions on the parameters, we prove existence of local weak solutions, which can be extended globally provided the damping term dominates the source in an appropriate sense. Moreover, a blow-up result is proved for solutions with negative initial total energy. (Received September 04, 2015)

1116-35-509 **Nguyen H Lam***, 301 Thackeray Hall, Pittsburgh, PA 15217. *Existence and symmetry of maximizers for a family of Caffarelli-Kohn-Nirenberg interpolation inequalities.*

In this talk, we will use a suitable map to investigate the sharp constants and optimizers for the Caffarelli-Kohn-Nirenberg inequalities for a wide range of parameters. Moreover, We will compute the best constants and the explicit forms of the extremal functions in numerous cases. This is joint work with Guozhen Lu. (Received September 04, 2015)

1116-35-517 **John Albert**, The University of Oklahoma, 601 Elm Street, Norman, OK 73019, and **Santosh Bhattarai*** (bhattarais@trocaire.edu), Trocaire College, 360 Choate Ave, Buffalo, NY 14220. *Positive solutions with prescribed L^2-norm for a Schrodinger-KdV system.*

We will show the existence of solutions with prescribed L^2-norm in $H^1(\mathbb{R}) \times H^1(\mathbb{R})$ for a couple system of nonlinear Schrödinger-KdV equations. More precisely, we consider the following stationary system

$$\begin{cases} -\Phi'' + \sigma_1\Phi & = \tau|\Phi|^q\Phi + \alpha\Phi\Psi, \\ -\Psi'' + \sigma_2\Psi & = \dfrac{\lambda}{p+1}\Psi^{p+1} + \dfrac{\alpha}{2}|\Phi|^2, \end{cases}$$

and look for solutions satisfying

$$\int_{\mathbb{R}} |\Phi|^2 \, dx = c_1 \text{ and } \int_{\mathbb{R}} |\Psi|^2 \, dx = c_2,$$

where $c_1 > 0$ and $c_2 > 0$. These types of solutions are of special interest in physics. We also consider the stability issue of the corresponding NLS-KdV solitary waves.

References

J. Albert and S. Bhattarai, Existence and stability of a two-parameter family of solitary waves for an NLS-KdV system, Adv. Differential Eqs., **18**, 1129-1164 (2013). (Received September 05, 2015)

1116-35-518 **Julienne Kabre*** (jkabre@hawk.iit.edu), 7258 South Oglesby, Chicago, IL 60649. *Energy-Conserving Numerical Scheme for the Poisson-Nerst-Plank Equations.* Preliminary report.

The Poisson-Nernst-Planck equations are a system of nonlinear partial differential equations that describe flow of charged particles in solution. In particular, we are interested in the transport of ions in the biological membrane proteins (ion channels). This work is about the design of numerical schemes that preserve exactly (up to roundoff error) a discretized form of the energy dynamics of the system. We will present a scheme that achieves the goal of preserving the energy dissipation law and some preliminary numerical results. (Received September 05, 2015)

1116-35-531 **Keith Promislow*** (kpromisl@math.msu.edu), Department of Mathematics, C212 Wells Hall, East Lansing, MI 48824, and **Qiliang Wu**. *Dynamics and Bifurcation of Multicomponent Amphiphilic Membranes.*

Polymer chains are typically hydrophobic, the addition of functional groups to the backbone adds regions of hydrophilicity. The amphiphilic material (both hydrophobic and hydrophilic) has a strong affinity for solvent, imbibing it to self assemble charge-lined networks which serve as charge-selective ion conductors in a host of energy conversion applications. We present a continuum model for the free energy of an amphiphilic mixture. The associated gradient flows admit dynamic competition between network morphologies of distinct co-dimension. We present a model for multicomponent amphiphilic mixtures that permits competitive geometric evolution for co-dimension 1 bilayers and co-dimension two pore morphologies, present an analysis of the associated spectral problems, and describe rigorous existence results for pearled morphologies. (Received September 05, 2015)

1116-35-539 **Qi Han*** (qhan@wpi.edu), Department of Mathematical Sciences, Worcester Polytechnic Institute, Worcester, MA 01609. *When does the Elastic Torsion Problem*

$$-\Delta u = 1$$

have a solution in R^N? Preliminary report.

In this talk, we discuss the solvability of the equation

$$-\Delta u + \mu u^q = 1 \quad \text{in} \quad R^N$$

when $N \geq 2$, which is the extension of the classical Elastic Torsion Problem

$$-\Delta u = 1$$

with zero Dirichlet data to the whole space.

Here, μ denotes a general Radon measure, and the general Sobolev space $M^{q,p}(R^N)$ and its fine properties are described. (Received September 06, 2015)

1116-35-550 **Phi LE*** (llc33@mail.missouri.edu), **Steve Hofmann** (hofmanns@missouri.edu), **Jose Maria Martell** (chema.martell@icmat.es) and **Kaj Nyström** (kaj.nystrom@math.uu.se). *Uniform rectifiability, harmonic and p-harmonic measure: The weak-A_∞ property of harmonic and p-harmonic measures implies uniform rectifiability.* Preliminary report.

Let $E \subset \mathbb{R}^{n+1}$, $n \geq 1$, be an Ahlfors-David regular set of dimension n. We show that the weak-A_∞ property of harmonic measure, for the open set $\Omega := \mathbb{R}^{n+1} \setminus E$, implies uniform rectifiability of E. More generally, we establish a similar result for the Riesz measure, p-harmonic measure, associated to the p-Laplace operator, $1 < p < \infty$. (Received September 06, 2015)

1116-35-583 **Michail E Filippakis*** (mfilip@unipi.gr), University of Piraeus, Department of Digital, Systems, 126 Grigoriou Labraki Str., Piraeus 18532, 18532 Piraeus,, Greece. *Multiple and nodal solutions for nonlinear equations with a nonhomogeneous differential operator and concave-convex term.*

In this paper we consider a nonlinear parametric Dirichlet problem driven by a nonhomogeneous differential operator (special cases are the p-Laplacian and the (p,q)-differential operator) and with a reaction which has the combined effects of concave ($(p-1)$-sublinear) and convex ($(p-1)$-superlinear) terms. We do not employ the usual in such cases AR-condition. Using variational methods based on critical point theory, together with truncation and comparison techniques and Morse theory (critical groups), we show that for all small $\lambda > 0$ (λ is a parameter), the problem has at least five nontrivial smooth solutions (two positive, two negative and the fifth nodal). We also prove two auxiliary results of independent interest. The first is a strong comparison principle and the second relates Sobolev and Hőlder local minimizers for C^1 functionals. The publication of this paper has been partly supported by the University of Piraeus Research Center. (Received September 08, 2015)

1116-35-591 **Dipendra Regmi***, Farmingdale State College, Farmingdale, NY 11735. *The two-and-half dimensional magnetohydrodynamic equations with horizontal dissipation and horizontal magnetic diffusion.* Preliminary report.

We study the global regularity of classical solution to two-and-half dimensional magnetohydrodynamic equations with horizontal dissipation and horizontal magnetic diffusion. We prove that any possible finite time blow-up can be controlled by the L^∞-norm of the vertical components. (Received September 08, 2015)

1116-35-635 **Tracy L. Stepien*** (tstepien@asu.edu), School of Mathematical & Statistical Sciences, Arizona State University, P.O. Box 871804, Tempe, AZ 85287-1804, and **Hal L. Smith** (halsmith@asu.edu), School of Mathematical & Statistical Sciences, Arizona State University, P.O. Box 871804, Tempe, AZ 85287-1804. *Existence and uniqueness of similarity solutions of a generalized heat equation arising in a model of cell migration.*

We study similarity solutions of a nonlinear partial differential equation that is a generalization of the heat equation. Substitution of the similarity ansatz reduces the partial differential equation to a nonlinear second-order ordinary differential equation on the half-line with Neumann boundary conditions at both boundaries. The existence and uniqueness of solutions is proven using Ważewski's Principle. (Received September 09, 2015)

1116-35-678 **Michael Goldberg***, Department of Mathematical Sciences, University of Cincinnati, Cincinnati, OH 45221-0025, and **William Green**, Department of Mathematics, Rose-Hulman Institute of Technology, Terre Haute, IN 47803. *L^p Bounds for Wave Operators for the Schrödinger Equation with a Threshold Eigenvalue.*

The wave operators $W_\pm$ are a valuable tool for linking properties of the Schrödinger evolution $e^{itH}P_{ac}(H)$ to properties of the corresopnding free evolution $e^{-it\Delta}$. We consider operators of the form $H = -\Delta + V(x)$ in $\mathbb{R}^n$, $n \geq 5$ which have an eigenvalue at zero. The potential is assumed to decay at the rate $|V(x)| \leq C(1 + |x|)^{-(n+3+\varepsilon)}$.

It was recently proved by Yajima that the wave operators are bounded on $L^p(\mathbb{R}^n)$ for all $1 < p < \frac{n}{2}$. We recover this result, including the $p = 1$ endpoint, and show that the upper end of the range can be expanded if the eigenspace satisfies certain cancellation conditions: If $\int V\phi\,dx = 0$ for each eigenfunction ϕ, then L^p-bundedness of wave operators holds for $1 \leq p < n$. If the first moments of $V\phi$ also vanish for each eigenfunction, then L^p-boundedness of wave operators holds for $1 \leq p < \infty$. (Received September 10, 2015)

1116-35-687 **John A. Toth*** (jtoth@math.mcgill.ca), Department of Mathematics, McGill University, 805 Sherbrooke St. West, Montreal, Quebec H3A 2K6, Canada. *L^2 restriction bounds for quantum ergodic eigenfunctions.* Preliminary report.

Let (M, g) be a compact Riemannian surface and (ϕ_λ) be a quantum ergodic (QE) sequence of L^2-normalized Laplace eigenfunctions. Given any simple, closed, smooth curve $H \subset M$ with positive geodesic curvature, we show that the L^2-restrictions, $\|\phi_\lambda\|_{L^2(H)}$, are uniformly bounded above and below by positive constants as $\lambda \to \infty$. (This is joint work with Y. Canzani and H. Christianson) (Received September 10, 2015)

1116-35-706 **Hong-Ming Yin*** (hyin@wsu.edu), Department of Mathematics and Statistics, Washington State University, Pullman, WA 99164. *Panel Discussion for Problems and Challenges in Financial Engineering and Risk Management.* Preliminary report.

The organizers will lead a open discussion about the problems and challenges in Financial Engineering and Risk Management. The discussion will focus on the following topics: (a) Education and Research in Financial Engineering and risk management; (b) Commodity Pricing and currency issues; (c) Program trading and Market Manipulation; (d) Economic Data and Government Policy. (Received September 10, 2015)

1116-35-712 **Panagiota Daskalopoulos*** (pdaskalo@math.columbia.edu), Department of Mathematics, Columbia University, 2990 Broadway, New York, NY 10027. *Ancient solutions to parabolic partial differential equations.*

Some of the most important problems in geometric partial differential equations are related to the understanding of *singularities*. This usually happens through a *blow up* procedure near the potential singularity which uses the scaling properties of the equation. In the case of a *parabolic* equation the blow up analysis often leads to special solutions which are defined for all time $-\infty < t \leq T$, for some $T \leq +\infty$. We refer to them as *ancient* if $T < +\infty$ and *eternal* if $T = +\infty$. The classification of such solutions, when possible, often sheds new insight to the singularity analysis.

We will give a survey of recent research progress on *ancient* solutions to *geometric flows* such as the Ricci flow, the Mean Curvature flow and the Yamabe flow. Our discussion will also include other models of nonlinear parabolic partial differential equations.

We will address both *Liouville* type results for the classication of ancient or eternal solutions to parabolic equations as well as the construction of new ancient solutions from the *gluing* of two or more *solitons*. (Received September 10, 2015)

1116-35-735 **Petronela Radu*** (pradu@math.unl.edu), 203 Avery Hall, Lincoln, NE 68588, **Grozdena Todorova**, Knoxville, TN , and **Boris Yordanov**, Sofia, Bulgaria. *Diffusion phenomenon and decay rates for nonlocal wave equations with damping.*

Nonlocal wave equations with damping have only recently started to be explored in the context of peridynamics and other theories that allow solutions to be discontinuous. In this talk I will focus on results that connect the asymptotic behavior of solutions to dissipative wave equations to solutions of the corresponding diffusion equations, more precisely, show that the abstract diffusion phenomenon takes place. The results hold true in fact for systems that involve two non-commuting self-adjoint operators in a Hilbert space. When the diffusion semigroup has the Markov property and satisfies a Nash-type inequality, we obtain precise estimates for the consecutive diffusion approximations and remainder. Also, I will present some applications including sharp decay estimates for dissipative hyperbolic equations with variable coefficients on an exterior domain. To our knowledge we have obtained the first decay estimates for nonlocal wave equations with damping terms; the decay rates are sharp. Some of these results have been obtained in collaboration with Grozdena Tododrova and Boris Yordanov. (Received September 11, 2015)

1116-35-736 **Robert Buckingham*** (buckinrt@uc.edu), **Robert Jenkins** (rjenkins@math.arizona.edu) and **Peter Miller** (millerpd@umich.edu). *Forward scattering for the semiclassical three wave equation.*

The three-wave resonant interaction equations model the evolution of three electrical pulses in a dispersive medium with quadratic linearity. Typical phenomena include the interaction of two soliton waves in two separate channels leading to the creation and eventual annihilation of a pulse in the third channel. Since interactions in these materials can be induced more rapidly than in those with cubic nonlinearities, the model has sparked interest in alternate possibilities for designing feasible all-optical switching devices. We analyze the small-dispersion (or semiclassical) behavior using the inverse scattering formalism. We present analytic results on the WKB approximation of the scattering data, as well as a numerical study of exact solutions that suggests semiclassical behavior (i.e. approximation of solutions by modulated elliptic functions) similar to that seen in other nonlinear wave equations such as the KdV, NLS, and sine-Gordon equations. This work is joint with Robert Jenkins and Peter Miller. (Received September 11, 2015)

1116-35-750 **W. Y. Chan***, Department of Mathematical Sciences, Montana Tech, Butte, MT 59701. *Finding the Critical Domain for Quenching Problems Using Conformal Mappings.*

Let Ω_1 and Ω_2 be square-shaped domains such that $\Omega_1 \subset \Omega_2$. We will determine the approximated critical domain of the problem (1)-(2) below by using a conformal mappping,

$$\left.\begin{aligned} \frac{\partial u}{\partial \theta} &= \frac{\partial^2 u}{\partial \chi^2} + \frac{\partial^2 u}{\partial \zeta^2} + \frac{1}{1-v} \text{ in } \Omega_1 \times (0,\infty)\,, \\ \frac{\partial v}{\partial \theta} &= \frac{\partial^2 v}{\partial \chi^2} + \frac{\partial^2 v}{\partial \zeta^2} + \frac{1}{1-u} \text{ in } \Omega_2 \times (0,\infty)\,, \end{aligned}\right\} \tag{1}$$

$$\left.\begin{array}{c} u\,(\chi,\zeta,0) = 0 \text{ for } (\chi,\zeta) \in \Omega_1 \text{ and } v\,(\chi,\zeta,0) = 0 \text{ for } (\chi,\zeta) \in \Omega_2, \\ u\,(\chi,\zeta,\theta) = 0 \text{ for } \theta > 0 \text{ and } (\chi,\zeta) \in \partial\Omega_1 \text{ and } v\,(\chi,\zeta,\theta) = 0 \text{ for } \theta > 0 \text{ and } (\chi,\zeta) \in \partial\Omega_2. \end{array}\right\} \tag{2}$$

(Received September 11, 2015)

1116-35-759 **Vinodh Kumar Chellamuthu***, Department of Mathematics, Dixie State University, 225 South 700 East, St. George, UT 84770, and **Azmy S. Ackleh**, **Jacoby Carter** and **Baoling Ma**. *A Mathematical Model for Frog Population Dynamics with Batrachochytrium dendrobatidis Infection.*

Chytridiomycosis is an emerging disease caused by the fungal pathogen *Batrachochytrium dendrobatidis (Bd)* that poses a serious threat to frog populations worldwide. Several studies have shown that inoculation of bacterial species *Janthinobacterium lividum (Jl)* can mitigate the impact of the disease. However, there are many questions regarding this interaction. A mathematical model of a frog population infected with chytridiomycosis is developed to investigate how the inoculation of *Jl* could reduce the impact of *Bd* disease on frogs. The model also illustrates the important role of temperature in disease dynamics. The model simulation results suggest possible control strategies for *Jl* to limit the impact of *Bd* in various scenarios. However, a better knowledge of *Jl* life cycle is needed to fully understand the interactions of *Jl*, *Bd*, temperature and frogs. (Received September 11, 2015)

1116-35-772 **Suzanne Lenhart*** (lenhat@math.utk.edu) and **Kokum DeSilva**. *Optimal control of parabolic PDE systems modeling competitive populations.*

We discuss an important ecological issue of population movement and its distribution in reaction to resources and to competition. We present the choices of directed movement through controlling the advective coefficients in a system of parabolic partial differential equations, modeling two competing species. We seek to maximize population levels while minimizing the cost of controls. In addition to presenting the optimal control analysis, different resource functions and corresponding directed movement choices are shown numerically. (Received September 12, 2015)

1116-35-800 **Michele Coti Zelati*** (micotize@umd.edu). *Nonlinear lower bounds for the fractional laplacian and applications.*

We analyze the regularity and asymptotic behavior of solutions to the so-called surface quasi-geostrophic equations. Most the results are obtained via the nonlinear lower bounds on the fractional Laplace operator recently discovered by P. Constantin and V. Vicol. We will provide several instances which show the robustness and flexibility of this approach, specifically for the derivation of optimal Sobolev and Holder estimates, which may be of independent interest. (Received September 13, 2015)

1116-35-816 **Alexander Kiselev** and **Xiaoqian Xu*** (xxu@math.wisc.edu). *Mixing versus chemotaxis.*

In this talk, we will consider parabolic-elliptic Keller-Segel equation in two and three dimensions with additional advection term modeling ambient fluid flow. Keller-Segel equation is one of the most studied PDE models of processes involving chemical attraction, for instance, the movement of bacteria. However, solution of Keller-Segel equation can exhibit dramatic collapsing behavior, where the population density of bacteria concentrates positive mass in a measure zero region. In other words, when the fluid flow is absent, there exist initial data leading to finite time blow up. Here we will prove that for any initial data, there exist incompressible fluid flows such that the solution to the equation stays globally regular. Thus presence of fluid can prevent the singularity formation. We will discuss two classes of flows that have the explosion arresting property. Both classes are known as very efficient mixers. (Received September 13, 2015)

1116-35-820 **Junping Shi*** (jxshix@wm.edu), Department of Mathematics, College of William and Mary, Williamsburg, VA 23187. *Structure of attractors for the reaction-diffusion systems in chemical and biological models.*

For many reaction-diffusion systems in chemical and biological models, it is known that an attractor exists for the underlying dynamics. But other than the gradient systems, the precise structure of the attractors is not known. We demonstrate that in many cases, the attractor is consisted of a large number of steady state solutions and periodic orbits, and the bifurcation diagram for the system can be very complicated. For simplified patch ODE models, we show that a more precise picture of the attractor can be obtained. (Received September 13, 2015)

1116-35-857 **Ebru Toprak*** (toprak2@illinois.edu), 1409 W. Green Street, Urbana, IL 61801. *A Weigthed estimate for two dimensional Schrödinger, matrix Schrödinger, and wave equations with resonance of the first kind at zero.* Preliminary report.

We study the two dimensional Schrödinger operator, $H = -\Delta + V$, in the weighted $L^1(\mathbb{R}^2) \to L^\infty(\mathbb{R}^2)$ setting when there is a resonance of the first kind at zero energy. In particular, we show that if $|V(x)| \lesssim \langle x \rangle^{-3-}$ and there is only s-wave resonance at zero of H, then

$$\big\| w^{-1}\big(e^{itH} P_{ac} f - \frac{1}{t} F f\big)\big\|_\infty \leq \frac{C}{|t|(\log|t|)^2} \|wf\|_1, \quad |t| > 2,$$

with $w(x) = \log^2(2 + |x|)$. Here $Ff = c\psi\langle f, \psi\rangle$, where ψ is an s-wave resonance function. We also extend this result to matrix Schrödinger and wave equations with potentials under similar conditions. (Received September 14, 2015)

1116-35-860 **Jesse Gell-Redman**, **Andrew Hassell** and **Steve Zelditch*** (zelditch@math.northwestern.edu), Department of Mathematics, Northwestern University, Evanston, IL 60208. *Distribution of phase shifts in semi-classical potential scattering.*

Let $S_V(E, h)$ be the scattering matrix for the semi-classical Schrodinger operator $-h^2\Delta + V$, where V is smooth and compactly supported. Fix E and consider how the eigenvalues of the unitary operator $S_V(E, h)$ depend on h as $h \to 0$. They are called phase shifts, and are well-known to cluster at the point 1 on the unit circle. On intervals of the unit circle away from 1, the main result is that the phase shifts become uniformly distributed as $h \to 0$ if the classical scattering map has zero measure of fixed points and periodic points. Joint work with Jesse Gell-Redman and Andrew Hassell. There is no assumption that the potential is radial, unlike most prior results. (Received September 14, 2015)

1116-35-862 **Natalie Elizabeth Sheils*** (nesheils@umn.edu). *Initial-to-Interface Maps.*
A map from the initial conditions to the values of the function and its first spatial derivative evaluated at the interface is constructed for the heat equation on an infinite domains with n interfaces. The existence of this map allows changing the problem at hand from an interface problem to a boundary value problem which allows for an alternative to the approach of finding a closed-form solution to the interface problem. (Received September 14, 2015)

1116-35-880 **Samantha Xu*** (samxu@illinois.edu), Department of Mathematics, 1409 W. Green St, 273 Altgeld Hall, Urbana, IL 61801. *Applications of Random Fourier Series to Non-linear Dynamics.*
We discuss one of the ways that random Fourier series sheds light on dynamical systems. We focus on the infinite dimensional Hamiltonian systems that arise from dispersive PDEs and analyze their invariant Gibbs measures. We introduce the seminal works of Bourgain as well as current results. (Received September 14, 2015)

1116-35-898 **Lihua Zuo*** (lihuazuo@gmail.com) and **Wei Yu**. *A Fractional Decline Model for Shale Gas Reservoirs.*
In recent several decades, researchers have designed various Decline Curve Analysis (DCA) methods to simulate the flow rate changes. While all DCA methods could be used in some cases under some assumptions and limits, each has its disadvantages and failed cases. In this paper, based on the anomalous diffusion phenomena and long-tail behavior seen in most unconventional reservoirs, the authors proposed a novel Fractional Decline Model (FDM) by using the solutions for fractional diffusion equations. After introducing the mathematical background, the authors proposed the FDM and analyzed its asymptotic properties. Then the authors proposed a four steps scheme to determine the parameters in the FDM. The effectiveness of this method was compared with other existing methods (Arp's, Stretched Exponential Decline Model, Duong Model) for five wells in Fayetteville field. (Received September 15, 2015)

1116-35-899 **Peter Y Pang*** (matpyh@nus.edu.sg). *Stochastic Partial Functional Differential Equations with Delay.*
We will present our recent results on the existence and uniqueness of strong solutions to stochastic partial functional differential equations (SPFDEs) with locally monotone coefficients, locally Lipschitz nonlinearity, and time delay. We note that, while SPFDEs have important applications, they are far less studied than SPDEs and SFDEs. Our results extend and widen the applicability of those of Liu-Röcker (2010), Caraballo et al (2000), and Taniguchi et al (2002). We illustrate the applicability of our results by applying them to a stochastic 2D Navier-Stokes equation with time delay, and a stochastic Nicholson's blowflies equation with time delay. (Received September 15, 2015)

1116-35-954 **Andrej Cherkaev**, **Predrag Krtolica** and **Andrejs E Treibergs*** (treiberg@math.utah.edu), 155 S 1400 E, JWB, Salt Lake City, UT 84112. *Compatibility conditions as a measure of rigidity of discrete structures.* Preliminary report.
An elasticity model for a rigid truss often results in an overdetermined system which requires compatibility conditions on elongations to be solvable. We study how one can regard the number of compatibility conditions as a measure of rigidity. A single compatibility equation is carried by an over-rigid unit substructure. When an edge of the truss is damaged (removed), then a surrounding substructure must be enlarged to carry a compatibility equation. We show that the discrete linearized compatibility conditions limit to the continuum compatibility conditions as the grid is refined. (Received September 21, 2015)

1116-35-956 **Hamid Hezari*** (hamid_hazari@yahoo.com) and **Gabriel Riviere**. *Small scale quantum ergodicity and applications.*
In a joint work with Gabriel Riviere, we improve the L^p bounds of eigenfunctions of the Laplacian on negatively curved manifolds. Our improvement is by a power of logarithm for a full density sequence of eigenfunctions. We also derive improvements on the size of the nodal sets. Our proof is based on a new quantum ergodicity property of independent interest, which holds for families of symbols supported in balls whose radius shrinks at

a logarithmic rate. In the case of a rational torus, this quantum ergodicity property holds in fact for symbols supported in balls with a radius shrinking at a polynomial rate. (Received September 15, 2015)

1116-35-991 **Alejandro Vélez-Santiago*** (avelez@math.ucr.edu). *Global regularity for solutions of nonlocal Robin problems in a class of "bad" domains.*

We consider the solvability of quasi-linear elliptic equations with nonlocal Robin boundary conditions, defined (in the generalized sense) on a bounded $W^{1,p}$-extension domain whose boundary is an upper d-set, for an appropriate $d \geq 0$. Then, we extend the fine regularity theory for weak solutions of the elliptic equations with the above boundary condition, known for bounded Lipschitz domains, to bounded $W^{1,p}$-extension domains whose boundaries are upper d-sets, by showing that such weak solutions are globally Hölder continuous. Consequently, we generalize substantially the class of bounded domains where weak solutions of boundary value problems of Robin type may be uniformly continuous (up to the boundary). (Received September 15, 2015)

1116-35-998 **Rachel Grotheer***, Department of Mathematical Sciences, O-110 Martin Hall, Box 340975, Clemson, SC 29634. *Towards a Better Image: The Hyperspectral Diffuse Optical Tomography Inverse Problem.*

Medical imaging devices play an increasingly significant role in disease diagnosis and detection. Diffuse optical tomography (DOT), which uses a low-energy light source in the visible to near infrared range, has become a popular alternative to traditional imaging techniques. The use of non-ionizing light and its ability to penetrate soft tissue, makes DOT an attractive option for breast cancer detection and neonatal brain imaging, for example. DOT uses the diffusion approximation of the radiative transport equation, an elliptic PDE, to model the diffusion of photons in the tissue during the imaging process. The DOT inverse problem is to create an image by reconstructing a spatial map of the optical parameters of the tissue being imaged given a known source and boundary measurements. In recent years, researchers have sought to apply hyperspectral imaging, the use of hundreds of optical wavelengths in the imaging process, to DOT in order to improve the resolution of the image by adding new information. In hyperspectral DOT (hyDOT), the optical parameters have both spatial and spectral dependence, adding an extra dimension to the inverse problem. We present an overview of how the spectral dependence of the optical parameters affects the image reconstruction problem of hyDOT. (Received September 15, 2015)

1116-35-999 **Adam L Prinkey*** (aprinkey2009@my.fit.edu), 3620 Misty Oak Drive, Melbourne, FL 32901, and **Ugur G Abdulla** (abdulla@fit.edu). *Analysis of Interfaces of the Double Degenerate Nonlinear Reaction-Diffusion Equation.*

We consider the problem of interface development and local behavior of solutions near the interface in the following Cauchy problem for the double degenerate PDE with reaction:

$$u_t = ((u^m)_x \left|(u^m)_x\right|^{p-1})_x - bu^\beta,\ x \in \mathbb{R},\ t > 0;\ u(x,0) = C(-x)_+^\alpha$$

The problem arises in analyzing turbulent filtration through a porous media. The interface behavior is determined by the competition between the diffusion and the reaction terms. The full solution of this problem for the reaction-diffusion equation ($p = 1$) was given in 2000 [Abdulla and King, SIAM J. Math. Anal., 32, 2(2000), 235-260] and 2002 [Abdulla, Nonlinear Analysis, 50, 4(2002), 541-560]. Our aim is to apply the methods of these papers to give a full classification for double degenerate reaction-diffusion equations with ($p > 1, mp > 1$). First we apply a nonlinear scaling method to identify which term dominates in the various regions of the (α, β)-parameter space. We then construct super/subsolutions and apply special comparison theorems in irregular domains to prove explicit formulae for the interface and local solution, with precise estimations up to constant coefficients. (Received September 15, 2015)

1116-35-1055 **Milena Stanislavova*** (stanis@ku.edu), 405, Snow Hall, Department of Mathematics, University of Kansas, Lawrence, KS. *Periodic traveling waves of the short pulse equation: existence and stability.*

We consider various periodic traveling waves solutions of the Ostrovsky/Hunter-Saxton/short pulse equation and its KdV regularized version. For the regularized short pulse model with small Coriolis parameter we describe a family of periodic traveling waves which are perturbation of appropriate KdV solitary waves. We show that these waves are spectrally stable. For the short pulse model, we construct a family of traveling peakons with corner crests. We show that the peakons are spectrally stable as well. (Received September 16, 2015)

1116-35-1102 **David P. Nicholls*** (davidn@uic.edu) and **Benjamin Akers** (benjamin.akers@afit.edu). *Traveling Wave Solutions of Nonlinear Dispersive Wave Equations: Existence, Stability, and Analytic Dependence.*

In this talk we discuss a general framework for establishing existence of traveling wave solutions of nonlinear dispersive wave equations, and investigating their dynamic spectral stability. Our approach is perturbative in nature (where the small parameter is the wave height/slope) and delivers branches of solutions and spectral data which are analytic with respect to this parameter. We outline not only rigorous theorems, but also present robust and highly accurate numerical results for solutions of particular equations. (Received September 17, 2015)

1116-35-1107 **Michael J Ward*** (ward@math.ubc.ca), Dept. of Mathematics, Univ. of British Columbia, Vancouver, BC V6T 1Z2, Canada, and **Phillipe Trinh** (trinh@maths.ox.ac.uk), Mathematical Institute, Oxford University, Andrew Wiles Building, Woodstock Road, Oxford, UK, OX26GG, United Kingdom. *The Slow Dynamics of Localized Spot Patterns for Reaction-Diffusion Systems on the Sphere.*

In the singularly perturbed limit corresponding to large a diffusivity ratio between two components in a reaction-diffusion (RD) system, many such systems admit quasi-equilibrium spot patterns, where the solution concentrates at a discrete set of points in the domain. In this context, we derive and study the differential algebraic equation (DAE) that characterizes the slow dynamics for such spot patterns for the Brusselator RD model on the surface of a sphere. Asymptotic and numerical solutions are presented for the system governing the spot strengths, and we describe the complex bifurcation structure and demonstrate the occurrence of imperfection sensitivity due to higher order effects. Localized spot patterns can undergo a fast time instability and we derive the conditions for this phenomena. In the absence of these instabilities, our numerical solutions of the DAE system for N=2,..,10 spots suggest a large basin of attraction to a small set of possible steady-state configurations. We discuss the connections between our results and the study of point vortices on the sphere, as well as the problem of determining a set of elliptic Fekete points, which correspond to globally minimizing the discrete logarithmic energy for N points on the sphere (Received September 17, 2015)

1116-35-1142 **Nathan Totz*** (totz@math.umass.edu). *Global Well-Posedness of 2D Nonlinear Schrödinger Equations of Indefinite Signature.*

In this talk, we describe a new method to obtain global a priori bounds in time for solutions to nonlinear Schrödinger equations (NLS) on $\mathbb{R}^2$ having power nonlinearities of arbitrary odd degree, and with large initial data in Sobolev space. The method presented here applies to both the usual NLS equations associated to the Laplacian and with a nonlinearity of defocusing sign, as well as to the more difficult so-called "hyperbolic" NLS which is associated to an indefinite signature. The latter is particularly interesting since its long time behavior is to date unknown.

We show that, by rigorously justifying that these equations govern the modulation limit of an artificially constructed equation with an advantageous structure, every subcritical Sobolev norm of the solution increases a priori at most exponentially in time. Global existence in all subcritical Sobolev spaces then follows by standard local well-posedness results for (NLS). (Received September 17, 2015)

1116-35-1224 **Yat Tin Chow*** (ytchow@math.ucla.edu). *Super-resolution in Imaging High Contrast Targets from the Perspective of Scattering Coefficients.*

In this talk, we are concerned with an acoustic / transverse electric (TE) / transverse magnetic (TM) inverse scattering problem. We mathematically analyze the experimentally-observed phenomenon of super-resolution in imaging high-contrast targets based on the concept of scattering coefficient.

We first introduce the notion of scattering coefficients for heterogeneous media and analyze this entity to help us understand the exponential ill-posed-ness of the problem at a fixed frequency. Based on this novel concept of scattering coefficients, sensitivity and resolution analysis are performed to mathematically assess the reconstruction quality and justify the super-resolution phenomenon in imaging some high contrast targets. We illustrate our main findings with a variety of numerical examples. These findings may help in developing resonant structures for resolution enhancement.

This talk is based on joint works with Habib Ammari (ETH) and Jun Zou (CUHK). (Received September 18, 2015)

1116-35-1243 **Derek L. Smith*** (`dls@math.ucsb.edu`). *Propagation of regularity of solutions to quasilinear Korteweg-de Vries type equations.*

We consider solutions $u = u(x,t)$ to quasilinear equations of the form

$$\partial_t u + a(u, \partial_x u, \partial_x^2 u)\partial_x^3 u + f(u, \partial_x u, \partial_x^2 u) = 0, \quad x, t \in \mathbb{R},$$

where a and f are smooth in all variables and $1/\kappa \leq a(\cdots) \leq \kappa$ for some $\kappa > 1$. Suppose that $u_0 \in H^7(\mathbb{R})$ is additionally contained in $H^k(0,\infty)$ for integer $k > 7$, that is, the function possesses k-derivatives when restricted to the half-line $(0,\infty)$. Then for positive times the solution also possesses k-derivatives on any half-line, i.e. $u(\cdot,t) \in H^k(x_0,\infty)$ for all $x_0 \in \mathbb{R}$. In other words, certain singularities travel to the left with infinite speed. This propagation of regularity result has been established for the k-generalized KdV equation and Benjamin-Ono equation; this work demonstrates that the result is more general in that it does not depend on the integrable character of the model. This result is a portion of a joint work with F. Linares and G. Ponce. (Received September 18, 2015)

1116-35-1293 **Katie L Oliveras*** (`oliveras@seattleu.edu`), Seattle University, Mathematics Department, 901 12th Ave, Seattle, WA 98122, and **Vishal Vasan**. *Stability of Waves with Vorticity.*

Euler's equations describe the dynamics of gravity waves on the surface of an ideal fluid with arbitrary depth. In this talk, we discuss the stability of periodic traveling wave solutions for the full set of Euler's equations with constant vorticity via a generalization of a non-local formulation of the water wave problem due to Ablowitz, et al., and Ashton & Fokas. We determine the spectral stability for the periodic traveling wave solution by extending Fourier-Floquet analysis to apply to the non-local problem. We will discuss some interesting and new relationships between the stability of the traveling wave with respect to long-wave perturbations and the structure of the bifurcation curve for small amplitude solutions. (Received September 18, 2015)

1116-35-1329 **Adam Larios*** (`alarios@unl.edu`), **Mark Petersen** (`mpetersen@lanl.gov`), **Edriss S Titi** (`titi@math.tamu.edu`) and **Beth Wingate** (`b.wingate@exeter.ac.uk`). *Analytical and Computational Results for Blow-Up Criteria for the 3D Incompressible Euler Equations Based on the Voigt Regularization.*

We will discuss a computational study of two new blow-up criteria for the 3D incompressible Euler equations, based on the 3D Euler-Voigt equations. Traditional computational searches for blow-up have analyzed the enstrophy coming from the 3D Euler equations themselves, which are not known to be globally well-posed, and moreover, are extremely difficult to simulate accurately. In contrast, the new blow-up criteria described here rely only on analyzing the enstrophy of the 3D Euler-Voigt equations, which are known to be globally well-posed and are less computationally intensive to simulate. (Received September 18, 2015)

1116-35-1379 **Vishal Vasan*** (`vishal.vasan@icts.res.in`), International Centre for Theoretical Sciences, TIFR Centre Building, IISc Campus, Subedarpalya, Malleshwaram, Bangalore, Karnataka 560012, India, **Diane Henderson**, 218 McAllister Bldg, Department of Mathematics, Penn State University, University Park, PA 16802, and **Harvey Segur**, Department of Applied Mathematics, 526 UCB, University of Colorado, Boulder, CO 80309. *Linear instability for a model of wind-generated gravity waves.* Preliminary report.

The study of wind driven surface gravity waves is one of the oldest and challenging topics in fluid flow. The precise nature of the transfer of momentum from wind to water involves a complicated interaction between the driving wind and viscous vortical flow of wind and water.

In this talk I will present a simple model for this interaction leading to an exact solution for the base flow. We then perturb the base flow and study the associated linear stability problem. Unlike the traditional approach, the base flow is time dependent and hence the linearised equations do not lead to a simple eigenvalue problem. Instead the equations will be analysed using the Uniform Transform Method (UTM). Recent work by Sheils and Deconinck has extended UTM to consider interface problems of which the present model is an example. In particular, the talk will present results on UTM applied a fourth order, mixed partial derivative equation. The ultimate goal is to derive an estimate of the fastest growing horizonal mode for the given base flow. (Received September 19, 2015)

1116-35-1389 **Triet M Le*** (`triet.m.le@nga.mil`), Springfield, VA 22150. *Local Scales.*

In this talk, I will go over a notion of measuring local scales or oscillations of functions and rectifiable measures via convolution with a radially symmetric kernel of various scales (e.g. Gaussian or Poisson kernel.) Certain boundedness of these local scale measurements can be used to quantify the smoothness of the objective object. (Received September 19, 2015)

1116-35-1390 **Petronela Radu**, **Daniel Toundykov** and **Jeremy Trageser*** (jtrageser@gwu.edu). *A fourth-order nonlocal operator and its connection with the local counterpart.*

This talk will discuss a nonlocal operator as a natural generalization to the biharmonic operator that arises in thin-plate theory. The operator is built in the nonlocal calculus framework and connects with the recent theory of peridynamics. This framework enables us to consider non-smooth approximations to fourth-order elliptic boundary value problems. For these systems we will introduce nonlocal formulations of the clamped and hinged boundary conditions that are well-defined even for irregular domains. Results on well-posedness of these nonlocal problems and regularity of the operator will be given. Lastly, a proof outline will be provided which demonstrates that when the interaction horizon goes to zero, solutions of the nonlocal problems convergence strongly in L^2 to functions in $W^{1,2}$. For regular domains we identify these limits as the weak solutions of the corresponding classical elliptic boundary value problems. (Received September 19, 2015)

1116-35-1411 **Yang Yang*** (yang926@purdue.edu). *Thermoacoustic Tomography in Bounded Domains.*

We study the mathematical model of thermoacoustic tomography in bounded domains with perfect reflecting boundary conditions. We propose an averaged sharp time reversal algorithm which solves the problem with an exponentially converging Neumann series. Numerical reconstruction is implemented in both full boundary data and partial boundary data cases. This is joint work with Plamen Stefanov. (Received September 19, 2015)

1116-35-1501 **Luan T Hoang*** (luan.hoang@ttu.edu), Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409. *On non-Darcy fluid flows in porous media.*

The most common equation to describe fluid flows in porous media is the Darcy law. However, this linear equation is not valid in many situations, particularly, when the Reynolds number is large. In that case, nonlinear Forchheimer equations are used in place of the Darcy Law. In this talk, we will survey the Forchheimer models and their generalizations for compressible fluids in homogeneous and heterogeneous porous media. We derive various estimates for the pressure and its spatial and time derivatives, especially for large time. We also establish the continuous dependence on the initial and boundary data, as well as structural stability with respect to the Forchheimer coefficients. (Received September 20, 2015)

1116-35-1506 **Ting Zhou*** (t.zhou@neu.edu), 360 Huntington Ave., Boston, MA 02130. *ON UNIQUENESS OF AN INVERSE PROBLEM FOR THE TIME-HARMONIC MAXWELL EQUATIONS.*

The inverse boundary value problem for the time-harmonic Maxwell equations is a nonlinear problem to determine electromagnetic parameters of the medium, namely the magnetic permeability, the electric permittivity and the conductivity, on a bounded domain using the measurements of the electromagnetic fields on the boundary of the domain. I will present both the boundary uniqueness and interior uniqueness of the parameters, where we assume that the unknown parameters are described by continuously differentiable functions. The key ingredient in proving the uniqueness is the complex geometrical optics (CGO) solutions. (Received September 20, 2015)

1116-35-1508 **Dana Mendelson*** (dana@math.mit.edu). *Global behavior and non-squeezing for the NLKG.*

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1116-35-1546 **Alexey Sukhinin*** (asukhinin@smu.edu), Southern Methodist University, Department of Mathematics, Dallas, TX 75275. *Spatial and temporal resolution analysis of collapsing high intensity pulses.* Preliminary report.

High intensity laser pulse tends to self focus during propagation in nonlinear media such as atmosphere. This fact is described by (2+1)D Nonlinear Schrodinger Equation (NLS). In my talk I will discuss self-focusing of two co-propagating high intensity pulses, their temporal dynamics and filamentation process. (Received September 20, 2015)

1116-35-1553 **Joshua Ballew** and **Gautam Iyer*** (gautam@math.cmu.edu), Dept of Math. Sci, WEH #6113, Carnegie Mellon University, Pittsburgh, PA 15213, and **Robert L Pego**. *Bose-Einstein condensation in a Kompaneets model for low density plasmas.*

In low density (or high temperature) plasmas, Compton scattering is the dominant process responsible for energy transport. Kompaneets '56 derived a non-linear degenerate parabolic equation for the photon energy distribution. In this talk we consider a simplified model obtained by neglecting diffusion of the photon number density. The equation now becomes a nonlinear hyperbolic PDE with a position dependent flux for which we completely describe the dynamics. While the total number of photons are formally conserved, we show that they will decrease in certain situations through an out flux of photons with 0 energy. This corresponds to the formation of a Bose-Einstein condensate. Further, we find an infinite family of non-trivial stationary solutions which the system approaches after long time. This is joint work with J. Ballew and R. L. Pego. (Received September 20, 2015)

1116-35-1558 **Dominique Zosso*** (zosso@math.ucla.edu), **Braxton Osting**, **Mengqi Xia** and **Stanley J. Osher**. *A fast primal-dual method for the obstacle problem.*

We solve the discrete obstacle problem using a primal-dual hybrid gradients (PDHG) method. We reformulate the a convex minimization as a primal-dual problem, based on the Legendre-Fenchel transform of the surface area and the Dirichlet energy, respectively. The resulting saddle-point problems are solved by the PDHG method, which consists of three iterative steps: the dual and primal variable proximal updates, and an extra-gradient step (overrelaxation) of the primal variable. The proximal updates can be solved efficiently, and in the linear case even particularly so.

Since this method requires no matrix inversions or explicit identification of the contact set it achieves state-of-the-art precision with a speed up of 1-2 orders of magnitude. In addition to being efficient, the proposed algorithm benefits from a highly interesting physical interpretation: over iterations, there is build-up of a certain "momentum" that accelerates the updates beyond the limits of the usual CFL step-size criteria. Similarly, the scheme can be brought into a form that is highly reminiscent of a damped wave equation.

The derivation of this method is disciplined and can be adapted to a wide range of other constrained convex optimization problems and the solution of elliptic PDE. (Received September 20, 2015)

1116-35-1559 **Agnieszka Swierczewska-Gwiazda*** (aswiercz@mimuw.edu.pl), University of Warsaw, Institute of Applied Mathematics and Mechanic, Krakowskie Przedmiescie 26/28, 00-927 Warszawa, Poland. *On ill-posed hyperbolic systems of Euler type.*

We consider several modifications of the Euler system of fluid dynamics including the Savage-Hutter system describing granular flows and the pressureless variant driven by non-local interaction repulsive-attractive and alignment forces in the space dimension $N = 2, 3$. The second type of models arise in the study of self-organisation in collective behavior modelling for animals and crowds. We will concentrate on showing that there exist infinitely many weak solutions to these problems. Our approach is based on the method of convex integration. We also consider the class of dissipative solutions satisfying, in addition, the associated global energy balance (inequality). We identify a large set of initial data for which the problem admits infinitely many dissipative weak solutions. The talk is based on the following results:

[1] J.A. Carrillo, E. Feireisl, P. Gwiazda, and A. Swierczewska Gwiazda.Non-uniqueness of weak solutions for Euler systems with non-local interactions, submitted

[2] E. Feireisl, P. Gwiazda, and A. Swierczewska Gwiazda. On weak solutions to the 2d Savage-Hutter model of the motion of a gravity driven avalanche flow, arXiv:1502.06223, to appear in Comm. in Partial Differential Equations (Received September 20, 2015)

1116-35-1561 **Piotr Gwiazda*** (pgwiazda@mimuw.edu.pl), University of Warsaw, Institute of Applied Mathematics and Mechanic, Krakowskie Przedmiescie 26/28, 00-927 Warszawa, Poland. *On measure-valued solutions to compressible Euler and similar systems.*

The theory for gravity driven avalanche flows is qualitatively similar to that of compressible fluid dynamics. I will present one of the models describing flow of granular avalanches - the Savage-Hutter model. Originally the model was derived in one-dimensional setting. Our interest is mostly directed to two-dimensional extension. Solutions of the Savage-Hutter system develop shock waves and other singularities characteristic for hyperbolic system of conservation laws. Accordingly, any mathematical theory based on the classical concept of smooth solutions fails as soon as we are interested in global-in-time solutions to the system. I will present the concept of measure-valued solutions (generalization by DiPerna and Majda). Then, I will discuss the issue of weak-strong uniqueness. The talk is based on the following results:

[1] P. Gwiazda On measure-valued solutions to a two-dimensional gravity-driven avalanche flow model. Math. Methods Appl. Sci. 28 (2005), no. 18, 2201-2223.

[2] P. Gwiazda, A. Swierczewska-Gwiazda, and E. Wiedemann. Weak-strong uniqueness for measure-valued solutions of the Savage-Hutter equations, to appear in Nonlinearity, arXiv:1503.05246 (Received September 20, 2015)

1116-35-1583 **John Gemmer*** (john_gemmer@brown.edu), Division of Applied Mathematics, Brown University, 182 George St., Providence, RI 02906, **Shankar Venkataramani** (shankar@math.arizona.edu), Department of Mathematics, University of Arizona, 617 N. Santa Rita Ave., Tucson, AZ , and **Eran Sharon** (erans@vms.huji.ac.il), Racha Institute of Physics, Hebrew University of Israel, Jerusalem, Israel. *Isometric Immersions and Self Similar Buckling in Non-Euclidean Elastic Sheets.*

The edge of torn elastic sheets and growing leaves often form a hierarchical buckling pattern. Within non-Euclidean plate theory this complex morphology can be understood as low bending energy isometric immersions of hyperbolic Riemannian metrics. In this talk we show that for a large class of growth profiles there exist periodic and self-similar deformations of the sheet with vanishing in-plane strain. The construction of these surfaces consists of gluing together local solutions of an isometric immersion problem along "lines of inflection' and "branch points' in such a manner that the resulting surface has finite bending energy. For hyperbolic non-Euclidean sheets, complex wrinkling patterns are thus possible and our results identify the key role the regularity of the isometric immersion plays in determining the global structure of a non-Euclidean elastic sheet. (Received September 20, 2015)

1116-35-1595 **Ryan G Halabi** and **John K Hunter*** (jkhunter@ucdavis.edu), Department of Mathematics, University of California at Davis, Davis, CA 95616. *Nonlinear Surface Plasmons.*

Surface plasmons (SPs) are electromagnetic surface waves that propagate on an interface between a conductor and an insulator and decay exponentially away from the interface. In the high-wavenumber limit, SPs are quasi-static with constant linearized frequency, which results in complicated spatially nonlocal, nonlinear dynamics. We derive asymptotic equations for weakly nonlinear, quasi-static SPs on a planar interface between isotropic materials with a cubic Kerr nonlinearity. The asymptotic equations are Hamiltonian and couple the projections of the electric field on the interface onto its positive and negative wavenumber components. We discuss the well-posedness of these asymptotic equations and show that nonlinearity leads to strong spatial focusing of SPs. (Received September 20, 2015)

1116-35-1618 **Philip Isett*** (isett@mit.edu). *Regularity in time along the coarse scale flow for the incompressible Euler equations.*

A remarkable feature of known, nonstationary solutions to incompressible Euler is the phenomenon that fine scale velocity fluctuations are carried along the coarse scale flow of the solution. We will discuss how this phenomenon is captured in the proofs of several time regularity results that hold for incompressible Euler flows (possibly with low regularity). Among these results are a proof of the smoothness of trajectories in a regime just below the threshold for well-posedness, and improved time regularity results for the pressure and kinetic energy profile. We will also discuss a strengthening of Onsager's conjecture proposed in the work, which offers an explanation as to why the failure of anomalous dissipation for Euler flows with spatial regularity less than 1/3 should be generic. (Received September 20, 2015)

1116-35-1631 **Bruno Giuseppe Poggi Cevallos*** (poggi008@umn.edu), Minneapolis, MN 55455, and **Ugur G. Abdulla** (abdulla@fit.edu), 150 West University Blvd., Crawford 204, Melbourne, FL 32901. *Optimal Control of the Multiphase Stefan Problem.*

We consider the inverse multiphase Stefan problem, where information on the heat flux on the fixed boundary is missing and must be found along with the temperature and free boundaries. Optimal control framework is pursued, where boundary heat flux is the control, and optimality criteria consists of the minimization of the L_2-norm declination of the trace of the solution to the Stefan problem from the temperature measurement on the fixed right boundary. State vector solves multiphase Stefan problem in a weak formulation, which is equivalent to Neumann problem for the quasilinear parabolic PDE with discontinuous coefficient. Full discretization through finite differences is implemented and discrete optimal control problem is introduced. We prove well-posedness in Sobolev spaces framework and convergence of discrete optimal control problems to the original problem both with respect to cost functional and control. Along the way the convergence of the method of finite differences for the weak solution of the multiphase Stefan problem is proved. The proof is based on achieving a uniform L_∞ bound, and $W_2^{1,1}$-energy estimate for the discrete multiphase Stefan problem. (Received September 20, 2015)

1116-35-1645 **Christoph Koutschan** (christoph.koutschan@ricam.oeaw.ac.at), Johann Radon Institute for Computational and, Applied Mathematics, Altenberger Straße 69, A-4040, Linz, Austria, **Erwin Suazo** (erwin.suazo@utrgv.edu), 1201 W. University Drive, Edinburg, TX TX 78541, and **Sergei K. Suslov*** (sks@asu.edu), Tempe, AZ 85287-1804, Tempe, AZ 85287-1. *Fundamental Laser Modes in Paraxial Optics: From Computer Algebra and Simulations to Experimental Observation.*

We study multiparameter solutions of the inhomogeneous paraxial wave equation in a linear and quadratic approximation which include oscillating laser beams in a parabolic waveguide, spiral light beams, and other important families of propagation invariant laser modes in weakly varying media. (Received September 20, 2015)

1116-35-1658 **Jennifer L Mueller*** (mueller@math.colostate.edu), Department of Mathematics, Colorado State University, Fort Collins, CO 80523. *D-bar Methods for Functional Pulmonary Imaging with Electrical Impedance Tomography.*

D-bar methods are a class of direct (noniterative) reconstruction methods for EIT based on complex geometrical optics solutions to a partial differential equation related to the governing mathematical model for the physical problem. In this talk, new advances in their practical use for functional pulmonary imaging will be described, and examples of reconstructions from clinical data will be shown. (Received September 21, 2015)

1116-35-1665 **Nathaniel Trask**, **Martin Maxey**, **Kyungjoo Kim**, **Mauro Perego**, **Michael L Parks*** (mlparks@sandia.gov), **Kai Yang**, **Jinchao Xu**, **Wenxiao Pan** and **Alex Tartakovsky**. *A Massively Parallel Scalable Implicit SPH Solver.*

The most commonly used Smoothed Particle Hydrodynamics (SPH) implementation for solving the compressible Navier-Stokes (NS) equations is the Weakly Compressible SPH (WCSPH) method. This conventional approach suffers from convergence issues resulting from the spatial discretization – running WCSPH at larger scales to refine the discretization does not improve the quality of the solution. Further, small timesteps may be required, as dictated by the CFL condition, requiting substantial computational expense. To address these issues, we utilize local correction tensors in the context of an implicit SPH method, providing second order convergence while allowing for much larger timesteps. We provide a scalable massively parallel implementation of the resulting Implicit Smoothed Particle Hydrodynamics (ISPH) method in the LAMMPS molecular dynamics code, utilizing Krylov solvers and algebraic multigrid preconditioners from the Trilinos library, and demonstrate the method on several problems of interest. (Received September 21, 2015)

1116-35-1670 **Robert M. Strain** and **Tak Kwong Wong*** (takwong@math.upenn.edu). *Axisymmetric flow of ideal fluid moving in a narrow domain: a study of the axisymmetric hydrostatic Euler equations.*

In this talk, we will introduce a new model to describe the leading order behavior of an ideal and axisymmetric fluid moving in a very narrow domain. Under a new sign condition, the formal derivation and mathematical analysis of this model will be discussed. (Received September 21, 2015)

1116-35-1719 **Kyle Claassen** and **Mathew A. Johnson*** (matjohn@ku.edu), University of Kansas, Department of Mathemaitcs, 405 Snow Hall, 1460 Jayhawk Blvd., Lawrence, KS 66045. *Nondegeneracy and Stability of Periodic Standing Waves in Fractional NLS Equations.* Preliminary report.

In the stability and blowup for traveling or standing waves in nonlinear Hamiltonian dispersive equations, the nondegeneracy of the linearization about such a wave is of paramount importance. That is, one must verify the kernel of the second variation of the Hamiltonian is generated by the continuous symmetries of the PDE. The proof of this property can be far from trivial, especially in cases where the dispersion admits a nonlocal description where shooting arguments, Sturm-Liouville theories, and other ODE methods may not be applicable. In this talk, we discuss the nondegeneracy of the linearization associated to antiperiodic constrained energy minimizers in class of defocusing NLS equations with fractional dispersion. Key to our analysis is the development of a ground state theory and oscillation theory for linear periodic Schrodinger operators with antiperiodic boundary conditions. The antiperiodic nature of the problem greatly complicates the analysis, as even in the classical (local) case linear Schrodinger operators with periodic potentials need not have simple antiperiodic ground states. As an application, we obtain the nonlinear (orbital) stability of such antiperiodic standing waves with respect to antiperiodic perturbations. (Received September 21, 2015)

1116-35-1736 **Zhongwei Shen** and **Shu Gu*** (gushu0329@uky.edu). *Homogenization of Stokes systems and Uniform Regularity Estimates.*

In this talk, we study the uniform regularity estimates for a family of Stokes systems with rapidly oscillating periodic coefficients. By using compactness method, we here establish interior Lipschitz estimates for velocity and L^∞ estimates for the pressure as well as a Liouville property for solutions in $\mathbb{R}^d$. We also obtain the boundary $W^{1,p}$ estimates in a bounded C^1 domain for any $1 < p < \infty$. (Received September 21, 2015)

1116-35-1739 **Ru-Yu Lai*** (rylai@umn.edu), 127 Vincent Hall, 206 Church St. SE, Minneapolis, MN 55455. *Increasing stability in inverse problems.*

The problem of recovering the conductivity from boundary measurements has been studied since the 1980s. It is well known that a logarithmic stability estimate holds and is optimal. However, the logarithmic stability makes it difficult to design reliable reconstruction algorithms in practice since small errors in the data of the inverse problem result in large error in numerical reconstruction of physical properties of the medium. It has been observed numerically that the stability improves if one increases the frequency in some cases. The main purpose of this talk is to discuss several results which rigorously demonstrate the increasing stability behavior in different settings. (Received September 21, 2015)

1116-35-1749 **Aseel Farhat** and **Evelyn M. Lunasin*** (lunasin@usna.edu), United States Naval Academy, Annapolis, MD 21403, and **Edriss S. Titi**. *Data Assimilation algorithm for 3D Benard convection in porous media employing only temperature measurements.*

In this paper we propose a continuous data assimilation (downscaling) algorithm for the Bénard convection in porous medium using only coarse mesh measurements of the temperature field. In this algorithm, we incorporate the observables as a feedback (nudging) term in the evolution equation of the temperature. We show that under an appropriate choice of the nudging parameter and the size of the mesh, and under the assumption that the observed data is error free, the solution of the proposed algorithm approaches at an exponential rate asymptotically in time to the unique exact unknown reference solution of the original system, associated with the observed (finite dimensional projection of) temperature data. Moreover, in the case where the observational measurements are not error free, one can estimate the error between the solution of the algorithm and the exact reference solution of the system in terms of the error in the measurements.

This is joint work with Aseel Farhat and Edriss S. Titi (Received September 21, 2015)

1116-35-1762 **Peter Constantin***, Department of Mathematics, Princeton University, Fine Hall, Washington Road, Princeton, NJ 08544, and **Mihaela Ignatova**, Department of Mathematics, Princeton University, Fine Hall, Washington Road, Princeton, NJ 08544. *Nonlocal equations, electroconvection.*

We will discuss recent results concerning nonlocal equations in bounded domains, with application to electroconvection. (Received September 21, 2015)

1116-35-1766 **Jerome Goddard II*** (jgoddard@aum.edu), Department of Mathematics & Computer Science, Auburn University Montgomery, P.O. Box 244023, Montgomery, AL 36124, and **R. Shivaji** (shivaji@uncg.edu). *Modeling the effects of U-shaped density dependent dispersal via reaction diffusion equations.*

Dispersal is broadly defined as movement from one habitat patch to another and typically is considered to encompass three stages: 1) emigration, 2) inter-patch movement, & 3) immigration. Dispersal can have both beneficial and detrimental effects on the persistence of spatially structured systems. Recent empirical results indicate that certain organisms' emigration from a patch is dependent on their own density—known as density dependent emigration. In fact, a U-shaped relationship between density and emigration has been observed in several organisms in field studies. To date, little is known about the patch-level consequences of such a dispersal strategy. In this talk, we will discuss a population model built upon the reaction diffusion framework that is designed to model the patch-level effects of U-shaped density dependent emigration. In particular, we will discuss the existence and stability properties of positive steady state solutions to this model for both one- and two-dimensional habitat patches. A brief discussion regarding ecological conclusions of the model's predictions will also be included. Several methods from nonlinear analysis will be employed such as time map analysis (quadrature method), sub-super solutions, and linearized stability analysis. (Received September 21, 2015)

1116-35-1769 **Lidia Mrad*** (lmrad@purdue.edu) and **Daniel Phillips**. *Dynamic Analysis of Chevron Structures in Liquid Crystal Cells.*

Liquid crystals are intermediate phases between an isotropic liquid and a crystalline solid. Their molecules posses flow-like properties of liquids and structured order of solids, a combination that renders them useful in optical and display devices, for example. A Chiral Smectic C phase develops in liquid crystals as molecules self-organize into layers with a tilt tracing a helix across layers. In a thin cell, these layers deform into V-shaped layers exhibiting a chevron structure. This defect formation inhibits the use of smectics in design, though they promise better quality than nematics which are currently used. We study the molecular reorientation dynamics of this structure between two stable states caused by an applied electric field. Our model is based on the Chen-Lubensky energy and we use an iterative minimization technique to construct a sequence of discrete-in-time gradient flows. We establish the existence of a continuous gradient flow that describes the switching process. Moreover, we prove the uniqueness of the solution independent of the choice of minimizers at each time step as well as independent of the particular discretization used. (Received September 21, 2015)

1116-35-1792 **Stephen B Robinson*** (sbr@wfu.edu) and **Mauricio Rivas**. *Eigencurves and Resonance.*

This paper describes the existence of (weak) solutions of the nonlinear boundary value problem

$$\begin{aligned} -\Delta u &= \mu\, m_2 u + f(x,u) && \text{in } \Omega \\ \frac{\partial u}{\partial \nu} + b(x)u &= \lambda\, m_1 u + g(x,u) && \text{on } \partial\Omega \end{aligned} \tag{1}$$

where Ω is a smooth bounded region in $\mathbb{R}^N$, $(\lambda,\mu)\in\mathbb{R}^2$, f and g are Caratheodory functions satisfying sublinear growth conditions, and the coefficient function $b(x)$ and the weights m_1, m_2 lie in appropriate L^p-spaces. In particular we characterize *eigencurves* $(\lambda, \mu_n(\lambda))$ associated with the problem and then prove existence for resonance problems subject to a generalized Landesman-Lazer condition. Our results were motivated by, and are complementary to, the recent work of Mavinga and Nkashama. (Received September 21, 2015)

1116-35-1811 **Alfonso Castro*** (castro@g.hmc.edu), Mathematics, Harvey Mudd College, Claremont, CA 91711, and **Rosa Pardo**. *A priori estimates for positive solutions to second order elliptic boundary problems.* Preliminary report.

A priori estimates for positive solutions to second order semilinear elliptic boundary value problems make hypotheses on the geometry of region under consideration and the nonlinearity, f. The use of moving plane arguments allows for the convexity of the region to replace some assumptions on $f(s)/s^{(N+2)/(N-2)}$. We will show that for regions with *convex-starlike* boundaries such assumptions may be eliminated. Examples of regions with convex-starlike boundary are *ring-like* regions, that is regions of the form $\Omega = \Omega_1 - \Omega_2$, with Ω_1 convex, Ω_2 starlike, and $\bar{\Omega}_2 \subset \Omega_1$. (Received September 21, 2015)

1116-35-1842 **Saulo Orizaga*** (sorizaga@math.arizona.edu), Tucson, AZ 85735, and **K. Glasner** (kglasner@math.arizona.edu). *Improving the accuracy of convexity splitting methods for gradient flow equations.*

This paper introduces numerical time discretization methods which significantly improve the accuracy of the convexity-splitting approach of Eyre (*Unconditionally gradient stable time marching the Cahn-Hilliard equation*, MRS Proceedings, vol. 529, 1998), while retaining the same numerical cost and stability properties.

A first order method is constructed by iteration of a semi-implicit method based upon decomposing the energy into convex and concave parts. A second order method is also presented based on backwards differentiation formulas. Several extrapolation procedures for iteration initialization are proposed. We show that, under broad circumstances, these methods have an energy decreasing property, leading to good numerical stability.

The new schemes are tested using two evolution equations commonly used in materials science: the Cahn-Hilliard equation and the phase field crystal equation. We find that our methods can increase accuracy by many orders of magnitude in comparison to the original convexity-splitting algorithm. In addition, the optimal methods require little or no iteration, making their computation cost similar to the original algorithm. (Received September 21, 2015)

1116-35-1863 **AYNUR BULUT*** (abulut@umich.edu), 530 Church Street, Ann Arbor, MI 48109. *Negative energy blowup for the focusing Hartree hierarchy via identities of virial and localized virial type.*

In this talk we report on new negative energy blowup results for the Hartree hierarchy, an infinitely coupled system of PDEs arising from the study of many-body quantum mechanics. The results are obtained both with and without an assumption of finite variance on the initial data with the key tools involved are virial identities for the Hartree hierarchy, together with localized variants of these identities. The most delicate case of the analysis is the proof without finite variance – here, we use a suitable quantum de Finetti theorem and a carefully chosen truncation lemma allowing for the control of additional terms appearing from the localization procedure. (Received September 21, 2015)

1116-35-1894 **Maya Chhetri***, Department of Mathematics and Statistics, UNC Greensboro, Greensboro, NC 27402, and **Petr Girg**. *Elliptic systems with exponential growth in dimension two.*

We consider an elliptic system of the form

$$\left.\begin{aligned} -\Delta u &= \lambda f(v) \quad \text{in} \quad \Omega; \\ -\Delta v &= \lambda g(u) \quad \text{in} \quad \Omega; \\ u = 0 &= v \quad \text{on} \quad \partial\Omega, \end{aligned}\right\}$$

where $\lambda \in \mathbb{R}$ is the bifurcation parameter and $\Omega \subset \mathbb{R}^2$ is a bounded, convex domain with smooth boundary $\partial\Omega$. The nonlinearities $f,\ g : \mathbb{R} \to (0, \infty)$ are non-decreasing Lipschitz continuous functions that depend exponentially on v and u, respectively. We discuss the existence of positive solution for $\lambda > 0$ small using bifurcation theory. (Received September 21, 2015)

1116-35-1921 **Sebastian Acosta*** (sebastian.acosta@bcm.edu). *Photoacoustic tomography taking into account thermoelastic attenuation.* Preliminary report.

We consider a mathematical model for photoacoustic imaging to take into account attenuation due to thermoelastic dissipation. The propagation of acoustic waves is governed by a scalar wave equation coupled to the heat equation for the excess temperature. We seek to recover the initial acoustic profile from knowledge of boundary measurements. This inverse problem is a special case of boundary observability for a thermoelastic system. This leads to the use of control/observability tools to prove the unique and stable recovery of the initial acoustic profile in the weak thermoelastic coupling regime. We propose and implement (numerically) a reconstruction algorithm. (Received September 21, 2015)

1116-35-1946 **Peter Polacik*** (polacik@math.umn.edu). *On the quasiconvergence property of solutions of parabolic equations on the real line.*

We examine bounded solutions of semilinear parabolic equations on the real line. Such a solution is quasiconvergent, if, as time goes to infinity, it approaches a set of steady states in a localized topology. As we show, not all bounded solutions are quasiconvergent. Our goal then is to identify classes of initial data which yield quasiconvergent solutions. (Received September 21, 2015)

1116-35-1952 **Dmitry Zakharov*** (dvzakharov@gmail.com), 251 Mercer Street, New York, NY 10002. *Non-periodic bounded potentials of the Schrödinger operator and solutions of KdV.*

We propose a new method of constructing bounded non-vanishing potentials of the one-dimensional Schrödinger operator. The potentials are constructed by considering the closure of the set of reflectionless Bargmann potentials and are described by a non-local Riemann–Hilbert problem, which can be solved numerically. Such potentials have the spectral structure of finite-gap potentials, but are not in general quasi-periodic. From a physical point of view, these potentials allow ballistic transport of wave packets, and hence describe one-dimensional aperiodic conductors. The corresponding solutions of the KdV hierarchy are bounded but non-vanishing at infinity, and become stochastic under time evolution. (Received September 22, 2015)

1116-35-1974 **N. Mavinga*** (mavinga@swarthmore.edu) and **M. Nkashama** (nkashama@math.uab.edu). *Bifurcation and multiplicity of strong solutions for elliptic equations with nonlinear boundary conditions.*

We present multiplicity results for solutions of second order elliptic partial differential equations with nonlinear boundary conditions. We impose asymptotic resonance conditions type with respect to the Steklov spectrum on the boundary nonlinearity and use the Lyapunov-Schmidt procedure to establish a priori estimates. We prove the results using topological degree and bifurcation from infinity arguments. (Received September 21, 2015)

1116-35-1995 **Thomas C. Sideris*** (sideris@math.ucsb.edu), Department of Mathematics, University of California, Santa Barbara, CA 93106. *Global behavior of the free boundary of an ideal fluid surrounded by vacuum in the class of affine deformations.*

We consider solutions of the initial value problem for the three-dimensional compressible and incompressible Euler equations with physical vacuum boundary condition. Local well-posedness has been established in a series of papers by various authors. We shall discuss the global existence and asymptotic behavior of solutions in the class of affine deformations. Here the free boundary of the fluid domain is ellipsoidal, and its diameter grows at a rate proportional to time. After rescaling, a wide variety ellipsoidal configurations can be realized, including degenerate cases. (Received September 21, 2015)

1116-35-2014 **Georg Hetzer*** (hetzege@auburn.edu) and **Lourdes Tello** (l.tello@upm.es). *A Two-Species Competition System with Slow Diffusion.* Preliminary report.

Two-species competition is considered under homogeneous Neumann conditions in case that dispersal is modeled by a p-Laplacian with $p > 2$ and the reaction terms are spatially homogeneous and differ only by a constant factor. We show that each strictly positive solution will converge to a strictly positive equilibrium. (Received September 21, 2015)

1116-35-2033 **Mae L Markowski*** (mmarkows@masonlive.gmu.edu), Fairfax, VA 22030. *A fractional diffusion model for electric signal propagation through cardiac muscle tissue.*

It is well known that cardiac muscle tissue is heterogenous. However, the standard model used to describe electric current propagation in cardiac muscle tissue, an extension of the diffusion equation, assumes the tissue is perfectly homogenous. We propose a fractional space-time diffusion model, which will better account for the spatial complexity of the region. (Received September 21, 2015)

1116-35-2059 **Slim Ibrahim*** (ibrahims@uvic.ca), Department of Mathematics & Statistics, University of Victoria, PO BOX 1700 STN CSC, Victoria, BC V8W 2Y2, Canada, **Pierre-Gilles Lemarie**, Evry, France, and **Nader Masmoudi**, NY. *Title: Existence and Stability of small time-periodic solutions of the Navier-Stokes-Maxwell system.*

Abstract: We study the Navier-Stokes system coupled with Maxwell's equations via the Lorenz force. In the presence of small and time-periodic external forces, we construct a time-periodic solution in a "critical" type space. We also show the stability of this class of solutions. This is a join work with P.-G. Lemarie and N. Masmoudi (Received September 21, 2015)

1116-35-2079 **Vera Mikyoung Hur*** (verahur@math.uiuc.edu), 1409 W Green Street, Urbana, IL 60801. *Instabilities in shallow water models.*

I will speak on the wave breaking and the modulational instability in the Whitham equation, which combines the dispersion relation of water waves and the nonlinearity of the shallow water equations. I will then discuss their extensions to bi-directional Whitham, or Boussinesq-Whitham equations. (Received September 21, 2015)

1116-35-2094 **Konstantina Trivisa*** (trivisa@math.umd.edu). *On a nonlinear model for tumor growth: Global existence of weak solutions.*

Mechanical models for tumor growth are used extensively in recent years for the analysis of medical observations and for the prediction of cancer evolution based on imaging analysis. This work deals with the dynamics of a nonlinear system for tumor growth and establishes the global existence of weak solutions. The system under investigation is given by a multi-phase flow model: the densities of the different cells are governed by a transport equation for the evolution of tumor cells, whereas the velocity field is given by a Brinkman regularization of the classical Darcy's law. Furthermore, an efficient finite difference scheme is proposed and shown to converge to a weak solution of the system. Our approach relies on convergence and compactness arguments in the spirit of Lions (1998). (Received September 21, 2015)

1116-35-2163 **Christopher Swierczewski*** (cswiercz@gmail.com), University of Washington, Dept. of Applied Mathematics, Lewis Hall #202, Box 353925, Seattle, WA 98195-3925. *Computing Solutions to the Kadomtsev-Petviashvili Equation.*

Krichever showed that the Kadomtsev-Petviashvili equation admits a family of quasiperiodic so-called "finite-genus" solutions which are dense in the space of all periodic solutions. Such a solution can be determined from a Riemann surface and a divisor on the surface. In this talk we will demonstrate a symbolic-numerical approach to obtaining these solutions using the Python software package "abelfunctions". (Received September 21, 2015)

1116-35-2231 **Tucker Andrew Hartland*** (tucker.hartland@gmail.com), 249 West 11th St., Chico, CA 95928, and **Vladimir Rosenhaus**. *Infinite Symmetry Algebras of Partial Differential Equations.* Preliminary report.

We study partial differential equations invariant under infinite symmetry algebras parametrized by arbitrary functions of dependent variables and their derivatives. We find the class of scalar differential equations of the first and second order possessing infinite symmetries containing an arbitrary function of the dependent variable. We generate a partial differential equation of the second order in a real two-dimensional space possessing infinite symmetries with an arbitrary function of all first derivatives. We give geometric interpretation of the results and generalize them to n-dimensional space. (Received September 22, 2015)

1116-35-2253 **Walter Rusin*** (walter.rusin@okstate.edu), Stillwater, OK 74078. *On persistence of regularity for the non-dissipative viscous MG equation.*

We consider the problem of persistence of regularity of the weak solutions to the three-dimensional magneto-geostrophic equation with kinetic viscosity and no dissipation. We show that the initial regularity is propagated by the evolution and the single exponential growth depends only on the L^3-norm of the initial data. The proof uses frequency localization techniques and generalizes the result of Friedlander and Suen to a large class of Besov spaces. Moreover, the obtained growth estimates are sharper. (Received September 22, 2015)

1116-35-2271 **Beyza Aslan*** (beyza.aslan@unf.edu), University of North Florida, Department of Mathematics and Statistics, 1 UNF Dr., Bldg 14/2731, Jacksonville, FL 32224. *Modeling the change in electric potential due to lightning in a sphere.*

The change in electric potential as a result of lightning in a sphere of radius 1 is evaluated. Eigenfunctions obtained by utilizing spherical Bessel functions are used to evaluate the new potential. The change in the electric potential is a constant along the lightning channel, and it is the same as the pre-flash potential outside the channel. The governing equation for the electric potential is obtained from Maxwell's equations. (Received September 22, 2015)

1116-35-2272 **J. Douglas Wright*** (jdoug@math.drexel.edu). *Overhanging traveling gravity-capillary waves.*

We present a formulation of the governing equations for traveling gravity-capillary waves (in 2D) which allows for the possibility that the fluid interface is not a graph over the horizontal coordinate. In particular the formulation allows for solutions which "overhang." We analyze the system using both local and global bifurcation methods. One consequence is that we can perturb the pure capillary overhanging waves of Crapper (which are, remarkably, given by an explicit formula) and show they persist if gravity is included. This work is joint with B. Akers, D. Ambrose, and W. Strauss. (Received September 22, 2015)

1116-35-2281 **Francois S Monard*** (monard@umich.edu), Department of Mathematics, U of Michigan, 2074 East Hall, 530 Church Street, Ann Arbor, MI 48109-1043. *Inversion of the attenuated geodesic X-ray transform on simple surfaces.*

In this talk, we will present explicit reconstruction algorithms for the attenuated geodesic X-ray transform over functions and vector fields, with applications to Computerized Tomography and Doppler tomography in media with varying refractive index. Derivations and numerical implementations will be presented in the case of simple surfaces. (Received September 22, 2015)

1116-35-2340 **Kenneth M. Golden*** (golden@math.utah.edu), University of Utah, Department of Mathematics, 155 S 1400 E, RM 233, Salt Lake City, UT 84112-0090. *Mathematics of Sea Ice.*

I will give an overview of how different branches of mathematics are being used to study sea ice and its role in the climate system, and describe in some cases how studying sea ice has led to new mathematics. (Received September 22, 2015)

1116-35-2359 **Yuncheng You*** (you@mail.usf.edu). *Random Attractors of Stochastic Reaction-Diffusion Systems.*

For a typical autocatalytic reaction-diffusion system with additive noise, the reversible Gray-Scott equations, the existence of a random attractor and the related robustness will be presented with comments on the asymptotic compactness for high-order nonlinearity and unbounded domain. (Received September 22, 2015)

1116-35-2366 **Bahaudin A Hashmi*** (bhashmi88@gmail.com). *Modeling of Pattern Formation in Vapor-to-Particle Reactions.*

Liesegang ring formation is a special type of chemical pattern formation in which the spatial order is formed by density fluctuations of a weakly soluble salt. The vapor-to-particle nucleation process that is believed to produce these Liesegang rings is theorized to be the cause of mini-tornadoes and mini-hurricanes developed in a lab. In this talk, we develop a one-dimensional finite element scheme for a model of laboratory experiments in which ammonia and hydrogen chloride vapor sources are presented to either end of tubes. A reaction zone develops and produces rings as it propagates along the tube. We show that the simulation results exhibit similarities with laboratory experiments. (Received September 22, 2015)

1116-35-2388 **Giles Auchmuty** and **Manki Cho*** (realmann@math.uh.edu), Department of Mathematics, University of Houston, Houston, TX 77024. *Analysis of Steklov representations of solutions of Laplace's equation with singularity.*

This talk will describe the analysis of the boundary integral kernels that represent solutions of Laplace's equation subject to various boundary data. These solutions are approximated by the Steklov expansions for harmonic functions in terms of harmonic Steklov eigenfunctions. The special case of harmonic functions with singularity on a rectangle in the plane is investigated, and very rapid decay of the Steklov coefficients is found. The analysis shows that these approximations converge very rapidly away from the boundary of the domain. (Received September 23, 2015)

1116-35-2414 **Yuliya Gorb*** (gorb@math.uh.edu), Department of Mathematics, University of Houston, Houston, TX 77204-3008. *Discrete Approximations for High Contrast Heterogeneous Media Problems.*

Many natural and man-made materials exhibit vast spatial variability in most of their properties. Mathematically this means that the processes in such heterogeneous media are described by partial differential equations with highly oscillating coefficients that take extremely large and/or very small values in the domain. This talk presents efficient discrete approximation tools that allow to accurately capturing the overall behavior of the considered system. The key issue of relationship between a continuum problem and the corresponding discrete approximation is also investigated. Various applications are discussed. (Received September 22, 2015)

1116-35-2415 **Patrick Dondl*** (patrick.dondl@durham.ac.uk), Abteilung für Angewandte Mathematik, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 10, 79104 Freiburg, Germany, and **Stephan Wojtowytsch**. *A phase field model for Willmore's energy with topological constraint.*

We consider the problem of minimizing Willmore's energy on confined and connected surfaces with prescribed surface area. To this end, we approximate the surface by a level set function u admitting the value $+1$ on the inside of the surface and -1 on its outside. The confinement of the surface is now simply given by the domain of definition of u. A diffuse interface approximation for the area functional, as well as for Willmore's energy are well known. We address the main difficulty, namely the topological constraint of connectedness by a penalization of a geodesic distance which is chosen to be sensitive to connected components of the phase field level sets and provide a proof of Gamma-convergence of our model to the sharp interface limit in case of a two-dimensional ambient space. Furthermore, we show some numerical results. This is joint work with Stephan Wojtowytsch (Durham) and Antoine Lemenant (Paris 7). (Received September 22, 2015)

1116-35-2466 **Yuri Antipov**, Department of Mathematics, Louisiana State University, Baton Rouge, LA 70803, and **Ashar Ghulam*** (aghula2@lsu.edu), Department of Mathematics, Louisiana State University, Baton Rouge, LA 70803. *Boundary value problem for the Helmholtz equation in a semi-infinite strip and the Riemann-Hilbert problem.*

The Helmholtz equation in a semi-infinite strip subject to the boundary conditions $[U_j(\partial_\tau)\partial_n + \mu_j]u = f_j$ on the side j $(j = 1, 2, 3)$, is analyzed. Here, ∂_τ and ∂_n are the tangential and normal derivatives, U_j are order-$2m_j$ differential operators with constant coefficients which have terms of even order only, μ_j are constants, and f_j are given functions. The problem reduces to two scalar Riemann-Hilbert problems which admit closed form solutions. The particular case when $U_j(s)$ are constants is analyzed in detail. In this case, the representation formulas for the solution are reducible to the ones obtained by the finite integral transformation and solution of the associated Sturm-Liouville problem. Both methods ultimately require determining roots of the same transcendental equation. These are found by quadratures on applying the Burniston-Siewert method and solving a certain Riemann-Hilbert problem on two segments. (Received September 22, 2015)

1116-35-2517 **Yuanyuan Song*** (ysong12@crimson.ua.edu), **David Halpern** and **James Grotberg**. *The influence of surfactant on the stability of a liquid bilayer inside a rigid tube.* Preliminary report.

Many airways in the lung are coated with a bilayer consisting of a serous layer adjacent to a more viscous mucus layer which is contiguous with the gas core. An instability due to high surface tension at the interfaces may lead to the formation of a liquid plug that blocks the passage of air. This phenomenon is known as airway closure. Here we investigate the linear stability for the case when the thin liquid bilayer is Newtonian and coated within a rigid tube with the presence of an insoluble surfactant monolayer at the mucus-gas interface. Surfactant affects the surface tension and also induces a surface stress at the interface. A system of equations for the deflections of the interfaces and the surfactant concentration is derived by using lubrication theory. These equations are linearized,and by applying the method of normal modes, a dispersion equation for the growth rate of the disturbances is obtained. Its dependence on the viscosity ratio, the thickness ratio of the two liquid layers, the base state surface tension ratio, and the Marangoni number is investigated, and comparisons with previous single layer models are discussed. (Received September 22, 2015)

1116-35-2546 **Nicola Garofalo** (rembrandt54@gmail.com) and **Kevin Rotz*** (kevin.rotz@gmail.com), Purdue University, Department of Mathematics, 150 N. University St, West Lafayette, IN 47907. *Properties of functionals of Almgren- and Weiss-type for harmonic functions on Carnot groups.*

We give a definition of Almgren's frequency at the identity of a Carnot group of arbitrary step and analyze its properties. An important quantity in our analysis is called the *discrepancy* of a function u at the identity. Our main result is that if u is harmonic with vanishing discrepancy at the identity, then our definition of Almgren's frequency is non-decreasing. This in turn implies the strong unique continuation property for such functions. We reinforce the importance of discrepancy by providing a definition of the Weiss-type functionals $\mathcal{W}_\kappa$ for $\kappa \geq 0$ on Carnot groups. Under the same assumptions on u, $\mathcal{W}_\kappa$ is non-decreasing, and constant if and only if u is homogeneous of degree κ. (Received September 22, 2015)

1116-35-2548 **Tingting Huan*** (thuan@holycross.edu), One College Street, P.O Box 48A, Worcester, MA 01610. *Reaction Diffusion Equations with Fractional Laplacian.*

We consider the traveling fronts of the reaction diffusion equation:

$$u_t + (-\Delta)^s u = f(u), \quad \text{in } \mathbb{R} \times \mathbb{R},$$

for $f \in C^1(\mathbb{R})$. We show the nonexistence of traveling fronts in the combustion model with fractional Laplacian $(-\Delta)^s$ when $s \in (0, 1/2]$. Our method can be used to give a direct and simple proof of the nonexistence of traveling fronts for the usual Fisher-KPP nonlinearity. Also we prove the existence and nonexistence of traveling waves solutions for different ranges of the fractional power s for the generalized Fisher-KPP type model. When considering the Allen-Cahn type nonlinearity, we show the approach of the solution to the traveling front for a large range of initial value problems. (Received September 22, 2015)

1116-35-2583 **R. Dhanya**, **Quinn Morris*** (qamorris@uncg.edu) and **R. Shivaji**. *Existence of positive radial solutions for superlinear, semipositone problems on the exterior of a ball.*

We study positive radial solutions to $-\Delta u = \lambda K(|x|) f(u)$; $x \in \Omega_e$ where $\lambda > 0$ is a parameter, $\Omega_e = \{x \in \mathbb{R}^N \mid |x| > r_0, r_0 > 0, N > 2\}$, Δ is the Laplacian operator, $K \in C([r_0, \infty), (0, \infty))$ satisfies $K(r) \leq \frac{1}{r^{N+\mu}}$; $\mu > 0$ for $r >> 1$, and $f \in C^1([0, \infty), \mathbb{R})$ is a class of non-decreasing functions satisfying $\lim_{s\to\infty} \frac{f(s)}{s} = \infty$ (superlinear) and $f(0) < 0$ (semipositone). We consider solutions, u, such that $u \to 0$ as $|x| \to \infty$, and which also satisfy the nonlinear boundary conditon $\frac{\partial u}{\partial \eta} + \tilde{c}(u)u = 0$ when $|x| = r_0$, where $\frac{\partial}{\partial \eta}$ is the outward normal derivative, and $\tilde{c} \in C([0, \infty), (0, \infty))$. We will establish the existence of a positive radial solution for small values of the parameter λ. We also establish a similar result for the case when u satisfies the Dirichlet boundary conditon $(u = 0)$ for $|x| = r_0$. We establish our results via variational methods, namely using the Mountain Pass Lemma. (Received September 22, 2015)

1116-35-2607 **Eun Kyoung Lee**, **Ratnasingham Shivaji** and **Byungjae Son*** (b_son@uncg.edu), Department of Mathematics and Statistics, UNCG, Greensboro, NC 27412. *Positive radial solutions to classes of singular problems on the exterior domain of a ball.*

We study positive radial solutions to singular boundary value problems of the form:

$$\begin{cases} -\Delta u = \lambda K(|x|) \frac{f(u)}{u^\alpha}, \text{ in } \Omega, \\ \frac{\partial u}{\partial \eta} + \tilde{c}(u)u = 0, \ |x| = r_0, \\ u(x) \to 0, \ |x| \to \infty, \end{cases}$$

where $\Delta u := \mathrm{div}(\nabla u)$ is the Laplacian operator of u, $\Omega = \{x \in \mathbb{R}^N ||x| > r_0 > 0, N > 2\}$, $\lambda > 0$, $K \in C([r_0, \infty), (0, \infty))$ is such that $K(s) \leq \frac{1}{s^{N+\hat{\beta}}}$ for $s \gg 1$ for some $\hat{\beta} > 1$, $\alpha < \min\{1, \frac{\hat{\beta}}{N-2}\}$ and $\frac{\partial u}{\partial \eta}$ is the outward normal derivative of u on $|x| = r_0$. Here, $f \in C^1([0, \infty), \mathbb{R})$ is such that $\frac{f(s)}{s^{1+\alpha}} \to 0$ as $s \to \infty$, and $\tilde{c} \in C([0, \infty), (0, \infty))$. We analyse the cases when (a) $f(0) > 0$ and (b) $f(0) < 0$. We discuss existence, non-existence, multiplicity and uniqueness results. We prove our existence results by the method of sub and supersolutions. (Received September 22, 2015)

1116-35-2614 **Alexis F. Vasseur*** (vasseur@math.utexas.edu) and **Marjolaine Puel** (marjolaine.puel@unice.fr). *Global weak solutions to the inviscid 3D quasi-geostrophic equation.*

We show the existence of global weak solutions to the inviscid three-dimensional quasi-geostrophic system of equations. This system of equations models the evolution of the temperature in the atmosphere. It is widely used in geophysics and meteorology. It involves a coupling between a transport equation in the whole domain, and an other one on the boundary of the domain, at the surface of the earth. (Received September 22, 2015)

1116-35-2621 **Cynthia V Flores*** (cynthia.flores@csuci.edu) and **Derek L Smith** (dls@math.ucsb.edu). *On the controllability and stabilization of the linearized Dispersion Generalized Benjamin-Ono equation on a periodic domain.* Preliminary report.

In this talk, solutions of the linearized Dispersion Generalized Benjamin-Ono equation are studied

$$\partial_t u(x,t) + D^{1+a}u(x,t) = f(x,t) \tag{1}$$

for $0 < a < 1$, $x \in [0, 2\pi]$ and $t \geq 0$ where D^{1+a} denotes the homogeneous derivative. We impose that

$$\frac{\partial^k u}{\partial x^k}(0,t) = \frac{\partial^k u}{\partial x^k}(2\pi,t)$$

for $k = 0, 1$, and 2 so that the process is 2π-periodic in x, and additionally, it is assumed that the distributed control f is generated by a linear feedback aw conserving the volume $\int_0^{2\pi} u(x,t)dx$. Included in the discussion are the related controllability and stabilizability preliminary results. (Received September 22, 2015)

1116-35-2655 **Ken-ichi Maruno*** (kmaruno@waseda.jp), , Japan, and **Arata Nagahara**. *A numerical study of line-soliton interactions of the Davey-Stewartson II system.*

The study of line-soliton interactions of the (2+1)-dimensional integrable systems has attracted much attention. Especially, the line-soliton interactions for the KP II equation has been studied intensively by Kodama and his collaborators. However, line-soliton interactions of the Davey-Stewartson (DS) system is much less studied. We propose a novel numerical scheme to simulate line-soliton interactions of the DS II system. This new numerical method is a combination of the split-step Fourier method and the double window method which makes us possible to simulate PDEs with non-vanishing boundary conditions. We investigate line-soliton interactions of the DS II system by using our numerical scheme and exact line-soliton solutions. (Received September 22, 2015)

1116-35-2671 **Andras Vasy*** (andras@math.stanford.edu), Dept of Math, Stanford University, Bldg 380, 450 Serra Mall, Stanford, CA 94305-2125. *Analysis on asymptotically hyperbolic and de Sitter spaces.*

I will describe recent work on the spectral family of the Laplace, respectively wave, operators on asymptotically hyperbolic, respectively de Sitter spaces obtained by gluing these spaces at their conformal boundaries. The resulting operator is on a compact manifold without boundary, and it is very amenable to Fredholm analysis even though it changes type (elliptic vs. hyperbolic). (Received September 22, 2015)

1116-35-2757 **Dhanapati Adhikari*** (dadhikari@marywood.edu), 2300 Adams Avenue, Marywood University, Scranton, PA 18509. *Global regularity results for the 2D Boussinesq equations with partial dissipation.*

The two-dimensional (2D) incompressible Boussinesq equations model geophysical fluids and play an important role in the study of the Raleigh-Bernard convection. Mathematically this 2D system retains some key features of the 3D Navier-Stokes and Euler equations such as the vortex stretching mechanism. The issue of whether the 2D Boussinesq equations always possess global (in time) classical solutions can be difficult when there is only partial dissipation or no dissipation at all. This paper obtains the global regularity for two partial dissipation cases and proves several global *a priori* bounds for two other prominent partial dissipation cases. These results take us one step close to a complete resolution of the global regularity issue for all the partial dissipation cases involving the 2D Boussinesq equations. This is a joint work with C. Cao, H. Shang, J. Wu, X. Xu, and Z. Ye. (Received September 22, 2015)

1116-35-2759 **Katya Krupchyk*** (katya.krupchyk@uci.edu), University of California, Irvine, CA. *Spectral Estimates and Inverse Boundary Problems for Elliptic Operators.*

We shall discuss some recent progress concerning Lebesgue-space estimates for resolvents of elliptic partial differential operators. Applications to inverse boundary problems for elliptic operators with coefficients of low regularity as well as to spectral theory for periodic Schrödinger operators will be presented. This talk is based on joint works with Gunther Uhlmann. (Received September 22, 2015)

1116-35-2761 **Alfredo Villanueva*** (villanuevaa@savannahstate.edu). *Solutions of nonlinear Schrodinger equations.*

Analytic methods for solving Nonlinear Schrodinger Equations (NLSE) have been developed in some cases. In this article we modified an ansatz substitution (this was used for solving NLSE with variable quadratic Hamiltonian, where the authors found solitons and soliton-like solutions) to solve the Chiral NLSE with time-dependent coefficients and integrability condition. We also, look at higher-order non-linear Schrodinger equations. (Received September 22, 2015)

1116-35-2769 **Benjamin Louis Segal*** (bsegal@uw.edu), 925 N 73RD ST APT 201, Seattle, WA 98103. *Analyzing the stability spectrum for elliptic solutions to the focusing NLS equation*

The one-dimensional focusing cubic nonlinear Schrödinger (NLS) equation is one of the most important integrable equations, arising in a multitude of applications. The stability of the stationary periodic solutions of NLS is well studied, leading to, for instance, the iconic figure-eight spectrum for its cnoidal wave solutions. We present an explicit expression for the linear stability spectrum of both the trivial- and nontrivial-phase solutions. We use this expression to generate many explicit results about the spectrum.
(Received September 22, 2015)

1116-35-2816 **Peter A Caday*** (pac5@rice.edu). *Computing Fourier Integral Operators with Caustics.*

Fourier integral operators (FIOs) make appearances in PDEs, integral geometry, and are a common tool in studying inverse problems. With these applications in mind, it would be useful to have an algorithm for computing a given FIO, given a description of its canonical relation and principal symbol. Most work in numerical computation of FIOs focuses on operators associated with canonical graphs. These encompass many FIOs of practical interest and have local integral representations which are particularly amenable to efficient numerical computation. A complication arises when the canonical transformation has caustics, and the local representation breaks down.

In this talk, I will present a numerical implementation of an algorithm of de Hoop, Uhlmann, Vasy, and Wendt which uses suitable coordinate changes and microlocal cutoffs to reduce any FIO associated with a canonical graph to a sum of local representations. The local representations are then approximated modulo lower-order terms with a technique inspired by wave packets. Many pictures will be included, illustrating the application of the new algorithm to various FIOs. (Received September 22, 2015)

1116-35-2830 **Tatiana Toro*** (toro@uw.edu). *Analysis on non-smooth domains.*

In this lecture we will focus on the deep interplay that exists between the geometry of a domain and the smoothness of solutions to elliptic partial differential equations. This will illustrate the way in which ideas and tools from geometric measure theory, harmonic analysis and partial differential equations come together to produce interesting and surprising results. (Received September 22, 2015)

1116-35-2868 **Masoud Yari***, School of Engineering and Computing Sciences, Corpus Christi, TX 78412. *Transient states in vegetation pattern model of semi-arid ecosystems.*

The purpose of this talk is to present and analyze a PDE model for macro-scale study of vegetation propagation/degradation in semi-arid ecosystems. I will focus on structural stability and transitions of localized patterns I will also discuss strategies in qualitative parameter approximation for such systems. Such an analysis is useful in determining uncertainty regions, finding tipping points, and revealing other hidden dynamics. (Received September 22, 2015)

1116-35-2944 **Sedar Ngoma*** (nzb0015@auburn.edu), Department of Mathematics and Statistics, 221 Parker Hall, Auburn, AL 36849, and **Dmitry Glotov**, **Willis E. Hames** and **A. J Meir**. *On a parabolic inverse source problem arising in geochronology.*

We investigate a problem arising in geochronology, the study of dating of rock formations and geological events, and in particular the reconstruction of temperature histories of rocks, and dating the cooling of rocks through exhumation. Reconstructing the temperature history amounts to solving a time-dependent, inverse source problem for an integral constrained PDE. Using Rothe's method and an energy argument, we show the existence and uniqueness of weak solutions. We describe a numerical scheme which can be used to approximate solutions of the inverse problem. Numerical experiments illustrate the accuracy and efficiency of the proposed method. (Received September 23, 2015)

1116-35-2973 **Julia Anderson-Lee*** (juliaal@iastate.edu), 2811 West St, Apt 202, Ames, IA 50014, and **Scott Hansen** (shansen@iastate.edu), 396 Carver Hall, Ames, IA 50014. *Model of Rocking Structures: A Mathematical Approach.*

The study of seismic engineering is extremely interesting not only from an engineering perspective but also within other disciplines which have applications in engineering and modeling of dynamical systems. In particular, rocking systems– made popular as a research area by G.W. Housner with his paper regarding modeling the displacement of block-shaped structures —involve interesting mathematics in the area of coupled partial differential equations. In this talk, a coupled system of partial differential equations incorporating the strain energy of the block, and internal longitudinal vibrations is presented. Then, using only the internal vibrations and the angle of rocking, a coefficient of restitution is formulated. These results are used to construct the expected motion of the block and compared to the motion of the block predicted by Housner. (Received September 23, 2015)

37 ► Dynamical systems and ergodic theory

1116-37-14 **Alex Eskin*** (eskin@math.uchicago.edu). *The $SL(2,\mathbb{R})$ action on moduli space.*

I will discuss ergodic theory over the moduli space of compact Riemann surfaces and its applications to the study of polygonal billiard tables. There is an analogy between this subject and the theory of flows on homogeneous spaces; I will talk about some successes and limitations of this viewpoint. This is joint work with Maryam Mirzakhani and Amir Mohammadi. (Received May 10, 2015)

1116-37-85 **Ugur G Abdulla** and **Rashad U Abdulla***, abdullar@sas.upenn.edu, and **Alyssa L Turnquist**, **Muhammad U Abdulla** and **Naveed Iqbal**. *On the Fine Classification of Periodic Orbits of Continuous Endomorphisms on the Real Line and Universality in Chaos.*

We complete the classification of the periodic orbits of period $2^n(2k+1)$, $k>1$, of the continuous endomorphisms on the real line which are minimal with respect to Sharkovski ordering. By developing the new constructive method suggested in *Abdulla et al. J. of Diff. Equat. and Appl., 19,8(2013), 1395-1416,* it is proved that independent of k, there are $2^{2^{n+1}-2}$ types of digraphs with accuracy up to inverse digraphs. We pursue full analysis of the second minimal 7-orbits, where second minimal odd orbits immediately follow the minimal orbits with respect to Sharkovski ordering. It is proved that there are 9 types of second minimal 7-orbits with accuracy up to inverses. We apply this result to the problem on the distribution of superstable periodic windows within the chaotic regime of the bifurcation diagram of the one-parameter family of logistic type unimodal maps. It is revealed that by fixing the maximum number of appearances of the periodic windows there is a universal pattern of distribution. Yet another important development of this research is the revelation of the pattern of the pattern dynamics with respect to increased number of appearances. Understanding the nature of this universal route is an outstanding open problem for future investigations. (Received July 27, 2015)

1116-37-125 **Buddhi Pantha*** (pantha@math.utk.edu), 301 Woodlawn Pike, Apt E9, Knoxville, TN 37920, and **Judy Day** and **Suzanne Lenhart**. *Early Disease Dynamics in an Inhalational Anthrax Infection.*

Buddhi Pantha

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Inhalational *anthrax* is one of the most fatal forms of all anthrax which starts after the inhaled spores are phagocytosed by lung's macrophages and transported to nearby lymph nodes where the spores germinate. We formulate a mathematical model consisting of a system of ODEs as a way to understand the early disease dynamics of an inhalational anthrax infection. We focus on the three main processes that take place right after infection: uptake, germination and killing. We investigate whether the initial spore load plays a significant role in these processes as well as growth of the survived bacteria. Experimental data are used to estimate parameters and simulation results of the ODEs are presented. (Received August 03, 2015)

1116-37-147 **Katherine J. Meyer*** (meye2098@umn.edu), 127 Vincent Hall, 206 Church St. SE, Minneapolis, MN 55455. *Potential Quantitative Meanings of Resilience.*

Promoting a natural system's resilience—broadly defined as its ability to retain basic structure and function in the face of change—has emerged as an important goal in natural resource management. What does resilience mean from a mathematical viewpoint? The description above leaves room for multiple quantitative interpretations. After reviewing some of these from the ecological literature, I will present a mathematical method for characterizing resilience to repeated, discrete state variable perturbations in models based on ordinary differential equations. (Received August 06, 2015)

1116-37-158 **Justin Eastman***, Department of Mathematics, Millersville University, 17551-0302, and **Julian Sass**, Department of Mathematics and Statistics, University of Maryland, Baltimore County, Baltimore, MD 21250. *Inducing Alternans in Cardiac Models using Delay Differential Equations.* Preliminary report.

Cardiac electrical alternans is a period-2 dynamical behavior with alternating long and short action potential durations (APD) that often precedes dangerous arrhythmias associated with cardiac arrest. Despite the importance of alternans, many current ordinary differential equations models of cardiac electrophysiology do not produce alternans, thereby limiting the use of models to study the mechanisms that underlie this conditions. Because delay differential equations (DDEs) commonly induce complex dynamics in other systems, we investigate whether incorporating DDEs can lead to alternans development in cardiac models. We use the Fox et al. canine ventricular action potential model, which produces alternans as published. After suppressing the alternans in the original model, we restore alternans by introducing DDEs and quantitatively compare the DDE-induced alternans with the alternans present in the original model. We analyze the gating variables of the model to study the effects of implementing DDEs and to determine how alternans is restored, and we discuss the mathematical and physiological implications of our findings. In the future, we aim to extend our approach to induce alternans in models that do not naturally produce such dynamics. (Received August 10, 2015)

1116-37-271 **Eugen A Ghenciu*** (ghenciue@uwstout.edu) and **Simon Baker**. *Dynamical properties of S-gap shifts and other shift spaces.*

We study the dynamical properties of certain shift spaces. To help study these properties we introduce two new classes of shifts, namely boundedly supermultiplicative (BSM) shifts and balanced shifts. It turns out that any almost specified shift is both BSM and balanced, and any balanced shift is BSM. However, as we will demonstrate, there are examples of shifts which are BSM but not balanced. We also study the measure theoretic properties of balanced shifts. We show that a shift space admits a Gibbs state if and only if it is balanced.

Restricting ourselves to S-gap shifts, we relate certain dynamical properties of an S-gap shift to combinatorial properties from expansions in non-integer bases. This identification allows us to use the machinery from expansions in non-integer bases to give straightforward constructions of S-gap shifts with certain desirable properties. We show that for any $q \in (0,1)$ there is an S-gap shift which has the specification property and entropy q. We also use this identification to address the question, for a given $q \in (0,1)$, how many S-gap shifts exist with entropy q? For certain exceptional values of q there is a unique S-gap shift with this entropy. (Received August 19, 2015)

1116-37-301 **Robert L. Devaney*** (bob@bu.edu), Mathematics Dept., 111 Cummington Mall, Boston University, Boston, MA 02215. *Mandelpinski Structures in the Parameter Planes of Rational Maps.*

In this talk we shall describe three different types of Mandelpinski structures that arise in the parameter planes of singularly perturbed complex maps, namely Mandelpinski necklaces, spokes, and mazes. Each of these objects consists of a collection of infinitely many different curves arranged in a particular manner along which are located a large number of (usually infinitely many) Mandelbrot sets and Sierpinski holes in alternating fashion. Here a Sierpinski hole is a disk in the parameter plane from which any parameter has a corresponding Julia set that is a Sierpinski curve, i.e., is homeomorphic to the Sierpinski carpet fractal. (Received August 24, 2015)

1116-37-335 **Ali Allahem*** (a.allahem@qu.edu.sa), School of Mathematics, Buraydah, Qassim P.O.Box 53, Saudi Arabia. *textbfThe concept of the dividing surface in collinear Hydrogen exchange reaction.* Preliminary report.

Transition state theory(TST) describes the elementary chemical reaction rate. There are three main regions in the reaction: reactant, product and the transition state (TS). The transition state must have two properties to make the transition state theory exact: all reactive trajectories must cross the TS (dividing surface) and the reactive trajectories cross it only once. Dynamical effects recrossing is possible from coupling in kinetic energy where TST provides upper bound of the exact reaction rate. Historically, (Wigner 1938) developed the reaction rate theory and extended the idea from configuration space to phase space. (Pollak et al 1978) found the structure of the dividing surface in the collinear $H_2 + H$ reaction. It is well-known as unstable periodic orbit dividing surface (PODS). We are going to talk about the reactivity on the dividing surface of this reaction. (Received August 26, 2015)

1116-37-418 **Hexi Ye*** (yehexi@math.ubc.ca), 121-1984 Mathematics Road, Vancouver, BC V6T 1Z2, Canada. *Some applications of the Arithmetic euqidistribution theorem in Complex Dynamics.*

Arithmetic equidistribution theorem plays an important role in the study of Algebraic Dynamics. In the recent years, Arithmetic questions arose and were studied in Complex Dynamics. One of more important tools is the equidistribution theorem. In this talk, I would like to discuss some applications of the equidistribution theorem in Complex Dynamics. (Received August 31, 2015)

1116-37-560 **Anca Radulescu*** (radulesa@newpaltz.edu), 1 Hawk Drive, FOB S7, New Paltz, NY 12561. *Dynamics in template and networks of complex quadratic maps.*

Behavior under iterations of quadratic maps has been one of the earliest and most studied topics in discrete dynamics, in both the real and complex case. However, many subtler aspects of discrete dynamics centered around the behavior of logistic maps remain largely unexplored.

For example, while iterations of a single map have been exhaustively studied, less effort has been directed towards addressing what happens (1) when the map itself evolves in time according to a symbolic template and (2) when the maps are organized as nodes in a network, and interact in a time-dependent fashion. We investigate how the traditional theory changes in these cases, illustrating how the hardwired structure (e.g., symbolic template, or respectively adjacency graph) can affect dynamics (behavior of orbits, topology of Julia set, etc.)

This is of potential interest to a variety of applications (including genetic and neural coding), since (1) investigates how an occasional or a reoccurring error in a replication or learning algorithm may affect the outcome and (2) relates to algorithms of synaptic restructuring and neural dynamics in brain networks. (Received September 07, 2015)

1116-37-637 **Svetlana Jitomirskaya** (szhitomi@math.uci.edu), Irvine, CA , and **Shiwen Zhang*** (shiwez1@uci.edu), Irvine, CA. *Lower quantum dynamical bounds and arithmetic criterion of full spectral dimensionality for analytic quasi-periodic Schrödinger operators.*

We will present a purely arithmetic criterion of full spectral dimensionality for discrete analytic quasi-periodic Schrödinger operators in the positive Lyapunov exponent regime. The lower bound estimate for spectral dimension works for general Schrödinger operators with potentials that are exponentially close to periodic ones. This leads to a number of applications to quantum transport and fractal dimensional properties, including arithmetic conditions for quasi-ballistic motion of critical almost Mathieu operators, Sturmian Hamiltonians. (Received September 16, 2015)

1116-37-656 **Hongying Shu*** (hshu@tongji.edu.cn), 1239 Siping Road, Shanghai, 200092, Peoples Rep of China. *Bounded global Hopf branches for the Nicholson's blowflies equation.*

We investigate Nicholson's blowflies model with natural death rate incorporated into the delay feedback. We consider the delay as a bifurcation parameter and examine the onset and termination of Hopf bifurcations of periodic solutions from a positive equiibrium. We show that the model has only a finite number of Hopf bifurcation values and we describe how branches of Hopf bifurcations are paired so the existence of periodic solutions with specific oscillation frequencies occurs only in bounded delay intervals. The bifurcation analysis and numerical simulations to identify ranges of parameters for coexisting multiple attractive periodic solutions. (Received September 10, 2015)

1116-37-695 **Mattias Jonsson** and **Paul Reschke*** (preschke@umich.edu), Dept. of Math., Univ. of Mich., 530 Church St, 2076 East Hall, Ann Arbor, MI 48109. *Complex dynamics of birational surface maps defined over number fields.*

For a birational self-map with non-trivial first dynamical degree on a complex surface, Bedford and Diller defined an energy condition which when satisfied guarantees nice dynamical properties for the map (with regard, in particular, to a naturally defined invariant measure). However, Buff showed that the energy condition can fail and that in fact maps without the nice dynamical properties do exist. We show that the energy condition is always satisfied when the birational self-map is defined over a number field. Our proof relies in part on a construction of a natural dynamical height function for the map, which expands upon work by Silverman and Kawaguchi. (Received September 10, 2015)

1116-37-747 **Holly Krieger*** (hkrieger@math.mit.edu), 77 Massachusetts Avenue, Cambridge, MA 02139. *The dynamical André-Oort conjecture.*

I will discuss recent progress on the dynamical André-Oort conjecture concerning the geometry of post-critically finite maps in algebraic families of rational maps. (Received September 11, 2015)

1116-37-753 **Robert Rumely*** (rr@math.uga.edu), Department of Mathematics, University of Georgia, Athens, GA 30602. *Arithmetic Coordinates on Dynamical Moduli Space.* Preliminary report.

For the moduli space of quadratic rational functions, work of Doyle, Jacobs, and Rumely shows that the usual coordinates σ_1, σ_2 distinguish the different reduction types of non-Archimedean quadratic rational functions. This talk will present similar results for cubic polynomials, and work in progress for cubic rational functions. (Received September 11, 2015)

1116-37-835 **Chong Gyu Lee*** (cglee@ssu.ac.kr). *Genralized dynamical systems, from monoid actions to homomorphisms.* Preliminary report.

We can define a dynamical system with a self map f on a set S. We may consider this dynamical systems as a monoid action on a set S. In such point of view, we can generalize the concept of dynamical systems. For examples, when we consider an algebraic group, we consider n-multiplication map on a gorup and consider dynamical systems defined by n-multiplication. Then the torson group is the set of prepereiodic points. We may consider ont only iterations of n-multiplication but all multiple maps and get the same result. So we can generalize the dynamical system as an action by a set of self maps with some specific condition. Such points of view will give us one more step, we may have a set of homomorphisms whose codomain is noe the same with the domain, like isogenies of two elliptic curves. In this talk, we examine sime examples of such generalization and find some condition which dynamical system between projective spaces can have small preperiodic points. (Received September 14, 2015)

1116-37-929 **Clayton Petsche***, Department of Mathematics, Oregon State University, Corvallis, OR 97331. *On the distribution of orbits in affine varieties.*

Given an affine variety X, a morphism $\phi : X \to X$, a point $\alpha \in X$, and a Zariski closed subset V of X, we show that the forward ϕ-orbit of α meets V in at most finitely many infinite arithmetic progressions, and the remaining points lie in a set of Banach density zero. This may be viewed as a weak asymptotic version of the Dynamical Mordell-Lang Conjecture for affine varieties. The results hold in arbitrary characteristic, and the proof uses methods of ergodic theory applied to compact Berkovich spaces. A more general result has been independently obtained, using different methods, by Bell-Ghioca-Tucker and Gignac. (Received September 15, 2015)

1116-37-1171 **Kenneth Scott Jacobs*** (kjacobs2@uga.edu). *Lyapunov Exponents in non-Archimedean Dynamics.*

The Lyapunov exponent of a rational map ϕ measures the rate of growth of a point in a generic orbit. It is related to the orbits of the critical points of ϕ, and when ϕ is defined over $\mathbb{C}$, a sharp lower bound is $\frac{1}{2}\log d$, where d is the degree of the map.

Much less is known about Lyapunov exponents for maps defined over non-Archimedean fields. In this talk, we will give an explicit lower bound similar to the one over $\mathbb{C}$ which is sharp for maps of good reduction. We will also give a formula relating Lyapunov exponents to Silverman's critical height. (Received September 17, 2015)

1116-37-1255 **Hanlun Yap** and **Armin Eftekhari***, armin.eftekhari@gmail.com, and **Michael B Wakin** and **Christopher J Rozell**. *Delay-coordinate Mapping in the Presence of Noise: A Stable Takens' Theorem.*

When the states of a dynamical system are confined to an (often low-dimensional) *attractor*, the Takens' theorem asserts that states of the system can be reconstructed from noise-free time-series data (through *delay-coordinate mapping*). A rich literature exists on often heuristic ways of handling noise in time-series data. In this work, we use tools and ideas from Compressive Sensing to systematically extend the celebrated Takens' theorem to account for measurement noise. In particular, we show that under certain conditions, delay-coordinate mapping stably embeds attractors of dynamical systems. (Received September 18, 2015)

1116-37-1401 **Alanna Hoyer-Leitzel*** (ahoyerle@mtholyoke.edu) and **Anna M. Barry**. *Existence and stability of relative equilibria with a dominant vortex.*

Point vortex models propose that the motion of small-core, well-separated vortices in a two-dimensional fluid can be described by a set of ordinary differential equations that treats each vortex as a single point. This is commonly known as the n-vortex problem. In this paper, we analyze existence and stability of point vortex relative equilibria with one dominant vortex and N vortices with infinitesimal circulation. We show that the problem can be reduced to an infinitesimal circulation limit, and that both existence and stability are characterized by properties of critical points of a particular real-valued function of N angular variables. We use these results to prove that symmetric configurations require equality of two circulation parameters in the $(1+3)$-vortex problem, and we show that there can be stable asymmetric configurations. (Received September 19, 2015)

1116-37-1424 **Michel L Lapidus** and **Sean Watson*** (watson@math.ucr.edu). *Fractal geometry and complex dimensions in Ahlfors regular spaces.* Preliminary report.

While classical analysis dealt primarily with smooth spaces, much research has been done in the last half century on expanding the theory to the nonsmooth case. Metric Measure (MM) spaces are the natural setting for such analysis, and it is thus important to understand the geometry of subsets of these spaces. Our talk will focus on the geometry of MM-spaces under additional regularity conditions, the Ahlfors regular spaces. Historically, fractals have been studied using different ideas of dimension, such at the Minkowski and Hausdorff dimensions, which have all proven to be unsatisfactory to some degree. We offer a brief overview of the theory of complex dimensions, developed by Lapidus and a number of collaborators, in an effort to better understand fractality in the Euclidean case and which seeks to overcome these problems. Of particular interest is the recent theory of complex dimensions in higher-dimensional Euclidean spaces, as studied by M.L.L., G. Radunovic, and D. Zubrinic. We will then show that this new theory of complex dimensions naturally generalizes to the case of Ahlfors regular spaces, along with illustrative examples from a selection of such spaces. (Received September 19, 2015)

1116-37-1461 **Wenxia Li*** (wxli@math.ecnu.edu.cn), 500 Dongchuan Road, Minghan, Dept. of Math., East China Normal University, Shanghai, Shanghai 200241, Peoples Rep of China. *ON the Hausdorff dimension of unique Beta expansions.* Preliminary report.

We fix a positive integer M, and we consider expansions in arbitrary real bases $q > 1$ over the alphabet $\{0, 1, \ldots, M\}$. We denote by $\mathcal{U}_q$ the set of real numbers having a unique expansion. Completing many former investigations, we give a formula for the Hausdorff dimension $D(q)$ of $\mathcal{U}_q$ for each $q \in (1, \infty)$. Furthermore, we prove that the dimension function $D : (1, \infty) \to [0, 1]$ is continuous, and has a bounded variation. Moreover, it has a Devil's staircase behavior in (q', ∞), where q' denotes the Komornik–Loreti constant: although $D(q) > D(q')$ for all $q > q'$, we have $D' < 0$ a.e. in (q', ∞). (Received September 20, 2015)

1116-37-1497 **Yixin Guo** and **Aijun Zhang*** (az003@uark.edu), Department of Mathematical Sciences, 309 SCEN -1 University of Arkansas, Fayetteville, AR 72701. *Existence and Nonexistence of Traveling Pulses in a Lateral Inhibition Neural Network.*

We study the spatial propagating dynamics in a neural network of excitatory and inhibitory populations. Our study demonstrates the existence and nonexistence of traveling pulse solutions with a nonsaturating piecewise linear gain function. We prove that traveling pulse solutions do not exist for such neural field models with even(symmetric) couplings. The neural field models only support traveling pulse solutions with asymmetric couplings. We also show that such neural field models with asymmetric couplings will lead to a system of delay differential equations. We further compute 1-bump traveling pulse solutions using the system of delay differential equations. Finally, we develop Evans functions to assess the stability of 1-bump traveling pulse solutions. (Received September 20, 2015)

1116-37-1535 **Lien-Yung Kao*** (lkao@nd.edu), University of Notre Dame, Department of Mathematics, 255 Hurley Hall, Notre Dame, IN 46556. *Entropy, Hausdorff Dimension and Immersed Surfaces in Hyperbolic 3-Manifolds.*

We consider a π_1–injective immersion $f : \Sigma \to M$ from a compact surface Σ to a hyperbolic 3–manifold M. Let Γ denote the copy of $\pi_1\Sigma$ in $\mathrm{Isom}(\mathbb{H})^3$ induced by the immersion f, and we endow Σ with the induced metric. Using the Thermodynamic Formalism, when Σ is negatively curved and Γ is convex cocompact, we prove an inequality relating the topological entropy $h(\Sigma)$ of the geodesic flow on T^1M and the Hausdorff dimension of the limit set $\Lambda(\Gamma)$ of Γ: $C_1(\Sigma, M) \cdot \dim_H(\Lambda(\Gamma)) \le h(\Sigma) \le C_2(\Sigma, M) \cdot \dim_H(\Lambda(\Gamma))$, where $C_1(\Sigma, M)$ and $C_2(\Sigma, M)$ are two geometric constants. Herein, we investigate the geometry meaning of these two constants in detail. Furthermore, we study the rigidity phenomenon coming from this inequality. Lastly, we apply our results to immersed minimal surfaces in hyperbolic 3–manifolds, and these discussions lead us to a similar study as A. Sanders' work on the moduli space of Σ introduced by C. Taubes. (Received September 20, 2015)

1116-37-1760 **Elizabeth Sattler***, elizabeth.sattler.1@ndsu.edu. *Fractal dimensions of subfractals induced by sofic subshifts.* Preliminary report.

In this talk, we will consider subfractals of hyperbolic iterated function systems which satisfy the open set condition. The subfractals will consist of points associated with infinite strings from a subshift of finite type or sofic subshift on the symbolic space. We find that the zeros of the associated lower and upper topological pressure functions are lower and upper bounds, respectively, for the Hausdorff, packing, lower and upper box dimensions of the subfractal. (Received September 21, 2015)

1116-37-1784 **Kaitlin Hill*** (k-hill@u.northwestern.edu), Northwestern University, 2145 Sheridan Rd M426, Evanston, IL 60208, and **Dorian S Abbot** and **Mary Silber**. *Analysis of an Arctic sea ice loss model in the limit of a discontinuous albedo.* Preliminary report.

As Arctic sea ice extent decreases with increasing greenhouse gases, there is a growing interest in whether there could be a bifurcation associated with its loss, and whether there is significant hysteresis associated with that bifurcation. A challenge in answering this question is that the bifurcation behavior of certain Arctic energy balance models have been shown to be sensitive to how ice-albedo feedback is parameterized. We analyze an Arctic energy balance model in the limit as a smoothing parameter associated with ice-albedo feedback tends to zero, which makes the system piecewise-smooth. Our analysis provides a case study where we use the piecewise-smooth system to explore bifurcation behavior of the smooth system. In this case study, we demonstrate that certain qualitative bifurcation behaviors of the smooth system can have nonsmooth counterparts, and we use this link to provide an alternative perspective on how parameters of the model affect bifurcation behavior. We expect our approach, which exploits the width of repelling sliding intervals for understanding the hysteresis loops, would carry over to other positive feedback systems with a similar natural piecewise-smooth limit, and when the feedback strength is likewise modulated with seasons or other periodic forcing. (Received September 21, 2015)

1116-37-1797 **Chris Cox*** (ccox@math.wustl.edu) and **Renato Feres**. *No-slip Billiards in Dimension Two.*

In no-slip billiards the specular reflections of standard billiards are replaced by conservative collisions which nonetheless allow an exchange between linear and angular momentum. This interchange may result in bounded orbits and provides a new mechanism for periodicity, distinct from the purely geometric periodicity of standard billiards. We extend boundedness results and characterize periodic orbits for the wedge and circle. Additionally, we consider the intricately patterned phase portraits and what they suggest about ergodicity. (Received September 21, 2015)

1116-37-1810 **Joao Alberto de Faria** and **Benjamin Hutz*** (hutzba@slu.edu). *Automorphism Groups and Invariant Theory on PN.* Preliminary report.

Let K be a field and $f : \mathbb{P}^N \to \mathbb{P}^N$ a morphism. There is a natural conjugation action on the space of such morphisms by elements of the projective linear group PGL_{N+1}. The group of automorphisms, or stabilizer group, of a given f for this action is known to be a finite group. In this talk, we discuss a mainly computational problem concerning automorphism groups: Given a finite subgroup of PGL_{N+1} determine endomorphisms of $\mathbb{P}^N$ with that group as subgroup of its automorphism group. In particular, we show that every finite subgroup occurs infinitely often and discuss some associated rationality problems. (Received September 21, 2015)

1116-37-1814 **Erin Denette*** (edenette@uri.edu), University of Rhode Island, Department of Mathematics, 5 Lippitt Road, Kingston, RI 02881, and **Araceli Bonifant** (bonifant@math.uri.edu). *Constructing Ergodic Families of Combinatorially Obtained Minimal Cantor Sets.*

A Cantor set is a perfect, zero dimensional, compact metric space. Given a Cantor set X, a continuous map $f : X \to X$ is called a minimal Cantor set if every orbit of f is dense in X. In 2006, Gambaudo and Martens gave conditions under which it can be guaranteed that a minimal Cantor set can be obtained as the inverse limit of certain directed topological graphs by introducing specific nonnegative integer matrices, called winding matrices, to describe the projection between each graph. They went on to claim that non-uniquely ergodic minimal Cantor sets can be obtained from winding matrices whose unbounded entries grow "fast enough", but did not address the necessary growth rate. In this talk, a family of minimal Cantor sets that can be obtained using square winding matrices will be introduced and the growth rate needed to guarantee either unique or non-unique ergodicity within the family will be established. (Received September 21, 2015)

1116-37-1850 **Anushaya Mohapatra*** (iitmmanu@gmail.com), 1237 NW 23rd Street Apt 10, Corvallis, OR 97330, and **Haley Ohms**, **Dave Lytle** and **Patrick De Leenheer**. *Population Models with Partial Migration.*

We discuss several discrete-time population models to investigate the coexistence of migrants and residents. We study both linear and non-linear model, density dependence effects are incorporated by non-linear models. The asymptotic dynamics is determined in terms of the value of a locally defined basic reproduction number: If it is less than one, then the entire population goes extinct, whereas it settles at a unique fixed point consisting of a mixture of residents and migrants, when it is larger than one. Thus, the value of the basic reproduction number can be used to predict the stable coexistence or collapse of populations exhibiting partial migration. (Received September 21, 2015)

1116-37-1906 **Eli Shlizerman*** (shlizee@uw.edu), Applied Mathematics, Box 353925, University of Washington, Seattle, WA 98195. *Functional connectomics from data: Constructing probabilistic graphical models for neuronal networks.*

The nervous system of the nematode Caenorhabditis elegans (C. elegans) is comprised of 302 neurons for which the connectivity map is fully resolved. Although the static connectome is available, inference of dominant neural pathways that control sensorimotor responses is challenging since neurons are dynamical objects and interactions within the network are also dynamic. In our study, we construct a Probabilistic Graphical Model (PGM) for the C. elegans connectome that represents the 'effective connectivity' between the neurons (correlations) and takes into account the dynamics. The structure of the PGM is learned using Bayesian methods capable of learning the structure of an undirected graphical model from a collection of time series. The collections are obtained by a systematic excitation of neurons in a recently developed computational dynamical model for the C. elegans that simulates single neural responses and interactions between the neurons. Bayesian posterior inference methods applied to the constructed PGM allow us to extract neural pathways in the connectome of C. elegans responsible for experimentally well characterized movements of the worm such as forward and backward locomotion. (Received September 21, 2015)

1116-37-1938 **Kamal Mani Adhikari*** (kadhikari@siu.edu), 1245 Lincoln Drive, Department of Mathematics, Southern Illinois University Carbondale, Carbondale, IL 62901, and **Michael Sullivan** (prof.michael.sullivan@gmail.com). *Simple Smale flows with n-band templates (n=3,4).*

In the talk we will mainly focus on the linking structure of periodic orbits (attractor and repeller) in simple Smale flows using some branched 2 manifolds called templates and discuss the realizations of the non-singular Smale flows using 3-band and 4-band template models. This extends the work done by M. Sullivan on Lorenz Smale flows, Bin Yu on realizing Lorenz Like Smale flows on 3-manifold and continues the work of Elizabeth Haynes and M.Sullivan on realizing simple Smale flows with a four band template on 3-sphere. (Received September 21, 2015)

1116-37-1990 **William Bench*** (wmbench@email.wm.edu). *Computational Dynamics of a Map with Multiple Stable States.*

I use an automated method to locate and prove the existence of fixed points and periodic points of a population model.

Predictions of behavior of a system are often difficult because of chaos, error, computational limits, and the interactions between them. Outer approximation and topology are two methods used to extract dynamics. They allow us to automate analysis of a system, be aware of the limitations of the analysis, and prove the existence and location of certain dynamics.

Models of how biological populations change over time are a type of dynamical system. I illustrate the use of outer approximation and topology in the analysis of a biological model. This process is almost entirely automated by a program written by William D. Kalies. I use his program to prove the existence of dynamics of the model. The model I analyze is mentioned in Robert May's paper *Thresholds and breakpoints in ecosystems with a multiplicity of stable states.* (Received September 21, 2015)

1116-37-2016 **Dinesh Kasti*** (dkasti@fau.edu) and **William D Kalies** (wkalies@fau.edu). *Lifting sublattices of attractors/repellers to the lattice of (pre-)Lyapunov functions.*

Under the context of general dynamical systems where the underlying map may not be a diffeomorphism and may be merely a continuous map, we describe the lifting of its sublattices of attractors (and repellers) to the lattice of (pre-)Lyapunov functions. This work is motivated from the authors' previous work on the conditions of the existence and the algorithmic construction of a lift of sublattices of attractors to the lattices of forward invariant sets and the lattices of attracting neighborhoods. We explore the conditions under which such a lift can exist and also provide algorithmic construction of such a lift when it exists. We illustrate our algorithms with some examples. (Received September 21, 2015)

1116-37-2025 **Kelly B. Yancey*** (kbyancey1@gmail.com) and **Jon Fickenscher**. *Structure of Rigidity Sequences for Substitution Dynamical Systems.* Preliminary report.

A special class of dynamical systems that we will focus on are substitutions. Let $\mathcal{A}$ be a finite alphabet. The set $\mathcal{A}^*$ refers to the set of all finite words over the alphabet $\mathcal{A}$. A map $\theta : \mathcal{A} \to \mathcal{A}^*$ which induces a map from $\mathcal{A}^*$ to $\mathcal{A}^*$ by $\theta(ab) = \theta(a)\theta(b)$ where $a, b \in \mathcal{A}$ is called a substitution. This class of systems provides a variety of ergodic theoretic behavior and is connected to self-similar interval exchange transformations.

During this talk we will explore rigidity sequences for these systems. A sequence (n_m) is a rigidity sequence for the dynamical system (X, T, μ) if $\mu(T^{n_m} A \cap A) \to \mu(A)$ for all positive measure sets A. We will discuss the structure of rigidity sequences for substitutions that are rank-one and substitutions that have constant length. (Received September 21, 2015)

1116-37-2073 **Robert G Niemeyer*** (robert.niemeyer@maine.edu), 332 Neville Hall, Dept.of Mathematics & Statistics, University of Maine, Orono, Orono, ME 04469. *A fractal perturbation of a nanowire.*

Recent results on the T-fractal billiard are applied to the electron-hole dynamics of a nanowire. We show that a fractal perturbation of a nanowire effectively mimics the cutting of the wire into two pieces. Also introduced in this talk is the notion of Andreev reflection and how an Andreev billiard table cannot have an associated flat surface, in the sense generally understood. (Received September 21, 2015)

1116-37-2081 **Tim Tennant*** (timothy_tennant@baylor.edu), **Brian Raines** and **Johnathan Meddaugh**. *Invariant measures on set-valued functions with the specification property.* Preliminary report.

The specification property is known to show that in the space of invariant measures on a compact metric, there is a dense G-delta of non-atomic measures with full support. We show that this partially extends in the case of set-valued functions with the specification property, and give some results which characterize when this extension holds. (Received September 21, 2015)

1116-37-2084 **Nathan Averbeck*** (nathan_averbeck@baylor.edu), One Bear Place 97328, Waco, TX 76798, and **Brian E. Raines**. *Distributional Chaos in Dendritic and Circular Julia Sets.*

If x and y belong to a metric space X, we call (x, y) a DC1 scrambled pair for $f : X \to X$ if the following conditions hold:

1) For all $t > 0$, $\limsup\limits_{n\to\infty} \dfrac{1}{n} \left|\{0 \le i < n : d(f^i(x), f^i(y)) < t\}\right| = 1$, and

2) For some $t > 0$, $\liminf\limits_{n\to\infty} \dfrac{1}{n} \left|\{0 \le i < n : d(f^i(x), f^i(y)) < t\}\right| = 0$.

If $D \subset X$ is an uncountable set such that every $x, y \in D$ forms a DC1 scrambled pair for f, we say f exhibits *distributional chaos of type 1.* If there exists $t > 0$ such that condition 2) holds for any distinct points $x, y \in D$, then the chaos is said to be *uniform*.

A *dendrite* is a locally connected, uniquely arcwise connected, compact metric space. In this paper we show that a certain family of quadratic Julia sets (one that contains all of the quadratic Julia sets which are dendrites and many others which contain circles) has uniform DC1 chaos. (Received September 21, 2015)

1116-37-2258 **James P Kelly*** (james.kelly@cnu.edu). *The Specification Property for Certain Classes of Linear Operators.*

We study the specification property for three specific types of linear operators: generalized backward shift operators and their commutants on Frechét spaces, backward shifts on Frechét spaces with unconditional bases, and translation operators on spaces of the form $L^p_v(\mathbb{R}_+)$ or $L^p_v(\mathbb{R})$ where v is an admissible weight. For the latter two classes of operators, we show that the specification property is equivalent to chaos in the sense of Devaney, and for generalized backward shift operators and operators in their commutants, we give a sufficient condition for an operator to have the specification property. (Received September 22, 2015)

1116-37-2404 **Tova Brown*** (tlindberg@math.arizona.edu). *Combinatorial Hamiltonian Dynamics.* Preliminary report.

Analytical Combinatorics brings to bear methods of complex function theory on the asymptotic analysis of enumerative generating functions. In recent times this subject has been gaining in popularity and applicability motivated by other developments in mathematics and computer science such as the study of random matrices and expander graphs. In this talk we will discuss some further extensions of this line of study that arise through analytical dynamics related to the combinatorics of maps. In particular we will focus on problems related to two aspects of four-valent maps: geodesic distance on the sphere and the asymptotics of generating functions for higher genus maps. We will show how both of these problems are connected to the same family of combinatorial dynamical systems which are in fact Hamiltonian in nature, a feature that is key in this study. (Received September 22, 2015)

1116-37-2433 **William Gignac*** (william.gignac@math.gatech.edu). *A nonarchimedean approach to local holomorphic dynamics in dimension two.*

Let f be a rational endomorphism of a complex algebraic surface X, and suppose that f has a fixed point x. Analyzing the dynamics of f near such a fixed point is often an essential step in understanding the global dynamical behavior of f on X. In this talk, I will describe a nonarchimedean approach to analyzing the local dynamics in the case when f is noninvertible near x. Instead of considering directly the dynamics of f near x in X, we will instead equip the field of complex numbers with the trivial absolute value and study the local dynamics of f near x in the corresponding Berkovich analytification of X. This will allow us to understand the dynamics of f on certain birationally equivalent models of X, and in turn deduce concrete information about the original (archimedean) dynamical system. Our main application is that one can almost always find modifications of X over x on which f exhibits a desirable "algebraic stability" property. (Received September 22, 2015)

1116-37-2501 **Brandon Edwards*** (edwardbr@math.oregonstate.edu). *Calculating Veech Groups of Translation Surfaces.* Preliminary report.

Translation surfaces are topological surfaces that when punctured are equipped with an atlas of local charts to the complex plane for which the transition functions are translations. This atlas gives us a well defined notion of whether or not a map from one translation surface to another has a constant Jocobian or is 'affine'. The Veech group of a translation surface is the group of Jacobians of orientation preserving affine automorphisms of the surface. The size of this group can inform us on the dynamics (periodic/ergodic) of the geodesic flow in a given direction [Veech 1989]. I will discuss an equivalent condition for Veech group membership that I use in an algorithm for computing generators of lattice Veech groups. (Received September 22, 2015)

1116-37-2552 **Rachel Neville*** (neville@math.colostate.edu). *Persistent Homology of Dynamical Systems on Networks.*

In this talk, we will look at patterns in networks of dynamical systems revealed through an extension of the ideas in persistent homology. Persistent homology is a technique in computational topology that captures multi-scale information regarding the longevity or size of topological features of data. In this case data is generated by networks of dynamical systems. To compare persistence diagrams, a technique called persistence images is used, which allows for machine learning techniques to be applied to persistence diagrams. (Received September 22, 2015)

1116-37-2576 **Victor Donnay** and **Daniel Visscher*** (davissch@umich.edu). *Constructing embedded surfaces with Anosov geodesic flows.* Preliminary report.

Standard examples of Anosov geodesic flows come from manifolds of negative curvature. Negative curvature is a sufficient but not necessary condition, however–Donnay and Pugh showed the existence of embedded surfaces (thus having positive total curvature) with Anosov geodesic flows. It is not known what the genus of such a surface can be; by a result of Klingenberg, it must be at least two. We construct an embedded surface with Anosov geodesic flow, and thus get a genus for which this is possible. (Received September 22, 2015)

1116-37-2592 **Skyler C. Simmons*** (simmons@mathematics.byu.edu), 275 TMCB, Brigham Young University, Provo, UT 84602. *Stability of Broucke's Isosceles Triangle Orbit.*

Broucke's Isosceles triangle configuration was among the first periodic non-collinear orbits of the Newtonian n-body problem which featured collisions between two of the bodies. In 2012, the orbit is known to be linearly stable when all masses are equal. I will present linear stability results over a wide range of mass ratios, and give a connection between this orbit and other collision-based periodic orbits. (Received September 22, 2015)

1116-37-2611 **Eric J Oden*** (odene@southwestern.edu), SU Box # 6939, 1001 E. University Ave., Georgetown, TX 78626. *A Physical Application of the Hypergeometric Function.*

A particular interest in physics classes is the case of the simple pendulum, whose period is approximated in undergraduate studies under the assumption of negligible amplitude during the oscillation (T = 2*pi*sqrt[L/g] , where L is the length of the pendulum and g is the acceleration due to gravity). Through an introduction of the Gaussian hypergeometric function, an exact solution for the period can be derived. In an expository demonstration, the function is introduced (as well as the preliminary Pochhammer symbol) and then applied to analysis of the physical system. The chaotic behavior of the double pendulum is then explored, including an investigation of its sensitivity to initial conditions. (Received September 22, 2015)

1116-37-2705 **Maria F Correia*** (mfac@uevora.pt), 115 Pine St, MA, 01002, and **Hongkun Zhang**. *Elliptic islands and ergodicity of a family of moon-shaped billiard tables.*

We construct a two-parameter family of moon-shaped billiard tables with boundary made of two circular arcs. These tables fail the defocusing mechanism and other known mechanisms that guarantee ergodicity and hyperbolicity. We analytically study the stability of some periodic orbits and prove there is a class of billiards in this family with elliptic periodic orbits. These moon billiards can be viewed as generalization of annular billiards which all have KAM islands. (Received September 22, 2015)

1116-37-2706 **Raluca Tanase*** (raluca.tanase@stonybrook.edu), Institute for Mathematical Sciences, Stony Brook University, Stony Brook, NY 11794-3660. *Julia sets and discrete group actions.*

Consider the standard family of complex Hénon maps $H(x, y) = (p(x) - ay, x)$, where p is a polynomial of degree $d \geq 2$ and a is a complex parameter. Any polynomial automorphism of $\mathbb{C}^2$ with nontrivial dynamics is conjugate to a composition of Hénon maps, hence the dynamics of the Hénon map is both interesting and challenging to study. Let U^+ be the set of points that escape to infinity under forward iterations. The boundary J^+ of U^+ is a complicated fractal object on which the Hénon map behaves chaotically. J. Hubbard and R. Oberste-Vorth gave a complete description of the analytic structure of U^+ as a quotient of $(\mathbb{C} - \overline{\mathbb{D}}) \times \mathbb{C}$ by a discrete group of automorphisms Γ isomorphic to $\mathbb{Z}[1/d]/\mathbb{Z}$. We show how to extend the group action to the boundary and represent the Julia set J^+ as a quotient of $\mathbb{S}^1 \times \mathbb{C}/\,\Gamma$ by an explicit equivalence relation. We analyze this extension for quadratic Hénon maps that are perturbations of hyperbolic polynomials or polynomials with a parabolic fixed point. (Received September 22, 2015)

1116-37-2924 **Diana Davis*** (diana@math.northwestern.edu). *Negative Refraction and Tiling Billiards.*

Inner billiards is the study of a particle bouncing around inside a billiard table; outer billiards is the study of a particle reflecting through tangent lines outside the billiard table. In this talk, I'll introduce the new *tiling billiards* system, which has a trajectory refracting through a planar tiling. This system has certain similarities to both inner and outer billiards, and has very beautiful dynamics. It is motivated by a recent discovery in physics, of physical materials with negative indices of refraction. I'll discuss some results and open questions, and show some beautiful pictures. (Received September 23, 2015)

39 ► Difference and functional equations

1116-39-53 **Jeffrey T Neugebauer*** (jeffrey.neugebauer@eku.edu), 521 Lancaster Ave., 313 Wallace Building, Eastern Kentucky University, Richmond, KY 40475-3133. *Existence and Comparison Results for Fourth Order Discrete Eigenvalue Problems.*

We study the existence and comparison of smallest positive eigenvalues of the fourth order difference equations $\Delta^4 y_{i-2} = \lambda_1 p_i y_i$, $\Delta^4 y_{i-2} = \lambda_2 q_i y_i$, $i \in \{1, \ldots, n\}$, each satisfying the boundary conditions $y_0 = \Delta^2 y_{-1} = \Delta y_n = \Delta^3 y_{n-1}$, by applying the theory of u_0-positive operators with respect to a cone in a Banach space. (Received June 26, 2015)

1116-39-473 **Nicholas Joseph Russell*** (nicholas.russell1@marist.edu), Department of Mathematics, Marist College, Poughkeepsie, NY 12601, and **Lingju Kong**, **Jacob Parsely** and **Kaitlin Rizzo**. *Anti-Periodic Solutions to a Higher Order Difference Equation with a p-Laplacian.*

We study a higher order difference equation defined on Z with a p-Laplacian and containing both advance and retardation. We obtain some criteria for the existence of infinitely many anti-periodic solutions of the equation. Several consequences of the main theorems are also presented. An example is included to illustrate the applicability of the results. (Received September 03, 2015)

1116-39-585 **Vlajko L Kocic*** (vkocic@xula.edu), Mathematics Department, Xavier University of Louisiana, 1 Drexel Dr., New Orleans, LA 70125, **Raegan J Higgins** (raegan.higgins@ttu.edu), Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409, **Candace M Kent** (cmkent@vcu.edu), Department of Mathematics, Virginia Commonwealth University, Richmond, VA 23284, and **Yevgeniy Kostrov** (ykostrov@xula.edu), Mathematics Department, Xavier University of Louisiana, 1 Drexel Dr., New Orleans, LA 70125. *Dynamics of nonlinear discrete discontinuous population model.*

In this paper we study the dynamics of a class of nonilinear discrete population models exhibiting Allee-type effects. In particular we focus on oscillations, structure of semicycles, periodicity, and attractivity are addressed.
(Received September 08, 2015)

1116-39-594 **Youssef Naim Raffoul*** (yraffoul1@udayton.edu), 300 College park, Dayton, OH 45469-2316. *Exponential Stability And Instability In Multiple Delays Difference Equations.*

We use Lyapunov functionals and obtain sufficient conditions that guarantee exponential stability of the zero solution of the difference equation with multiple delays

$$x(t+1) = a(t)x(t) + \sum_{j=1}^{k} b_j(t)x(t-h_j)$$

The novelty of our work is the relaxation of the condition $|a(t)| < 1$, in spite of the presence of multiple delays. Using a slightly modified Lyapunov functional, we obtain necessary conditions for the unboundedness of all solutions and for the instability of the zero solution. We provide an example as an application to our obtained results.
(Received September 08, 2015)

1116-39-669 **Murat Adivar*** (murat.adivar@ieu.edu.tr), Izmir University of Economics, Department of Mathematics, Balcova, 35330 Izmir, Turkey, and **Can Koyuncuoglu** (can.koyuncuoglu@ieu.edu.tr), Izmir University of Economics, Department of Mathematics, 35330 Izmir, Turkey. *Almost automorphic solutions of discrete delayed neutral system.*

We study almost automorphic solutions of the discrete delayed neutral dynamic system

$$x(t+1) = A(t)x(t) + \Delta Q(t, x(t-g(t))) + G(t, x(t), x(t-g(t)))$$

by means of discrete variant of exponential dichotomy and fixed point theory. We prove uniqueness of the projector of discrete exponential dichotomy and obtain some limit results leading to sufficient conditions for the existence of almost automorphic solutions of the neutral system. Unlike the existing literature we prove our existence results without assuming boundedness of inverse matrix $A(t)^{-1}$. Therefore, we significantly improve the existence results in the literature. We give two examples to illustrate effectiveness of our results. Finally, we also provide an existence result for almost periodic solutions of the system. (Received September 10, 2015)

1116-39-970 **U G Abdulla**, **Rashad U Abdulla**, **Muhammad U Abdulla**, **Alyssa Turnquist** and **Naveed H Iqbal*** (nchaudhr@my.fit.edu). *On the Fine Classification of Periodic Orbits of the Continuous Endomorphisms on the Real Line and Universality in Chaos.*

We pursue the classification of periodic orbits of continuous endomorphisms on $\mathbb{R}$ and clarify the structure and distribution of periodic orbits within the chaotic regime for the discrete nonlinear dynamical systems. By developing a new constructive method suggested by Abdulla et al. JDEA, 19(2013), no.9, we complete the classification of minimal orbits. We advance an open problem on the structure of the second minimal odd orbits, which are defined as those that immediately follow the minimal orbits under the Sharkovski ordering. We prove there are 9 types of second minimal 7-orbits with accuracy up to inverses. We apply this result to the problem on the distribution of superstable periodic windows within the chaotic regime of the bifurcation diagram of the one-parameter family of unimodal maps. It is revealed that by fixing the maximum number of appearances of the periodic windows there is a universal pattern of distribution. Another development of this research is the revelation of the pattern of the pattern dynamics with respect to increased number of appearances. Understanding the nature and characteristics of this fascinating universal route and classification of all the second minimal odd orbits is an outstanding open problem (Received September 15, 2015)

1116-39-973 **Carol H Gibbons**, **Senada Kalabusic** and **Carol B Overdeep*** (coverdeep@stmartin.edu), 5000 Abbey Way SE, Lacey, WA 98503. *More results on the trichotomy character of a second-order rational difference equation with period-two coefficients.*

We extend the known results of $x_{n+1} = \frac{\beta_n x_n + \gamma_n x_{n-1}}{A_n + B_n x_n}$ to the situation where (i) the parameters β_n, γ_n, A_n, and B_n are period-two sequences of nonnegative real numbers with γ_n not identically zero and $A_n + B_n \neq 0$; and (ii) the initial conditions x_{-1} and x_0 are such that $x_{-1}, x_0 \in [0, \infty)$ and $x_{-1} + x_0 \in (0, \infty)$. (Received September 15, 2015)

1116-39-1050 **Saber n. Elaydi*** (selaydi@trinity.edu), one Trinity place, san antonio, TX 78212. *Triangular maps and multi-species hierarchical competition models with the Allee effect.* Preliminary report.

A general notion of the Allee effect for higher-dimensional triangular maps is proposed. A global dynamics theory is established. The theory is applied to multi-species hierarchical models. Then we provide a detailed study of the global dynamics of three-species Ricker competition models with the Allee effect. Regions of extinction, exclusion, and coexistence are identified.
(Received September 16, 2015)

1116-39-1177 **Nika Lazaryan*** (lazaryans@vcu.edu) and **Hassan Sedaghat**. *Periodic and Non-Periodic Solutions and Multistability in a Second-Order Ricker Equation with Periodic Coefficients.* Preliminary report.

We study a second-order nonautonomous difference equation with periodic coefficients. The equation is derived from stage-structured population model with Ricker-type recruitment function. We show that the equation has periodic solutions, as excepted. However, the range of variation, or amplitude of the periodic coefficients, as well as whether their period is even or odd also play decisive roles. We show that the two cases where the coefficients have even or odd period lead to fundamentally different types of behaviors for the solutions of the equation. (Received September 17, 2015)

1116-39-1214 **Ralph Willox*** (willox@ms.u-tokyo.ac.jp), Graduate School of Mathematical Sciences, the University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo, 153-8914, Japan. *Singularity confinement 2.0 : an easily implementable and sufficient integrability criterion, at last ?*

It will be explained how the singularity confinement approach to detecting integrability in mappings of the plane, can be upgraded such that it becomes a sufficient integrability criterion. Notions such as ‘full deautonomisation’ and ‘late confinement’ which play a crucial role in this approach will be explained and, if time permits, the case of so-called anti-confining mappings will also be touched upon. (Received September 17, 2015)

1116-39-1226 **Adrian Stefan Carstea*** (carstea@gmail.com), National Institute of Physics and, Nuclear Engineering, Dept. of Theoretical, Phyics, Bucharest, Romania. *Lattice supersymmetric Korteweg de Vries equation and super-QRT mappings.*

Two integrable discretizations of supersymmetric KdV equation are constructed using Hirota's bilinear formalism. The integrability is established by constructing multi-supersoliton solution which displays two different type of interactions between supersolitons. Travelling wave reduction is also performed and the emergent super-QRT mapping is analyzed. The interesting fact is that, despite its integrability, it has unconfined singularities. (Received September 18, 2015)

1116-39-1484 **Teruhisa Tsuda*** (tudateru@econ.hit-u.ac.jp). *Hermite-Pade approximation, isomonodromic deformation and hypergeometric integral.*

This talk is based on a joint work with Toshiyuki Mano. (Ref: arXiv:1502.06695 [math.CA]) We develop an underlying relationship between the theory of rational approximations and that of isomonodromic deformations. We show that a certain duality in Hermite's two approximation problems leads to the Schlesinger transformations, i.e. transformations of a linear differential equation shifting its characteristic exponents by integers while keeping its monodromy invariant. Since approximants and remainders are described by block-Toeplitzs determinants, one can clearly understand the determinantal structure in isomonodromic deformations. We demonstrate our method in a certain family of Hamiltonian systems of isomonodromy type including the sixth Painlevé equation and Garnier systems; particularly, we present their solutions written in terms of iterated hypergeometric integrals. An algorithm for constructing the Schlesinger transformations is also discussed through vector continued fractions. (Received September 20, 2015)

1116-39-1496 **Candace M. Kent*** (cmkent@vcu.edu), 3510 Hanover Avenue, Richmond, VA 23221.
Piecewise-Defined Difference Equations with Every Solution Eventually Periodic: Open Problem.

We consider piecewise-defined autonomous and nonautonomous difference equations of the form

$$x_{n+1} = f_n(x_n, x_{n-1}, \ldots, x_{n-k}), \quad n = 0, 1, \ldots,$$

where $k \in \{0, 1, \ldots\}$, f_n is piecewise defined, and $f_n : D^{k+1} \to D$, $D \subset \mathbf{R}$, whose behavior of solutions is such that every solution is eventually periodic. We ask, "Why?" in most circumstances and "Why not?" in a few cases. This behavior of having every solution in D eventually periodic may occur in one of the following two settings:

(i) certain conditions on the parameters of the equation are present;

(ii) under all conditions on parameters of the equation.

We dedicate this talk to E.A. Grove and G. Ladas of the University of Rhode Island who asked the same question specifically with regard to reciprocal max-type difference equations. (Received September 20, 2015)

1116-39-1698 **William T Jamieson*** (jamieson_william@wheatoncollege.edu), Dept. of Mathematics and Computer Science, Wheaton College, 26 East Main Street, Norton, MA 02766. *A Classification of the Local Dynamics of Some Real Analytic Nonhyperbolic Planar Maps.*

A complete classification of the qualitative behavior of real analytic planar maps in a neighborhood of an isolated fixed point with exactly one characteristic value equal to ± 1 will be presented. (Received September 21, 2015)

1116-39-1781 **Heather Hunt Elfen***, Robert Morris University, 6001 University Blvd, Moon Township, PA 15108, and **Thomas Riedel** and **Prasanna Sahoo**. *A Functional Equation On Groups With An Involution Related To Quadratic Polynomials.*

Let G be a group and $\mathbb{C}$ the field of complex numbers. Suppose $\sigma : G \to G$ is an involution on G. We present the central solution $f : G \times G \to \mathbb{C}$ of the functional equation

$$\begin{aligned} &f(x_1\sigma y_1, x_2\sigma y_2) - f(x_1\sigma y_1, x_2) - f(x_1, x_2\sigma y_2) \\ &\qquad = f(x_1y_1, x_2y_2) - f(x_1y_1, x_2) - f(x_1, x_2y_2) \end{aligned}$$

for all $x_1, x_2, y_1, y_2 \in G$ based upon solutions of the functional equations

$$f(xy) + f(x\sigma y) = 2f(x)$$
$$f_1(xy) + f_2(x\sigma y) = f_3(x)$$

where $f, f_1, f_2, f_3 : G \to \mathbb{C}$. (Received September 21, 2015)

1116-39-1855 **Turhan Koprubasi*** (tkoprubasi@kastamonu.edu.tr), 1325 Waterford Oak Drive #305, Orlando, FL 32828. *SPECTRAL PROPERTIES OF DISCRETE STURM-LIOUVILLE EQUATION WITH QUADRATIC EIGENPARAMETER IN BOUNDARY CONDITION.*

Let the boundary value problem,

$$a_{n-1}y_{n-1} + b_ny_n + a_ny_{n+1} = \lambda y_n \ , \ n \in \mathbb{N},$$
$$(\gamma_0 + \gamma_1\lambda + \gamma_2\lambda^2)y_1 + (\beta_0 + \beta_1\lambda + \beta_2\lambda^2)y_0 = 0,$$

is considered where (a_n), (b_n) are complex sequences for $n \in \mathbb{N}$, $\gamma_i, \beta_i \in \mathbb{C}$ for $i = 0, 1, 2$ and λ is a eigenparameter. In this study, several spectral properties of the above boundary value problem as Jost solution, Jost function, eigenvalues and spectral singularities are mentioned for the condition

$$\sup_{n\in\mathbb{N}} \left[\exp(\varepsilon n^\delta)\left(|1 - a_n| + |b_n|\right)\right] < \infty,$$

where $\varepsilon > 0$ and $\frac{1}{2} \le \delta \le 1$. (Received September 21, 2015)

1116-39-1857 **Allan C. Peterson*** (apeterson1@math.unl.edu), 1144 T Street, Lincoln, NE 685880130, and **Bioguo Jia** and **Erbe Lynn**. *Comparison Theorems for Discrete Caputo Fractional Equations.*

We will prove comparison theorems for discrete Caputo fractional difference equations. Also qualitative results for fractional equations will be given along with examples. (Received September 21, 2015)

1116-39-2130 **Julia St. Goar*** (s-jstgoar1@math.unl.edu). *A Nonlinear Fractional Boundary Value Problem in Nabla Fractional Calculus.*

After reviewing the area of Nabla Fractional Calculus, we will consider a nonlinear right focal boundary value problem involving the Caputo difference operator in this context. We will define a Green's function and prove the existence of a positive solution by using cone theory. (Received September 21, 2015)

1116-39-2251 **Adrian Stefan Carstea**, **Anton Dzhamay** and **Tomoyuki Takenawa*** (takenawa@kaiyodai.ac.jp), 2-1-6 Etchu-jima, Koto-ku, Tokyo, 135-8533, Japan. *Fiber-dependent deautonomisation of integrable 2D mappings.* Preliminary report.

Although it is well known that the QRT mappings, two-dimensional mappings preserving a rational elliptic fibration, can be deautonomized to discrete Painlevé equations, it has not been well studied that how this procedure depends on the choice of the fibers. In this talk we establish the way of deautomization for the pairs of a QRT mapping and a fiber. (Received September 22, 2015)

1116-39-2305 **Hidetaka Sakai***, Graduate School of Mathematical Sciences, The University of Tokyo, Komaba 3-8-1, Meguro-ku, Tokyo, 153-8914, Japan. *Discrete Painlevé equations.*

The discrete Painlevé equations, which are a discrete analog of the Painlevé differential equations, were constructed by the research group led by A. Ramani and B. Grammaticos. These equations are associated with rational surfaces that are similar to, but slightly different from, the rational elliptic surfaces. By using theory of rational surfaces, we can comprehend algebraic properties of the equations, such as symmetry, special solutions, and so on. In this talk, I would like to present a simple introduction of the relation between the discrete Painlevé equations and the surface theory. (Received September 22, 2015)

1116-39-2405 **Marco Hamins-Puertolas*** (mghaminspuertola@smcm.edu), **Jessie Conrad**, **Genesis Islas**, **Adrien Bossogo-Egoume**, **Christopher Kribs** and **Benjamin Morin**.
Minimizing recidivism by optimizing profit: a theoretical case study of incentivized reform in a Louisiana prison.

Recidivism is the phenomenon where an individual returns to criminal activity after being released from prison. Many prisoners in the U.S. end up back in jail within 5 years. Using Louisiana as a case study, we show that prison management can minimize recidivism by subsidizing reform programs in for-profit prisons. Accounting for such an incentive program allows us to observe alterations in prison profit optimization. Within the model, the prison alters the proportion of time that each inmate spends in the reform program. The incarceration dynamics respond to the average proportion of time that prisoners spend in reform. We determine that the prison's profit is the most sensitive to the value of the incentive, the fixed cost per prisoner, the effectiveness of the instated reform program, the number of first time offenders currently in the prison, and the per diem rate per prisoner the prison receives from the state. Prisons with higher initial incomes require a larger incentive to obtain the same results as their less profitable neighbors. The reduction in recidivism has diminishing returns as the incentive is increased. (Received September 22, 2015)

1116-39-2527 **Catherine Payne*** (capayne2@uncg.edu) and **R. Fabiano**. *Stability conditions for linear neutral delay differential equations.* Preliminary report.

We study the stability of the C_0 semigroup associated with a neutral delay differential equation of the form

$$\frac{d}{dt}\left[x(t)+\sum_{k=1}^{n} C_k x(t-r_k)\right] = Ax(t)+\sum_{k=1}^{n} B_k x(t-r_k)$$

with initial data $x(0)+\sum_{k=1}^{n} C_k x(-r_k) = \eta_0$ for a given $\eta_0 \in \mathbb{C}^m$ and $x(\theta) = f_0(\theta)$ on $[-r_n, 0)$ for a given function $f_0(\theta) \in L_2(-r_n, 0; \mathbb{C}^m)$. We assume that A, $B_1, B_2, \ldots, B_n$ and $C_1, C_2, \ldots, C_n$ are complex $m \times m$ matrices for $m \in \mathbb{N}$. We search for delay-independent sufficient conditions on the matrices for exponential stability of the solution semigroup associated with this equation. In the case where A, B_i, and C_i are scalars, the best condition is known. In particular, Li proved a sufficient condition for a neutral equation with one delay and real matrices. Hu and Hu later improved this condition, which has been extended to multiple delays. These results are based on direct analysis of the associated characteristic equation. We obtain another sufficient condition by renorming the state space to obtain a strong dissipative inequality on the generator of the solution semigroup, and compare our condition to others. (Received September 22, 2015)

1116-39-2689 **Christopher M Ormerod*** (cormerod@caltech.edu), 1200 E California Blvd, Mathematics, MC 253-37, Caltech, Pasadena, CA 91125. *Discrete Garnier Sysetms.*

We present four classes of nonlinear systems which may be considered discrete analogues of Garnier systems. These systems arise as discrete isomonodromic deformations of systems of linear difference equations in which the associated matrices is presented in a factored form. The system of discrete isomonodromic deformations is completely determined by the commutation relation between factors. A distinguishing feature of this study is the presence of a symmetry condition on the associated linear probelms that only appears in Lax pairs for the least degenerate discrete Painleve equations. (Received September 22, 2015)

1116-39-2704 **Deja R Washington*** (dwashi11@xula.edu), 801 S Jefferson Davis Parkway, LLC Room 516a, New Orleans, LA 70125. *On the Boundedness Character of the First Order System of Rational Difference Equations with Nonconstant Coefficients.*

We will establish the boundedness character of the following system of rational difference

$$\begin{cases} x_{n+1} = \frac{\alpha_n}{\beta_n x_n + y_n} \\ y_{n+1} = \frac{a_n + c_n y_n}{A_n + x_n} \end{cases}$$

where the coefficients of the system are bounded sequences of nonnegative numbers, and the initial conditions x_0 and y_0 are nonnegative numbers, such the denominators are always positive. (Received September 22, 2015)

1116-39-2790 **M. N. Nkashama*** (nkashama@math.uab.edu), Department of Mathematics, University of Alabama at Birmingham, Birmingham, AL 35294-1170. *Asymptotic Behavior of Solutions to Neutral and Delay Functional Differential Equations.* Preliminary report.

We will present asymptotic behavior results for initial value and initial boundary value problems for delay and neutral functional differential equations. Some special equations coming up in applications will be considered. (Received September 22, 2015)

40 ► Sequences, series, summability

1116-40-329 **Simon Rubinstein-Salzedo*** (simon@eulercircle.com), Palo Alto, CA 94306, and **Ashvin Swaminathan** (aaswaminathan@college.harvard.edu). *Analysis on surreal numbers.*

The surreal numbers form a Field that shares many algebraic properties with the field of real numbers. By contrast, the analytic properties of the surreal numbers and surreal functions are more subtle. In this talk, we describe some properties that we might hope that a formulation of surreal analysis would have (and why we are sometimes disappointed), and we discuss one possible approach to surreal analysis that mimics much of real analysis. Ashvin Swaminathan's talk in the same session will discuss further aspects of our approach to surreal analysis. (Received August 25, 2015)

1116-40-2472 **Thomas J. Osler*** (osler@rowan.edu), Mathematics Department, Glassboro, NJ 08028. *Iterations for the lemniscate constant resembling the Archimedean algorithm for π.*

The lemniscate constant $L = 2.62205755429212\ldots$ is one half the perimeter of the unit lemniscate curve just as pi is one half the perimeter of the unit circle. It is well know that the Archemedian iterative algorithm

(1) $a(n+1) = 2a(n)b(n)/(a(n)+b(n))$ and

(2) $b(n+1) = \sqrt{a(n+1)b(n)}$ with initial values $a(1) = 4$ and $b(1) = 2\sqrt{2}$ converges to π.

In this paper we show that the iterative algorithm

(3) $a(n+1) = 2a(n)a(n)/(a(n)+b(n))$ and

(4) $b(n+1) = \sqrt{a(n+1)b(n)}$

with initial values $a(1) = 4$ and $b(1) = 2\sqrt{2}$ converges to the lemniscate constant L.

Notice that the only change is that $b(n)$ in (1) has been replaced by $a(n)$ in (3). (2) is exactly the same as (4) and the initial values are the same. The derivation is based on an infinite product of nested radicals given in recent years by Aaron Levin ([1] and [2]) that resembles the famous product of nested radicals for π by Vieta.

[1] Levin, A., A New Class of Infinite Products Generalizing Vi'ete's Product Formula for π, The Ramanujan Journal, 10(2005), pp. 305–324.

[2] Levin, A., A Geometric Interpretation of an Infinite Product for the Lemniscate Constant, The American Mathematical Monthly, Vol. 113, No. 6 (Jun. - Jul., 2006), pp. 510-520 (Received September 22, 2015)

41 ► Approximations and expansions

1116-41-31 **George A Anastassiou** (ganastss2@gmail.com), Department of Mathematical Sciences, University of Memphis, Memphis, TN 38152, and **Merve Kester*** (mkester@memphis.edu), Department of Mathematical Sciences, University of Memphis, Memphis, TN 38152. *Lp Approximation with Rates by Multivariate Generalized Discrete Singular Operators.*

Here we give the approximation properties with rates of multivariate generalized discrete versions of Picard, Gauss-Weierstrass, and Poisson-Cauchy singular operators over R to N, N greater equal 1. We treat both the unitary and non-unitary cases of the operators above. We derive quantitatively Lp convergence of these operators to the unit operator by involving the Lp higher modulus of smoothness of an Lp function. (Received June 05, 2015)

1116-41-33 **George A Anastassiou*** (ganastss2@gmail.com), Department of Mathematical Sciences, University of Memphis, Memphis, TN 38152. *Bivariate Left Fractional Polynomial Monotone Approximation.*

Let f be continuously differentiable on unit square of order (r,p), r, p in N, and let L be a linear left fractional mixed partial differential operator such that L(f) is non-negative, for all (x,y) in a critical region of unit square that depends on L. Then there exists a sequence of two-dimensional polynomials Qm,n(x,y) with L(Qm,n(x,y)) non-negative there, where m,n in N such that m>r, n>p, so that f is approximated left fractionally simultaneously and uniformly by Qm,n on unit square. This restricted left fractional approximation is accomplished quantitatively by the use of a suitable integer partial derivatives two-dimensional first modulus of continuity. (Received June 05, 2015)

1116-41-630 **Mohsen Razzaghi*** (razzaghi@math.msstate.edu), Department of Mathematics and Statistics, Allen Hall, Mississippi State, 39762. *Taylor series, and hybrid functions approximations for dynamical systems.*

Orthogonal functions and Taylor series, often used to represent an arbitrary time function, have recently been used to solve various problems of the dynamical systems. The main advantage of using orthogonal functions and Taylor series is that they reduce the dynamical systems problems to those of solving a system of algebraic equations.

In the present work, the Taylor series is first used to find the numerical solution of variational problems. It will be shown that to obtain the solution by using Taylor series, we need to use an ill conditioned matrix and hence, the applications of Taylor series are not satisfactory. To overcome this difficulty, we use the hybrid of block-pulse and Legendre polynomials. A numerical example is included to demonstrate the validity and applicability of the technique, and a comparison is made with existing results. (Received September 09, 2015)

1116-41-1244 **Jeff Ledford*** (jpledford@vcu.edu). *Polyhyperbolic Cardinal Splines.* Preliminary report.

In this talk we discuss solutions of differential equation $(D^2 - \alpha^2)^k u = 0$ on $\mathbb{R} \setminus \mathbb{Z}$, which we call polyhyperbolic splines. We develop the fundamental function of interpolation and cover various properties related to these splines. (Received September 18, 2015)

1116-41-1834 **Tariq M Qazi***, Department of Mathematics & Economics, Petersburg, VA 23806. *Inequalities for entire functions of exponential type.* Preliminary report.

We will discuss some inequalities for entire functions of exponential type which extend some known polynomial inequalities. (Received September 21, 2015)

1116-41-2013 **Alan M Lattimer*** (alattime@vt.edu), 130 Somerset St, Christiansburg, VA 24073. *Survey of Input-independent Model Reduction Techniques for Nonlinear Dynamical Systems.*

Controlling large-scale non-linear dynamical systems resulting from partial differential equation models is prohibitive and thus requires simplification, for example model reduction. When the objective is to approximate the system output given various inputs, the Iterative Rational Krylov Algorithm (IRKA) has been used with a high degree of success on linear systems by interpolating the transfer function. However, for nonlinear systems, proper orthogonal decomposition (POD) is on of the most common techniques used for reduction. This talk will focus on various ways that input-independent model reduction techniques, such as IRKA, can be modified to reduce nonlinear dynamical systems. Further, we look at how some of these techniques compare favorably to POD for the Burgers' equation. (Received September 21, 2015)

1116-41-2044 **Xiang-Sheng Wang*** (xswang@semo.edu). *Asymptotic analysis of difference equations.* Preliminary report.

Difference equations arise naturally from the study of orthogonal polynomials and continued fractions. In this talk, we will investigate asymptotic behaviors of solutions to difference equations with general coefficients. A unified technique will be developed to study asymptotic solutions in the outer and oscillatory regions, respectively. Uniform asymptotic solutions near the origin will also be discussed. (Received September 21, 2015)

1116-41-2907 **Palle E. T. Jorgensen*** (palle-jorgensen@uiowa.edu), Dept Math MLH, University of Iowa, Iowa City, IA 52242. *Operators and classification in sub-band filtering.*

We study systems of non-commuting operators arising in sub-band filters; and we give an account of new results on use of representations of the Cuntz relations O_N(a particular systems of non-commuting operators) in a class of filter problems (including the study of fractals, and geometric measure theory). This versatility is not surprising since Cuntz algebras are infinite algebras on a finite number of generators, and defined from certain relations. By their nature, these representations reflect intrinsic selfsimilar inherent in the problem at hand; and thus they serve ideally to encode iterated function systems (IFSs), their dynamics, and their measures. At the same time, the O_N -representations offer a new harmonic analysis of signals. Even though the Cuntz algebras initially entered into the study of operator-algebras and physics, in recent years these same Cuntz algebras, and their representation, have found increasing use in applied problems, such as wavelets, fractals, and signals. (Received September 23, 2015)

1116-41-2949 **Vidhya KrishnasamySaraswathy*** (vk81@msstate.edu), 319 North Jackson Street, Apt 4C, Starkville, MS 39759, and **Razzaghi Mohsen** (razzaghi@math.msstate.edu), Allen Hall, fourth floor, Mississippi State University, Mississippi State, MS 39762. *Approximate solution for the fractional integro-differential equations with fractional Taylor method.*

A new numerical method for solving the fractional integro-differential equations is given. This method is based on using fractional Taylor vector approximation. The operational matrix of the fractional integration for fractional Taylor vector is found and is utilized to reduce the solution of the fractional integro-differential equations to a system of algebraic equations. Illustrative examples demonstrates the validity and applicability of this technique. (Received September 23, 2015)

42 ► Fourier analysis

1116-42-132 **Christopher Sogge**, **Xing Wang** and **Jiuyi Zhu*** (jzhu43@math.jhu.edu). *Doubling estimates, vanishing order and nodal sets of Steklov eigenfunctions.* Preliminary report.

Recently the study of Steklov eigenfunctions has been attracting much attention. We investigate the qualitative and quantitative properties of Steklov eigenfunctions. We obtain the sharp doubling estimates for Steklov eigenfunctions on the boundary and interior of the manifold using Carleman inequality. As an application, optimal vanishing order is derived, which describes quantitative behavior of strong unique continuation property. We can ask Yau's type conjecture for the Hausdorff measure of nodal sets of Steklov eigenfunctions. We derive the lower bounds for interior and boundary nodal sets. In two dimensions, we are able to obtain the upper bounds for singular sets and nodal sets. Part of work is joint with Chris Sogge and X. Wang (Received August 10, 2015)

1116-42-187 **Christopher Ryan Loga*** (loga@math.utk.edu), 2734 Bakertown Rd., Apt. 18, Knoxville, TN 37931. *An Extension Theorem for Matrix Weighted Sobolev Space on a Lipschitz Domain.* Preliminary report.

Let $D \subset \mathbb{R}^n$ be a bounded Lipschitz domain and $1 < p < \infty$. Suppose for each $x \in \mathbb{R}^n$ that $W(x)$ is an $m \times m$ positive definite matrix which satisfies the matrix A_p condition. For $k = 0, 1, 2, 3, ...$ define the matrix weighted, vector valued, Sobolev space $L^p_k(D, W)$ with norm

$$\left|\left|\overrightarrow{f}\right|\right|^p_{L^p_k(D,W)} = \sum_{|\alpha|\le k} \int_D \left|\left| W^{1/p}\left(D^\alpha \overrightarrow{f}\right)\right|\right|^p \mathrm{d}x$$

where $\overrightarrow{f} = (f_1, \ldots, f_m) : D \to \mathbb{C}^m$. We show that for $\overrightarrow{f} \in L^p_k(D, W)$ there exists an extension $E\left(\overrightarrow{f}\right) \in L^p_k(\mathbb{R}^n, W)$ such that $E\left(\overrightarrow{f}\right) = \overrightarrow{f}$ on D and

$$\left|\left|E\left(\overrightarrow{f}\right)\right|\right|_{L^p_k(\mathbb{R}^n,W)} \le C \left|\left|\overrightarrow{f}\right|\right|_{L^p_k(D,W)}$$

for some constant independent of $\overrightarrow{f}$. This generalizes a known result for scalar A_p weights. (Received August 12, 2015)

1116-42-463 **Guozhen Lu** and **Lu Zhang*** (eu4347@wayne.edu). *L^p estimate for a bi-parameter trilinear pseudo-differential operator.*

We mainly study the L^p Hölder type estimate for a bi-parameter trilinear pseudo-differential operator, where the symbol is a product of two standard symbols in the bi-parameter Hörmander class $BBS^0_{1,0}$. Usually the difficulty for such work is to establish a Hölder type estimate for a corresponding bi-parameter flag type Fourier multiplier operator. In our work, we establish a modified result to overcome that difficulty, which enables us to get the desired L^p estimate for the bi-parameter trilinear pseudo-differential operators. In the proof we take advantage of a localization argument and some analysis on paraproducts as well. Such operators are bi-parameter pseudo-differential variants of flag paraproducts studied by of C. Muscalu. (Received September 02, 2015)

1116-42-470 **C Beneteau**, **D Khavinson**, **C Liaw** and **D Seco*** (dseco@mat.uab.cat), Departament de Matematica Aplicada i Analisi, Gran Via 585, 08001 Barcelona, Barcelona, Spain, and **A A Sola**. *Orthogonal polynomials and cyclicity.*

We present and exploit a connection between the orthogonal polynomials in certain spaces of functions and the closed subspaces generated by finitely many iterations of the shift starting from a function f in a Hilbert space of analytic functions over the disk. In this way, we give several new equivalent definitions of cyclicity and other applications. (Received September 03, 2015)

1116-42-752 **Jongchon Kim*** (jkim@math.wisc.edu). *Recent progress on radial Fourier multipliers and some generalizations.*

Recently, important progress has been made on the L^p mapping properties of radial Fourier multipliers. We review the results and introduce some generalizations. In particular, we prove a necessary and sufficient condition for a class of quasiradial Fourier multipliers and associated maximal functions to be bounded on $L^p(\mathbb{R}^d)$ for $d \geq 4$ and $1 < p < \frac{2(d-1)}{d+1}$, which generalizes a result by Heo, Nazarov and Seeger. (Received September 11, 2015)

1116-42-878 **Laura Cladek*** (cladek@math.wic.edu), 480 Lincoln Dr., Madison, WI 53706. *Bochner-Riesz multipliers associated to convex planar domains with rough boundary.*

We consider generalized Bochner-Riesz multipliers $(1-\rho(\xi))_+^\lambda$ where $\rho(\xi)$ is the Minkowski functional of a convex domain in $\mathbb{R}^2$, with emphasis on domains for which the usual Carleson-Sjölin L^p bounds can be improved. We produce convex domains for which previous results due to Seeger and Ziesler are not sharp. For integers $m \geq 2$, we find domains such that $(1-\rho(\xi))_+^\lambda \in M^p(\mathbb{R}^2)$ for all $\lambda > 0$ in the range $\frac{m}{m-1} \leq p \leq 2$, but for which $\inf\{\lambda : (1-\rho)_+^\lambda \in M_p\} > 0$ when $p < \frac{m}{m-1}$. We identify two key properties of convex domains that lead to improved L^p bounds for the associated Bochner-Riesz operators. First, we introduce the notion of the "additive energy" of the boundary of a convex domain. Second, we associate a set of directions to a convex domain and define a sequence of Nikodym-type maximal operators corresponding to this set of directions. We show that domains that have low higher order energy, as well as those which have asymptotically good L^p bounds for the corresponding sequence of Nikodym-type maximal operators, have improved L^p bounds for the associated Bochner-Riesz operators over those proved by Seeger and Ziesler. (Received September 14, 2015)

1116-42-915 **Malabika Pramanik*** (malabika@math.ubc.ca). *Point configurations in sparse sets.*

When does a Lebesgue-null set in Euclidean space contain an affine copy of a finite point configuration? The answer, not surprisingly, is when the set has large size, measured in terms of dimension. What is remarkable is that the answers turn out to be quite different depending on the notion of dimension used. I will give a survey of the literature based on this theme, and discuss joint work in part with Vince Chan, Allan Greenleaf, Kevin Henriot, Alex Iosevich and Izabella Laba. (Received September 15, 2015)

1116-42-1064 **Izabella Laba*** (ilaba@math.ubc.ca), Department of Mathematics, UBC, Vancouver, BC V6T1Z2, Canada. *Polynomial configurations in fractal sets.*

We prove that if μ is a measure on $\mathbb{R}^n$ obeying the appropriate ball condition and Fourier decay assumption (in particular, the Hausdorff dimension of its support must be sufficiently close to n), then the support of μ must contain certain configurations defined by nondegenerate matrix systems with a polynomial term. This extends the earlier work of Chen, Laba and Pramanik to a new polynomial setting. (Joint work with Kevin Henriot and Malabika Pramanik.) (Received September 16, 2015)

1116-42-1681 **Leonid Slavin*** (leonid.slavin@uc.edu) and **Vasily Vasyunin**. *The John–Nirenberg constant of* BMO^p.

For $p > 0$, BMO^p is the space of all functions φ for which the quantity $\|\varphi\|_{\mathrm{BMO}^p} := \sup_{\text{interval } Q} \big(\frac{1}{|Q|}\int_Q |\varphi - \frac{1}{|Q|}\int_Q \varphi|^p\big)^{1/p}$ is finite. The John–Nirenberg constant of BMO^p, $\varepsilon_0(p)$, is the supremum of all $c_0 > 0$ for which there exists a $C_1 > 0$ such that for any interval Q and any $\lambda \geq 0$,

$$\frac{1}{|Q|}\big|\{t \in Q : |\varphi(t) - \tfrac{1}{|Q|}\textstyle\int_Q \varphi| \geq \lambda\}\big| \leq C_1 e^{-c_0\lambda/\|\varphi\|_{\mathrm{BMO}^p}}.$$

This constant has proved difficult to compute: until recently, the only known cases were $p = 1$ and $p = 2$. We deal with this difficulty by considering the dual problem of estimating (from below) the BMO^p norms of logarithms of A_∞ weights. As a result, we obtain $\varepsilon_0(p)$ for all $p \geq 1$ and also show that for $1 \leq p \leq 2$ it is attained as c_0 above.

The proof relies on the computation of the appropriate Bellman functions, which in this setting are optimal convex solutions of the homogeneous Monge–Ampère equation on a non-convex plane domain. The geometry of these solutions is substantially different for different ranges of p. Part of the work is joint with Vasily Vasyunin. (Received September 21, 2015)

1116-42-1843 **Deguang Han** (deguang.han@ucf.edu), Department of Mathematics, Orlando, FL 32816, **David R Larson** (larson@math.tamu.edu), Department of Mathematics, College Station, TX 77843-3368, **Sam L Scholze*** (scholzes@math.tamu.edu), Department of Mathematics, Mailstop 3368, Texas A&M University, College Station, TX 77840-3368, and **Wenchang Sun** (sunwch@nankai.edu.cn), Department of Mathematics, Tianjin, 300071, Peoples Rep of China. *Signal Reconstruction from Frame and Sampling Erasures.*

In this talk, I will discuss three new, efficient algorithms for reconstructing signals from frame erasures. Older methods of reconstruction require inverting an $n \times n$ matrix, where n denotes the dimension of the underlying Hilbert space. The three new methods require only an $L \times L$ matrix inversion, where L denotes the size of the set of erased indices. The first two methods also apply for infinite frames and sampling theory, provided the erasure set is finite. The third method allows the signal recipient to correct for erasures without giving away knowledge of the encoding frame. I will discuss all three methods, display some numerical experiments, and discuss some of the underlying theory. This is joint work with Deguang Han, David Larson, and Wenchang Sun. (Received September 21, 2015)

1116-42-1998 **Neil Lyall***, Department of Mathematics, University of Georgia, Athens, GA 30602, and **Akos Magyar**. *On some problems in Geometric Ramsey Theory.* Preliminary report.

We will discuss progress on some problems in Geometric Ramsey Theory pertaining to the embedding of certain finite configurations into subsets of $\mathbb{R}^d$ and $\mathbb{Z}^d$ of positive upper density. (Received September 21, 2015)

1116-42-2108 **Marc Carnovale***, 231 West 18th Ave, Columbus, OH 43210. *Arithmetic progressions in sparse pseudorandom subsets of the real numbers.*

What does the arithmetic combinatorics of $\mathbb{R}$ look like? At least since Erdos and Volkmann posed the Erdos Ring Conjecture in 1966, we have known that the language for such questions is that of geometric measure theory. In this talk, we will be concerned with the simplest such arithmetic questions one may ask: How large must a subset of $[0, 1]$ be in order to contain k-term arithmetic progressions? As in the discrete world, a result of Keleti shows that once the set is sparse enough, it is necessary to make pseudorandomness assumptions. Using Roth-like arguments, in 2009 Laba and Pramanik showed that sets with sufficiently large "Fourier dimension" contain 3APs. We use Gowers uniformity norms to introduce a higher-order analog of the geometric-measure theory notion of Fourier dimension, and use this together with some Littlewood-Paley type arguments to demonstrate that sparse pseudorandom subsets of the real line contain k-term arithmetic progressions. (Received September 21, 2015)

1116-42-2111 **Alexander B Reynolds*** (abreynolds@asu.edu), Phoenix, AZ. *Edge Detection from Spectral Phase Data.*

Accurate feature detection in signals is necessary in wide-ranging applications from medical imaging to computer vision. Spectral data is often collected in such applications, where many methods are used to extract information about the signal. The concentration factor method uses a first order relationship between the Fourier coefficients and jumps of a signal to devise filters that generate approximations which concentrate at the singular support of the signal, resulting in a highly customizable edge detector. This method has recently been expanded upon to detect edges in a signal given noisy, intermittent, or non-uniform Fourier data.

Typical feature detection algorithms rely on both the magnitude and phase of the collected Fourier data. However, the spectral phase carries particularly useful information about the features of a signal. Thus, the development of an edge detector using only phase data will be beneficial in applications where the magnitude information is not able to be collected or is otherwise corrupted. Recent numerical results have shown that concentration factors can be designed for these situations. An analysis of the method will lend insight to the accuracy of the phase-only edge detector and its robustness to noisy, non-uniform, or intermittent data. (Received September 21, 2015)

1116-42-2710 **John D Jasper*** (`john.jasper@uc.edu`), **Matthew Fickus**, **Dustin G Mixon** and **Jesse D Peterson**. *Steiner systems, equiangular tight frames, and strongly regular graphs.*

An equiangular tight frame (ETF) is a set of unit vectors whose coherence achieves the Welch bound. Though they arise in many applications, there are only a few known methods for constructing ETFs. This leaves many open questions, especially for the study of complex ETFs. The situation for real ETFs is much better understood due to the connection with certain strongly regular graphs (SRGs). Indeed, our understanding of real ETFs owes a great deal to the work of graph theorists on SRGs. In this talk we discuss two ways that the study of ETFs is giving back to the graph theory community. First, we discuss a new construction of ETFs which uses Steiner triple systems as the essential ingredient. By the previously mentioned connection to SRGs we obtain a new infinite class of SRGs. Second, we establish a new connection between SRGs and a special class of ETFs. We use this new connection to establish new existence/nonexistence results for SRGs. (Received September 22, 2015)

1116-42-2877 **Jeff Irion** (`jlirion@math.ucdavis.edu`), One Shields Avenue, Davis, CA 95616, and **Naoki Saito*** (`saito@math.ucdavis.edu`), One Shields Avenue, Davis, CA 95616. *Multiscale basis dictionaries on graphs and their applications in signal and image processing.*

In recent years, the advent of new sensor technologies and social network infrastructure has provided huge opportunities and challenges for analyzing data recorded on such networks. In the case of data on regular lattices, computational harmonic analysis tools such as the Fourier and wavelet transforms have well-developed theories and proven track records of success. It is therefore quite important to extend such tools from the classical setting of regular lattices to the more general setting of graphs and networks. In this talk, we first review our recent effort of constructing multiscale basis dictionaries on a graph, including the Hierarchical Graph Laplacian Eigenbasis Dictionary and the Generalized Haar-Walsh Wavelet Packet Dictionary, which are viewed as generalizations of the classical hierarchical block Discrete Cosine Transforms and the Haar-Walsh wavelet packets, respectively, to the graph setting. Finally, we demonstrate the usefulness of our dictionaries by applying them in some signal and image processing problems where classical tools have difficulty, e.g., simultaneous segmentation and denoising of noisy signals sampled on regular lattices, and analysis of term-document matrices. (Received September 22, 2015)

43 ► Abstract harmonic analysis

1116-43-268 **Xiaoyue Cui*** (`cuix.wsu@gmail.com`), 727 W Martin Luther King Drive, Apt. 514W, Cincinnati, OH 45220, and **Guozhen Lu**. *New Characterizations of High Order Sobolev Space on Euclidean Spaces.*

The main purpose of this paper is to study some new characterizations of the high order Sobolev spaces $W^{m,p}\left({}^N\right)$.

Actually, we will present here two types of characterizations: by m-th differences and by m-Taylor reminder. Therefore, two of our main results are as follows: If $f \in L^p(\mathbb{R}^N) \cap L^\infty(\mathbb{R}^N)$, then

(1) $f \in W^{m,p}(\mathbb{R}^N)$ if and only if

$$\sup_{0<\delta<1} \int_{\substack{\mathbb{R}^N \\ |\triangle^{(m)} f(x,y)|>\delta}} \frac{\delta^p}{|x-y|^{N+mp}} dxdy < \infty.$$

(2)$f \in W^{m,p}(\mathbb{R}^N)$ if and only if

$$\sup_{0<\delta<1} \int_{\mathbb{R}^N} \int_{\mathbb{R}^N}_{|R^{m-1} f(x,y)|>\delta} \frac{\delta^p}{|x-y|^{N+mp}} dxdy < \infty, f \in W^{m-1,p}(\mathbb{R}^N)$$

(Received August 19, 2015)

1116-43-887 **Maria Gordina*** (`maria.gordina@uconn.edu`), Department of Mathematics, Storrs, CT 06269. *Hypoelliptic heat kernels on nilpotent Lie groups.*

We use structure theory and a Fourier transform on nilpotent Lie groups to derive an explicit formula for the hypoelliptic heat kernel. This can be interpreted as an eigenfunction expansion of a heat kernel. One of the main ingredients in proving this formula is Kirillov's orbit method. This allows us to write the corresponding hypoelliptic heat kernel using an integral formula over a Euclidean space. As an application, one can describe a short-time behavior of these heat kernels. This is based on joint work with Malva Asaad. (Received September 14, 2015)

1116-43-1095 **Mishko Mitkovski*** (mmitkov@clemson.edu) and **Aaron Flores Ramirez**. *Interpolation and sampling in reproducing kernel Hilbert spaces.* Preliminary report.

We will present some preliminary results about sampling and interpolation in a very general class of reproducing kernel Hilbert spaces. Our results include a general necessary density condition for sampling and interpolation which generalizes majority of the known density results. We will also present some sufficiency conditions for a more restricted class of reproducing kernel Hilbert spaces. (Received September 16, 2015)

1116-43-2089 **Maxim J Goldberg** (mgoldber@ramapo.edu), Ramapo College of NJ, TAS, Mahwah, NJ 07430, and **Seonja Kim*** (seonja.kim@quinnipiac.edu), Quinnipiac University, Department of Mathematics, Hamden, CT 06518. *Equivalence of local uniform convergence and local equicontinuity for a general symmetric diffusion semigroup.* Preliminary report.

For a diffusion semigroup given by $A_t f(x) = \int_\Omega a_t(x,y) f(y)\,dy$ on a measure space Ω, it is of interest to connect smoothness of a function f with the convergence of $A_t f$ to f as $t \to 0^+$. A natural preliminary step is to define a distance on Ω related to the diffusion. For a bounded, increasing, non-negative function g, we define the distance D_g by $D_g(x,y) = \sup_{0<t\le 1} g(t) \|a_t(x,\cdot) - a_t(y,\cdot)\|_{L^1}$.

We assume the following for our semigroup: it is symmetric, $A_t f$ converges to f strongly in L^2 (a reasonable and mild assumption), and balls of positive radius with respect to the distance D_g have positive measure. Our main result is that local equicontinuity of the family $\{A_t f\}$ is equivalent to locally uniform convergence of $A_t f$ to f as $t \to 0^+$, for example for f a bounded square-integrable function. As a corollary, we obtain that $A_{t+t_0} f$ converges to $A_{t_0} f$ locally uniformly. (Received September 21, 2015)

1116-43-2283 **Linden Anne Duffee*** (linden.duffee@gmail.com), Department of Mathematics, The University of Alabama, Box 870350, Tuscaloosa, AL 35487. *On the Harmonic and Geometric Maximal Operators.*

We will survey some results about harmonic and geometric maximal operators, in particular norm inequalities on weighted L^p spaces. Our main results include two weight bounds for dyadic versions of these operators in higher dimensions without doubling conditions on the weights. Time permitting, we will discuss further results for these operators on a general basis. (Received September 22, 2015)

1116-43-2572 **Ishwari Jang Kunwar*** (ikunwar3@math.gatech.edu). *Multilinear dyadic operators and their commutators.*

Paraproduct decomposition of the pointwise product of two functions is given by

$$f_1 f_2 = \sum_{I\in\mathcal{D}} \widehat{f}_1(I)\langle f_2\rangle_I h_I + \sum_{I\in\mathcal{D}} \langle f_1\rangle_I \widehat{f}_2(I) h_I + \sum_{I\in\mathcal{D}} \widehat{f}_1(I)\widehat{f}_2(I) h_I^2,$$

where $h_I = \frac{1}{\sqrt{|I|}}\left(\mathbf{1}_{I_+} - \mathbf{1}_{I_-}\right)$, $\widehat{f}_i(I) = \langle f_i, h_I\rangle_{L^2}$, $\langle f_i\rangle_I = \dfrac{1}{|I|}\displaystyle\int_I f_i$, and $\mathcal{D}$ is the standard dyadic grid on $\mathbb{R}$. In this talk, I will present a generalization of this decomposition to the pointwise product of $m \ge 2$ functions. On the basis of this decomposition, I will define multilinear dyadic paraproducts and Haar Multipliers, and discuss their boundedness porperties. Finally, I will present a characterization of dyadic BMO functions in terms of boundedness of the commutators of those multilinear dyadic operators. (Received September 22, 2015)

1116-43-2667 **Joseph W. Iverson*** (iverson@uoregon.edu), Department of Mathematics, University of Oregon, Eugene, OR 97403. *Frames generated by compact group actions.*

Let K be a compact group, and let ρ be a unitary representation of K on a Hilbert space $\mathcal{H}_\rho$. We introduce an operator-valued bracket $[\cdot,\cdot]\colon \mathcal{H}_\rho \times \mathcal{H}_\rho \to \bigoplus_{\pi\in\hat{K}} B(\mathcal{H}_\pi)$ which can be used to compute vital information about the structure of ρ. For $f \in \mathcal{H}_\rho$, we explain how the frame properties of the orbit $\{\rho(\xi)f\}_{\xi\in K}$ can be deduced from the eigenvalues of the operators $[f,f](\pi)$, $\pi \in \hat{K}$. If time permits, we will use bracket analysis to classify frames generated by unitary actions of K. (Received September 22, 2015)

1116-43-2938 **Benjamin Willson*** (bd-willson@wiu.edu). *Fixed point theorem for hypergroups with application to showing the existence of a Haar measure.*

This talk will present some fixed point theorems of hypergroups related to translation invariant means on function spaces.

In particular, the existence of a left invariant mean on the space of weakly right uniformly continuous functions is equivalent to certain actions of the hypergroup having fixed points.

Using this fixed point property, we will show the existence of a Haar measure for certain hypergroups. (Received September 23, 2015)

44 ► Integral transforms, operational calculus

1116-44-453 **Irina Holmes*** (irina.holmes@gatech.edu), **Michael T. Lacey** and **Brett D. Wick**. *Two-Weight Inequalities for Commutators with Calderón-Zygmund Operators.*

In a foundational paper, Coifman, Rochberg and Weiss relate the norm of the commutator $[b,T]$, where T is a Calderón-Zygmund operator, with the BMO norm of b. In this talk we discuss a recent weighted version of this result. Specifically, we study the case when the commutator acts between two weighted Lebesgue spaces $L^p(\mathbb{R}^n;\mu)$ and $L^p(\mathbb{R}^n;\lambda)$, where μ and λ are Muckenhoupt A_p weights. A first result in this direction was obtained by Bloom in 1985, for the Hilbert transform. We discuss an extension of Bloom's result to all Calderón-Zygmund operators, using dyadic methods. (Received September 02, 2015)

1116-44-458 **Natawat Klamsakul*** (klamsak2@illinois.edu). *T1 theorem on non homogeneous spaces by time-frequency analysis.* Preliminary report.

We apply the theory of tiles and trees to the proof of T1 theorem on non homogeneous spaces by Nazarov, Treil and Volberg. This provides an alternative and a more visualized point of view to some parts of the proof. We also prove the estimates from $L^p \times L^q$ to L^r where $1 < p, q < \infty$ and $1/p + 1/q = 1/r$ for the paraproducts arose in the proof under the measures in which doubling condition holds. (Received September 02, 2015)

1116-44-666 **Jarod V Hart*** (jvhart@ku.edu) and **Lucas Oliveira**. *A Proof of Weighted Hardy Space Estimates Using Invariance Properties of BMO.*

In this joint work with Lucas Oliveira, we give necessary and sufficient conditions for singular integral operators to be bounded on weighted Hardy spaces. For a Calderón-Zygmund operator T satisfying appropriate cancellation conditions, we prove that T is bounded on H^p_w when $p_0 < p < \infty$ and $w \in A_{p/p_0}$, where $0 < p_0 < 1$ depends on the operator T. Interestingly, these results do not collapse to the known Lebsgue space theory for Calderón-Zygmund operators when $1 < p < \infty$. In fact, it is possible for T to be bounded on H^p_w for $w \in A_q$ when $1 < p < q < \infty$, in which case T may not be bounded on L^p_w. We will also discuss the approach used to prove these estimates, which uses a weight invariant property of BMO spaces. In effect, this proof technique avoids proving many weighted estimates directly for the operator. Instead, we prove estimates for the operator that do not involve weights, and then pass through a weight invariant property that is intrinsic to BMO in order to obtain weighted estimates for the operator. (Received September 10, 2015)

1116-44-2186 **David V Finch*** (finch@math.oregonstate.edu), Kidder Hall 368, Corvallis, OR 97331-4605, and **Patcharee Wongsason**. *Transverse ray transform.* Preliminary report.

The transverse ray transform of a vector field at a point x in direction θ is the divergent beam transform of the component of the vector field normal to the direction of the line. It is less studied than the longitudinal transform, but does arise in a few applied problems. We discuss inversion for compactly supported vector fields in three space when the data is collected on a curve outside the convex hull. (Received September 22, 2015)

1116-44-2506 **Lance Nielsen***, Department of Mathematics, Creighton University, 2500 California Plaza, Omaha, NE 68178. *An Evolution Equation for Feynman's Operational Calculus in the Combined Continuous/Discrete Setting.* Preliminary report.

For Feynman's operational calculus in the setting where continuous time-ordering measures are used, an evolution equation satisfied by the disentangled exponential has been known since the late 1990's. In the setting where time-ordering measures with non-zero discrete parts are allowed, an evolution equation is more difficult to obtain. In this talk, we illustrate an evolution equation for the disentangled exponential using time-ordering measures with non-zero discrete parts and show that it reduces to the evolution equation for the continuous setting. (Received September 22, 2015)

45 ► Integral equations

1116-45-673 **Jill Sabrina Scarlett Resh*** (jresh123@g.rwu.edu), 4705 Deborah Dr., Reading, PA 19606, and **Yajni M Warnapala** (ywarnapala@rwu.edu), Department of Mathematics, 1 Old Ferry Road, Bristol, RI 02809. *Numerical Solutions of the Helmholtz Equation via the Modified Galerkin Method for the Shape of a Biconcave Disk.* Preliminary report.

The objective of this research is to investigate numerical solutions of several boundary value problems for the Helmholtz equation for the shape of a Biconcave Disk. The boundary value problems this research mainly focuses on are the Neumann and Robin boundary problems. The Biconcave Disk is a closed, simply connected, bounded shape modified from a sphere where the two sides concave toward the center, mapped by a sine curve. There are some numerical issues in this type of analysis; any integration is affected by the wave number k, because of the oscillatory behavior of the fundamental solution of the Helmholtz equation. This project was funded by NASA RI Space Grant and the NASA EPSCoR Grant for testing of boundary conditions for the Biconcave Disk. This method has already been investigated for the sphere, ellipsoid, superellipsoid, and the oval of cassini. The primary purpose of this research is to extend those known results to the Biconcave Disk with calculating the possibility of this shape acquiring sufficient conditions to be part of a spacecraft that might one day land on planet Mars. (Received September 10, 2015)

1116-45-813 **Oleksandr Karelin*** (karelin@uaeh.edu.mx), Hidalgo State University, Institute of Basic Sciences and Engineering, Carretera Pachuca-Tulancingo, Km.4.5, Pachuca, Hidalgo 42184, **Manuel Gonzalez Hernandez** (mghdez@uaeh.edu.mx), Hidalgo State University, Institute of Basic Sciences and Engineering, Carretera Pachuca-Tulancingo, Km.4.5, 42184 Pachuca, Hidalgo, Mexico, **Norberto Hernandez Romero** (nhromero@uaeh.edu.mx), Hidalgo State University, Institute of Basic Sciences and Engineering, Carretera Pachuca-Tulancingo, Km.4.5, 42184 Pachuca, Hidalgo, Mexico, and **Juan Carlos Seck-Tuoh Mora** (jseck@uaeh.edu.mx), Hidalgo State University, Institute of Basic Sciences and Engineering, Carretera Pachuca-Tulancingo, Km.4.5, 42184 Pachuca, Hidalgo, Mexico. *Application of Functional Operators with Shift to the Study of Equilibrium State of Systems with Two Renewable Resources Taking into Account Their Interactions.*

In previous works, we proposed a method for the study of systems with one renewable resource. Cyclic models, in which the initial state of the system coincides with the final state, were considered. In this work, we present cyclic models for systems with two renewable resources. The separation of the individual and the group parameters and the discretization of time led us to scalar linear functional equations with shift. The theory of linear functional operators with shift is the adequate mathematical instrument for the investigation of such systems. In modelling, the interactions and the reciprocal influences between these two resources are taken into account. Analysis of the models is carried out in weighted Hölder spaces. Balance correlations are obtained. A method for the solution of the balance system of equations is proposed. The equilibrium state of the system is found. (Received September 13, 2015)

1116-45-2137 **Nimisha S. Pathak*** (nimishasp@siu.edu), Southern Illinois University, Dept of Math MC 4408, 1245 Lincoln Drive, Carbondale, IL 62901, and **Om P. Agrawal**. .

In this paper, we present some Lyapunov-type inequalities for differential equations of order α, $3 < \alpha \leq 4$ defined in terms of Riemann-Liouville and Caputo derivatives. We consider several mixed boundary conditions. We obtain fractional Green's functions for the corresponding boundary value problems, and use maximum norm and some properties of the Green's functions to obtain the Lyapunov-type inequalities. We use these inequalities in two applications; first, to find lower bounds for the lowest eigenvalues, and second, to find the domains in which certain combination of Mittag-Leffler functions have no zeros. We further use the Cauchy-Schwarz inequality to improve the lower bounds for the smallest eigenvalues and stretch the domains in which certain combinations of Mittag-Leffler functions have no real zeros. We present here results for only a few integer order boundary conditions. We plan to present results for several other integer and fractional boundary conditions (including mixed and Robin boundary conditions) somewhere else.
(Received September 22, 2015)

1116-45-2580 **Thomas Höft*** (hoft@stthomas.edu). *Camera response function modeling for high dynamic range photography.*

We describe an inverse problem for jointly determining a high dynamic range image and the response function of a camera system from multiple photographs of a scene captured with different exposure times. This work focuses on few-parameter models of the camera response function and their impact on the inverse problem. (Received September 22, 2015)

1116-45-2908 **Tianyu Qiu*** (qty@udel.edu), 109 Ewing Hall, Newark, DE 19711. *Numerical solution of multilayer multiple acoustic wave scattering by time domain boundary integral equation.*

Despite its various advantages over the finite element method, the boundary integral equation method has long suffered from inability to handle differential equations with variable coefficients. We extend the idea proposed by Costabel and Stephan to deal with the wave equation with piecewise constant coefficient. For time discretization, we apply the convolution quadrature technique. In this talk, I am going to present the formulation and error estimates of the time domain boundary integral method applied to multilayer multiple wave scattering problem.
(Received September 23, 2015)

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1116-46-126 **Muhammad Nouman Aslam Khan*** (mailnouman@gmail.com), Room # 324, SCME, National University of, Sciences and Technology, Sector H-12, Islamabad, Islamabad 44000, Pakistan. *Coincidence Point of Sequence of Multivalued Maps using Graphic Contraction.* Preliminary report.

The coincidence points of a self map and sequence of multivalued maps is found using the multivalued G contractive type inequality. This generalizes the concept of Mizoguchi-Takahashi's fixed point theorem for multivalued mappings on a metric space endowed with a graph. As applications we obtain an existence theorem for the solution of system of Urysohn integral equations and fractional integral equations. Moreover we establish a result on the convergence of successive approximation of certain operators on a Banach space. (Received August 03, 2015)

1116-46-130 **Akbar Azam*** (akbarazam@yahoo.com), Department of Mathematics, COMSATS Institute, of Information Technology, Chak Shahzad, Islamabad, 44000, Pakistan. *Coincidence points of crisp and L-fuzzy mappings.*

The existence of common coincidence points for a non-fuzzy and a pair of L-fuzzy mappings has been investigated. We use phi-contraction condition on a metric space with the Hausdorff metric on the family of L-fuzzy sets. Moreover we prove common coincidence point theorem on a metric space by using the d-infinity metric on L-fuzzy sets. To approve the solidity and applicability of our results, we give some applications and apply it to achieve some existence and uniqueness theorems of solution for a class of non-linear integral equations. (Received August 04, 2015)

1116-46-355 **Muhammad Arshad Zia*** (marshad_zia@yahoo.com), Department of Mathematics and Statistics, International Islamic University, Islamabad, 44000, Pakistan. *Fixed point theorems for single and multi-valued dominating mappings in dualistic partial metric space.*

Matthews [1] established the relationship between partial metric and quasi metric. Later on, Oltra and Valero [2] established the relationship between dualistic partial metric and quasi metric. In this paper, we establish an order relation on quasi dualistic partial metric spaces. Later on, using this order relation, we prove fixed point theorems for single and multi-valued dominating mappings in dualistic partial metric space. Instead of monotone mappings, the notion of dominating mappings in Finance, Trade, Energy and Industry is also been applied to approximate solutions of nonlinear functional equations. We have used weaker conditions and weaker restrictions on the set of codomain to obtain fixed points. Several examples are given to make the paper readable for a larger audience. Moreover these examples show the superiority of our results over existing results. Our work improves/generalizes various well known primary and conventional results.

[1] S. G. Matthews, Partial Metric Topology, in proceedings of the 11th Summer Conference on General Topology and Applications, Vol. 728, pp. 183-197, The New York Academy of Sciences, August, 1995.

[2] S. Oltra, O. Valero, Banach's fixed point theorem for partial metric spaces, Rend. Ist. Mat. Univ. Trieste 36 (2004), 17-26. (Received August 27, 2015)

1116-46-412 **hudson akewe*** (hudsonmolas@yahoo.com), Department of Mathematics, University of Lagos, Akoka, Yaba, Lagos, +23401, Nigeria. *Hybrid iterative sequences of Jungck-type and common fixed point theorems.*

Abstract: Let E is a Banach space and Y a nonempty set such that $T(Y) \subseteq S(Y)$ and $S, T : Y \to E$ satisfying the generalized contractive-like operators $\|Tx - Ty\| \leq \delta\|Sx - Sy\| + \varphi(\|Sx - Tx\|),\ 0 \leq \delta < 1$, for $x, y \in Y$ where $\varphi : \Re^+ \to \Re^+$ is a monotone increasing sequence with $\varphi(0) = 0$ (Olatinwo [22]). It is shown that the Jungck-(Jungck-Mann) hybrid iterative sequences introduced in this paper, is used to approximate the unique common fixed point of S and T for the generalized contractive-like operators defined by the author [22] in a Banach space. We establish strong convergence of Picard-Mann, Picard iterative scheme for single map T as corollaries. Our theorem generalize and improve multitude of results in the literature, including recent hybrid schemes (Received August 31, 2015)

1116-46-455 **David Penneys*** (dpenneys@math.ucla.edu), UCLA Mathematics Department, Box 951555, Los Angeles, CA 90095-1555. *Bicommutant categories.*

I'll discuss an ongoing joint project with André Henriques. Just as a tensor category is a categorification of a ring, and its Drinfel'd center is a categorification of the center of a ring, a bicommutant category is a categorification of a von Neumann algebra. I'll define the notion of the commutant C' of a tensor category C inside an ambient

tensor category B. A bicommutant category is then a category which is equivalent to its own bicommutant inside B.

Because we are interested in von Neumann algebras, we work in the ambient category B=Bim(R), the tensor category of bimodules over a hyperfinite von Neumann factor R, which can be thought of as a categorification of B(H). Given a unitary fusion category C inside Bim(R), we identify its bicommutant C", which we show is, in fact, an example of a bicommutant category. Along the way, we provide machinery for constructing elements of C', and we see the Longo-Rehren subfactor appear naturally. (Received September 02, 2015)

1116-46-484 **Gareth Speight*** (gareth.speight@uc.edu). *A Measure Zero Universal Differentiability Set in the Heisenberg Group.*

The Heisenberg group $\mathbb{H}^n$ is a metric measure space equipped with translations and dilations. Lipschitz functions on $\mathbb{H}^n$ are Pansu differentiable almost everywhere, but $\mathbb{H}^n$ admits no bilipschitz embedding into a Euclidean space. We show there exists a measure zero 'universal differentiability set' in $\mathbb{H}^n$ containing a point of Pansu differentiability for every real-valued Lipschitz function. The proof adapts techniques from Banach space theory, showing that existence of an 'almost maximal' directional derivative implies Pansu differentiability. Joint work with Andrea Pinamonti. (Received September 03, 2015)

1116-46-515 **Tatsuya Tate***, 6-3, Aza-Aoba, Aramaki, Aoba-ku, Sendai, Miyagi 980-8578, Japan. *Localization for periodic unitary transition operators.* Preliminary report.

Localization, which is in the title, means a phenomenon that the transition probabilities at a site defined by a transition operator can not tend to zero as time goes to infinity. Such a kind of phenomenon arises easily for simple classes of one dimensional quantum walks. The periodic unitary transition operators, which is also in the title, is a generalization of quantum walks with constant coin matrices and their products in any dimension. In this talk, the localization phenomenon for the periodic unitary transition operators are discussed. In fact, it is easy to show that the localization does not happen if the transition operator has absolutely continuous spectrum. In the talk, a criterion for the periodic unitary transition operators to have absolutely continuous spectrum will be given. This criterion has been well-known for certain class of self-adjoint operators. However,it should be noted that known results for self-adjoint case are not used in our proof. Indeed, our proof is rather concrete and constructive. A criterion in terms of the coin matrix, which is obtained by a recent joint work with T.Komatsu, is also given. (Received September 05, 2015)

1116-46-580 **Sun Young Jang*** (jsym@ulsan.ac.kr), Department of Mathematics, University of Ulsan, Namgu, Daehakro 93, Ulsan, 680-749, South Korea. *Uniqueness property of semigroup C^*-algebras.*

The uniqueness property means that the sructure of C^*-algebras generated by isometries does not depend on the choice of isometries on a Hilbert space. I show that the unperforated property of semigroups has a deep relation with the uniqueness property of the C^*-algebras generated by isometric representations of left cancellative semigroups and the reduced semigroup C^*-algebras of subsemigroups of $\mathbb{Z}$ generating the integer group $\mathbb{Z}$ are isomorphic to the Toeplitz algebra.

Mathematics Subject Classification: 46L55, 46L05 (Received September 07, 2015)

1116-46-592 **Isaac Goldbring*** (isaac@math.uic.edu), Department of Mathematics, Science and Engineering Offices, 851 S. Morgan St., Chicago, IL 60607, and **Thomas Sinclair**. *Model theory and the Weak Expectation Property.*

A C* algebra $A \subseteq \mathcal{B}(H)$ is said to have the *weak expectation property* (WEP) if there is a u.c.p. map $\Phi : \mathcal{B}(H) \to A^{**}$ that is the identity on A. We first show how to use a result of Junge and Pisier together with some basic model theory to prove that no ultrapower of $\mathcal{B}(H)$ has the WEP. We then show how the WEP is equivalent to a kind of existential closednesss property and use this equivalence to give a simpler proof of a result of Kavruk, namely that the WEP is equivalent to the so-called complete tight Riesz interpolation property. Finally, we discuss a model-theoretic strategy for finding an example of a non-nuclear C* algebra that has both the WEP and the local lifting property. (Received September 08, 2015)

1116-46-690 **Remi Boutonnet** (rboutonnet@ucsd.edu), 9500 Gilman Dr, MC 0112, La Jolla, CA 92093, **Ionut Chifan*** (ionut-chifan@uiowa.edu), 14 Maclean Hall, Iowa City, IA 52242, and **Adrian Ioana** (aioana@ucsd.edu), AP&M 5210, Department of Mathematics, UCSD, 9500 Gilman Drive, La Jolla, CA 92093. *II_1 factors with non-isomorphic ultrapowers.*

In this talk we will show that there exist uncountably many separable II_1 factors whose ultrapowers (with respect to arbitrary ultra lters) are non-isomorphic. In fact, it will be proved that the families of non-isomorphic II_1

factors originally introduced by Dusa McDuff in the late sixties are such examples. This entails the existence of a continuum of non-elementarily equivalent II_1 factors, thus settling a well-known open problem in the continuous model theory of operator algebras. This is based on joint work with Remi Boutonnet and Adrian Ioana. (Received September 10, 2015)

1116-46-700 **Mira A. Peterka** and **Albert Jeu-Liang Sheu*** (asheu@ku.edu), Department of Mathematics, University of Kansas, Lawrence, KS 66045. *On Noncommutative Levi-Civita Connections.*

Following Jonathan Rosenberg's approach to Levi-Civita connections on noncommutative tori, we show that the Gauss-Bonnet theorem holds for two classes of non-conformal deformations of the flat metric on the noncommutative two-tori, including the case of non-commuting scalings along the principal directions of a two-torus. We also analyze how the curvature form and the uniqueness of torsion-free metric-compatible connection are affected when the connection operator for the inner *-derivations is not limited to the prominent one considered by Rosenberg, and find a complete answer. (Received September 10, 2015)

1116-46-724 **Arnaud Brothier*** (arnaud.brothier@vanderbilt.edu), Vanderbilt University, Department of Mathematics, 1326 Stevenson Center, Nashville, TN 37240. *Subfactors, Hecke pairs, and approximation properties.*

We consider subfactor planar algebras that are constructed with a group acting on a bipartite graph. There is a Hecke pair of countable discrete groups associated with this construction. We show that if this Hecke pair satisfies a given approximation property, then the subfactor planar algebra satisfies it as well. We exhibit an infinite family of subfactor planar algebras with non-integer index that are non-amenable, have the Haagerup property, and have the complete metric approximation property. (Received September 11, 2015)

1116-46-728 **Dale Frymark*** (dale_frymark@baylor.edu), **Constanze Liaw** and **Alexei Poltoratski**. *Iterated Rank-One Perturbations.*

We iteratively apply rank-one perturbations to a self-adjoint operator via its spectral representation. We remain in control of the expected value for the total Poisson mass of the resulting operators' absolutely continuous part. Applications of the method are shown for Anderson-type Hamiltonians. (Received September 11, 2015)

1116-46-867 **John E. Herr*** (jherr@iastate.edu) and **Eric S. Weber**. *Fourier Series for Singular Measures.*

Using the Kaczmarz algorithm, we prove that for any singular Borel probability measure μ on $[0,1)$, every $f \in L^2(\mu)$ possesses a Fourier series of the form $f(x) = \sum_{n=0}^{\infty} c_n e^{2\pi inx}$. We show that the coefficients c_n can be computed in terms of the quantities $\widehat{f}(n) = \int_0^1 f(x)e^{-2\pi inx} d\mu(x)$. We also demonstrate a Shannon-type sampling theorem for functions that are in a sense μ-bandlimited. (Received September 14, 2015)

1116-46-901 **Sofya S Masharipova*** (sofya.masharipova@ashford.edu), Ashford University, College HHSS, 400 N. Bluff Blvd, Clinton, IA 52732, and **Shukhrat M Usmanov** (shukhrat.usmanov@ashford.edu), Ashford University, College HHSS, 400 N. Bluff Blvd, Clinton, IA. *Positive cones, positive linear functionals and classification of algebras of operators on Pontryagin Π_1 space.* Preliminary report.

It is well known that in Pontryagin Π_1 space with an indefinite metrics all weakly closed algebras of bounded operators can be classified by 6 classes (models): types 0, I, II_a, II_b, III_a, III_b, accordingly to work of V. S. Shulman (Mat. Sbornik, 1972, 89, No 2). In this work we study positive operators on different classes of such algebras. The cones of positive operators are described. Also, we define positive linear functionals on such algebras. We study some important conditions, such as normality and trace property, for positive functionals, and define finite and semi-finite traces. It allows us to introduce finite, semi-finite and properly infinite algebras of operators on Pontryagin Π_1 space. (Received September 15, 2015)

1116-46-1115 **Urooj Malik*** (malikurooj050@gmail.com), Department of Mathematics, COMSATS Institute of Information Technology, Abbottabad, KPK 22060, Pakistan. *Fixed and common fixed point results of generalized cyclic contraction mappings.*

In this talk, I present fixed point results of mappings satisfying generalized contraction conditions. As an application, a common fixed point of a pair of weakly compatible mappings is also obtained. Some common fixed point results of pair of cyclic contraction mappings are also presented. Furthermore, some examples are presented to support the results proved herein. These results generalize and extend various results in the existing literature. (Received September 17, 2015)

1116-46-1152 **Michael Hartglass*** (michael.hartglass@ucr.edu), University of California, Riverside, Riverside, CA 92521. *Free graph operator algebras and laws of loops.*

A canonical (C^* or von Neumann algebra) associated to a weighted graph will be presented. Necessary and sufficient conditions for simplicity, uniqueness of trace, and factorality will be explored. The spectral measure of certain self-adjoint polynomials in the generators of this algebra will be shown to have atoms of as small a size as possible. An application to eigenvalues of self-adjoint polynomials in Wishart matrices will be presented. (Received September 17, 2015)

1116-46-1169 **Qasim Mahmood*** (qasim_math@yahoo.com), Department of Basic Sciences, Riphah International University, Sector I-14, Islamabad, Pakistan. *Fixed and common fixed point results in multiplicative partial metric spaces.*

In this paper, we study multiplicative partial metric space and obtain fixed and common fixed point results of mappings. Our obtained results extend and unify the results of mappings satisfying generalized rational contractive condition in the setup of multiplicative partial metric space. Moreover, we present an application to obtain the solution of integral equations. (Received September 17, 2015)

1116-46-1354 **Teffera M. Asfaw*** (teffera6@vt.edu), Virginia Tech, Department of Mathematics, 576 McBryde Hall, Blacksburg, VA 24061. *A new topological degree theory for pseudomonotone perturbations of the sum of two maximal monotone operators and applications.*

Let X be a real reflexive locally uniformly convex Banach space with locally uniformly convex dual space X^* and G be a nonempty, bounded and open subset of X . Let $T : X \supseteq D(T) \to 2^{X^*}$ and $A : X \supseteq D(A) \to 2^{X^*}$ be maximal monotone operators. Assume, further, that, for each $y \in X$, there exists a real number $\beta(y)$ and there exists a strictly increasing function $\phi : [0,\infty) \to [0,\infty)$ with $\phi(0) = 0$, $\phi(t) \to \infty$ as $t \to \infty$ satisfying

$$\langle w^*, x - y\rangle \geq -\phi(\|x\|)\|x\| - \beta(y)$$

for all $x \in D(A)$, $w^* \in Ax$, and $S : X \to 2^{X^*}$ be bounded of type (S_+) or bounded pseudomonotone such that $0 \notin (T + A + S)(D(T) \cap D(A) \cap \partial G)$ or $0 \notin \overline{(T + A + S)(D(T) \cap D(A) \cap \partial G)}$, respectively. New degree theory is developed for operators of the type $T + A + S$ with degree mapping $d(T + A + S, G, 0)$. The theory developed herein generalizes the Asfaw and Kartsatos degree theory for operators of the type $T + S$. New results on surjectivity and solvability of variational inequality problems are obtained. The degree theory developed herein is used to show existence of weak solution of nonlinear parabolic problem in appropriate Sobolev spaces. (Received September 18, 2015)

1116-46-1436 **Jared Burns**, Seton Hill University, **Chris Lennard***, University of Pittsburgh, and **Jeromy Sivek**, Temple University. *Recent developments in fixed point and Banach space theory.*

I will discuss recent developments in fixed point and Banach space theory. In particular, I will describe recently published joint work with Jared Burns and Jeromy Sivek, in which we prove that there exists a fixed point free contractive mapping on a weakly compact, convex subset of a Banach space. (Received September 19, 2015)

1116-46-1646 **Torrey M Gallagher*** (tmg34@pitt.edu), 618 Kirtland St, Pittsburgh, PA 15208. *Mean isometries are isometries.* Preliminary report.

In 2007, Goebel and Japon-Pineda introduced the so-called "mean nonexpansive" mappings as an extension to the usual class of nonexpansive mappings. They proved that a Banach space has the fixed point property for a nontrivial subclass of mean nonexpansive maps provided that the underlying space has the fixed point property for nonexpansive maps. Some interesting fixed point theorems have also been proven about isometries acting on closed, bounded, and convex subsets of certain spaces. We show that the extension of any fixed point theorem for isometries to mean isometries is trivial; that is, we show that a function on a metric space is an isometry if and only if it is a mean isometry. (Received September 21, 2015)

1116-46-1718 **Alexander A Katz*** (katza@stjohns.edu), Dep. of Math & CS, SJC of LAS, St. John's University, 8000 Utopia Parkway, SJH-334-G, Queens, NY 11439. *On locally order unit spaces and characterizations of locally JB-algebras.*

We introduce locally order unit spaces as locally convex spaces which are topologically isomorphic to projective limits of projective families of order unit spaces. It is shown that a unital Jordan lmc-algebra which is as well a locally order unit space such that the algebra identity coincides with the order identity, is a locally JB-algebra in the locally convex topology generated by the order seminorms. As a consequence we obtain that a unital Jordan lmc-algebra A in which each closed abelian Jordan lmc-subalgebra C(x) generated by an element x and the identity of A is a locally JB-algebra in the topology of A, is itself a locally JB-algebra. (Received September 21, 2015)

1116-46-1791 **Khazhak Navoyan*** (knavoyan@go.olemiss.edu). *Bases in the space of regular multilinear operators on Banach lattices.* Preliminary report.

For Banach lattices $E_1, \cdots, E_m$ let $\mathcal{L}^r(E_1, \cdots, E_m)$ denote the space of regular multilinear operators from $E_1, \cdots, E_m$ to $\mathbb{R}$. In this talk we give several characterizations of $\mathcal{L}^r(E_1, \cdots, E_m)$ having a basis if all $E_1, \cdots, E_m$ have shrinking bases.
(Received September 21, 2015)

1116-46-1839 **Brent A Nelson*** (brent@math.berkeley.edu). *An example of factoriality under non-tracial finite free Fisher information assumptions.*

Suppose M is a von Neumann algebra equipped with a faithful normal state φ generated by a finite set $G = G^*$, $|G| \geq 3$. We show that if G consists of eigenvectors of the modular operator Δ_φ and have finite free Fisher information, then the centralizer M^φ is a II_1 factor and M is a factor of type depending on the eigenvalues of G. We use methods of Connes and Shlyakhtenko to establish the existence of diffuse elements in M^φ, followed by a contraction resolvent argument of Dabrowski to obtain the factoriality. (Received September 21, 2015)

1116-46-1902 **Stephen Avsec*** (savsec@math.tamu.edu), Department of Mathematics, Mailstop 3368, Texas A&M University, College Station, TX 77843-3368. *Noncommutative Gaussian Spaces.*

Classically, Gaussian linear space is an $\mathbb{R}$-linear space of random variables on a probability space (Ω, Σ, μ) such that each variable in the space is a centered Gaussian. Typically, such a space is viewed as a subspace of $L^2_{\mathbb{R}}(\Omega, \Sigma, \mu)$. In this talk, we shall discuss a noncommutative analogue of these spaces, replacing a commutative L^2 space with L^2 of a finite von Neumann algebra. We shall also discuss the (quantum) symmetry groups of these spaces. This will include some joint work with Marius Junge. (Received September 21, 2015)

1116-46-2212 **William A. Feldman*** (wfeldman@uark.edu), University of Arkansas, Department of Mathematical Sciences, Fayetteville, AR 72701. *Nonlinear operators satisfying order theoretic properties on vector-valued functions.* Preliminary report.

Let $C(X, E)$ denote the space of all continuous functions from a compact topological space X to a Banach lattice E and similarly for $C(Y, F)$. Properties of non-linear operators that are monotone (order-preserving) from $C(X, E)$ to $C(Y, F)$ are considered. The analysis includes operators T that are finitely disjointness preserving (i.e., $\wedge f_i = 0$ for a finite collection implies $\wedge T f_i = 0$) and satisfy a property related to disjointly additivity (i.e., related to $f \wedge g = 0$ for $f, g \geq 0$, then $T(f + g) = T(f) + T(g)$). Given an appropriate continuity assumption for T, it is shown that $Tf(y)$ can be identified with the value of f at one point $x \in X$ dependent on y. This is then analogous to the scalar-valued and linear situation of a weighted composition operator. (Received September 22, 2015)

1116-46-2235 **Constanze Liaw** (constanze_liaw@baylor.edu), Department of Mathematics, Baylor University, One Bear Place #97328, Waco, TX 76798, and **John M. Osborn*** (john_osborn@baylor.edu), Department of Mathematics, Baylor University, One Bear Place #97328, Waco, TX 76798. *Moment Representations of the Exceptional X_1-Laguerre Orthogonal Polynomials.*

Exceptional orthogonal Laguerre polynomials can be viewed as an extension of the classical Laguerre polynomials by excluding polynomials of certain order(s) from being eigenfunctions for the corresponding exceptional differential operator. We are interested in the (so-called) Type I X_1-Laguerre polynomial sequence $\{L_n^\alpha\}_{n=1}^\infty$, $\deg p_n = n$ and $\alpha > 0$, where the constant polynomial is omitted.

We derive two representations for the polynomials in terms of moments by using determinants. The first representation in terms of the canonical moments is rather cumbersome. We introduce adjusted moments and find a second, more elegant formula. We deduce recursion formulas for both types of moments. The adjusted moments are also expressed via a generating function. (Received September 22, 2015)

1116-46-2351 **Oleg Friedman*** (friedman001@yahoo.com), Dep. of Math., Lander College, NY &, UNISA, RSA, 75-31 150th Street, Kew Garden Hills, NY 11367. *Two approaches to the notions of real locally C^*- and locally JB-algebras.*

We introduce real locally C*-algebras as topological algebras whose topology is generated by the consistent family of C*-regular seminorms. We obtain that symmetric complete essentially real locally C*-algebras are topologically *-isomorphic to the projective limits of projective families of some real C*-algebras. Similar result we get for locally JB-algebras (Received September 22, 2015)

1116-46-2474 **Julian M Buck*** (jbuck@fmarion.edu), L402, Department of Mathematics, Francis Marion University, PO Box 100547, Florence, SC 29506. *Classification of Crossed Products Arising From Actions on $C(X, A)$.* Preliminary report.

We survey some recent work related to the structure of crossed product C*-algebras arising from group actions on algebras of the form $C(X, A)$, where X is a compact Hausdorff space and A is some simple C*-algebra. Of particular interest are actions which "lie over" actions on X in an appropriate sense. Joint work with Aaron Tikuisis, and from a different perspective with Dawn Archey and N. C. Phillips, given condtions under which such crossed products are stable under tensoring with the Jiang-Su algebra $\mathcal{Z}$. We discuss under what conditions we might expect such crossed products to be classifiable by the Elliott invariants. We also discuss what can be said in the situations where the crossed product is not $\mathcal{Z}$-stable. (Received September 22, 2015)

1116-46-2615 **T. Cobler*** (tim.cobler@gmail.com) and **M. L. Lapidus**. *Quantized Modular Forms and Elliptic Curves.*

H. Herichi and M. L. Lapidus formalized the idea of the quantized Riemann zeta function, $\zeta(\partial)$, an operator whose spectrum localized the function to its values on vertical lines in the complex plane. Following their lead, we look at a different operator in order to localize further to the value of a function at a single point. This allows us to define quantized versions of the complex numbers, modular forms, and elliptic curves and study their relationships. (Received September 22, 2015)

1116-46-2681 **Carla Farsi** and **Elizabeth Gillaspy***, elizabeth.gillaspy@colorado.edu, and **Sooran Kang** and **Judith A. Packer**. *Wavelets, KMS states, and separable representations for higher-rank graphs.*

Higher-rank graphs are a generalization of directed graphs, which were introduced by Kumjian and Pask as a model for C^*-algebras. Higher-rank graphs make it easy to visualize many structural properties of the associated C^*-algebras.

Building on work by Marcolli and Paolucci, we construct a new type of representation of a higher-rank graph Λ. These representations give rise not only to separable representations of the associated C^*-algebra $C^*(\Lambda)$, but also to KMS states and to a wavelet decomposition of $L^2(\Lambda)$. We will end by describing how to apply this wavelet decomposition to traffic analysis on networks. (Received September 22, 2015)

1116-46-2795 **Ryan K. Tully-Doyle*** (ryan.tullydoyle@hamptonu.edu). *Convexity and free analytic functions.*

Matrix convex functions in one variable are an object of classical study, for example in the work of C. Löwner and F. Kraus. We will discuss an analogous notion of convexity for functions in the free analytic setting and implications for the structure of a class of convex free analytic functions. (Received September 22, 2015)

1116-46-2823 **Jon Brown**, **Gabriel Nagy** and **Sarah A. Reznikoff***, sarah@ksu.edu, and **Aidan Sims** and **Dana Williams**. *Cartan subalgebras of groupoid C*-algebras.*

The classical uniqueness theorems for representations of combinatorially defined C*-algebras demand either gauge invariance of the representation or aperiodicity of the underlying structure. Over the last five years an approach that relies on neither of these conditions has been developed. In particular, we have identified a special subalgebra in a graph, k-graph, or groupoid algebra that captures failure of aperiodicity in the underlying structure and in turn reflects failure of injectivity in the representation. Moreover, whether this subalgebra is Cartan depends on an interesting topological condition of the underlying combinatorial structure. (Received September 22, 2015)

1116-46-2926 **Peter Elbau*** (peter.elbau@univie.ac.at), Computational Science Center, University of Vienna, Oskar-Morgenstern-Platz 1, 1090 Vienna, Vienna, Austria. *Optimal Convergence Rate Results for Linear Inverse Problems.*

(joint work with V. Albani, R. Andreev, M. de Hoop, L. Qiu, O. Scherzer)

A lot of tasks in signal processing and imaging turn out to be (linear) inverse problems. The typical way to attack these problems is by choosing a suitable regularisation method and calculating a regularised solution of the problem which is stable with respect to noise and which will converge to the minimum-norm solution of the problem as the error in the data and the regularisation parameter properly tend to zero.

In this talk, we want to study the rate of this convergence in the Hilbert space setting. To obtain such rates, various a priori assumptions on the minimum-norm solution were suggested: for example classical (Groetsch), variational (Hofmann, Kaltenbacher, Pöschl, Scherzer), and approximative source conditions (Hofmann, Mathé).

We intend to generalise Neubauer's result on the equivalence between convergence rates and the spectral components of the minimum-norm solution to get equivalence results between the variaional or approximative source conditions (the classical conditions are known to be more restrictive) and arbitrary convergence rates for general regularisation methods. (Received September 23, 2015)

47 ► Operator theory

1116-47-51 **Cheng Chu*** (chengchu@math.wustl.edu), Department of Mathematics, Campus Box 1146, Washington University in St. Louis, One Brookings Drive, St. Louis, MO 63130, and **Dmitry Khavinson**. *A Spectral Area estimate of Toeplitz Operators.*

We show that for hyponormal Toeplitz operators, there exists a lower bound for the area of the spectrum. This extends the known estimate for the spectral area of Toeplitz operators with an analytic symbol. (Received August 28, 2015)

1116-47-351 **Stephan Ramon Garcia*** (stephan.garcia@pomona.edu), Department of Mathematics, Pomona College, 610 N College Ave, Claremont, CA 91711. *Two remarks on similarity.*

If A and B are normal, is AB similar to BA? Even in finite dimensions, this is a subtle and interesting problem with lots of nice variants. We also consider the problem of characterizing matrices that are similar to partial isometries. This is joint work with David Sherman. (Received August 26, 2015)

1116-47-385 **Pamela Gorkin*** (pgorkin@bucknell.edu), Department of Mathematics, Bucknell University, Lewisburg, PA 17837, and **Brett D. Wick**. *Thin Sequences and Model Spaces.*

Let (z_n) be a sequence in the open unit disk and T_p an operator taking an H^p function f to the sequence $(f(z_n)(1-|z_n|)^{1/p})$. Shapiro and Shields found conditions for the sequence to be interpolating; e.g, the range $T_p(H^p)$ equals the sequence space ℓ^p and the condition is Carleson's condition:

$$\inf_k \prod_{n\neq k} \left|\frac{z_k - z_n}{1-\overline{z_n}z_k}\right| \geq \delta > 0.$$

We consider interpolating sequences for model spaces, $K_\Theta := H^2 \ominus \theta H^2$, associated with an inner function θ. If we have a sequence for which the restriction of T_2 maps K_θ onto ℓ^2, then T_2 will map H^2 onto ℓ^2. For which sequences can we be sure that if $T_2 : H^2 \to \ell^2$ is surjective, then the restriction $T_2 : K_\theta \to \ell^2$ is surjective?

We answer this for the class of *thin sequences* – interpolating sequences for which $\lim_{k\to\infty} \prod_{j;j\neq k} \left|\frac{z_j - z_k}{1-\overline{z_j}z_k}\right| = 1$. (Received August 29, 2015)

1116-47-482 **Benjamin W Passer*** (bpasser@math.wustl.edu). *A Noncommutative Borsuk-Ulam Theorem.*

The Borsuk-Ulam theorem in algebraic topology places restrictions on odd maps between spheres, or between spheres and Euclidean space. When the topological sphere is replaced with its corresponding algebra of functions, various formulations of the Borsuk-Ulam theorem translate into the language of C*-algebras in different ways. I will discuss which of these formulations remain true when the algebra is theta-deformed (producing the Natsume-Olsen noncommutative spheres), with some key elements of proof. (Received September 03, 2015)

1116-47-490 **Chang-Pao Chen*** (cpchen@wmail.hcu.edu.tw), Center for General Education, Hsuan Chuang University, Hsinchu, ROC 30092, Taiwan. *Estimates of the modular-type operator norm of an integral operator over spherical cones.*

This paper provides an extended survey of my joint works in [3], [4], [5]. It is related to the study of Hardy-Knopp-type inequalities, Pólya-Knopp-type inequalities, and weighted norm inequalities. In [4], the Muckenhoupt-type estimate of the modular-type operator norm has been established. As a result, the Hardy-Knopp-type inequalities and the n-dimensional extensions of Levinson's, Stepanov's, Heinig's results can be derived. In [3] and [5], we introduced a new type of limit process to evaluate the modular-type operator norm. That would lead us to get the multidimensional extensions of Pólya-Knopp-type inequalities with general measures. Our results generalize Levin-Cochran-Lee-type inequalities and Carleson's result with an improvement in the estimates given. Furthermore, we have also provided new proofs of Persson-Stepanov's and Wedestig's results regarding to Pólya-Knopp-type inequalities. (Received September 03, 2015)

1116-47-640 **Chafiq Benhida**, **Raul Curto** and **George R. Exner*** (exner@bucknell.edu), Department of Mathematics, Bucknell University, Lewisburg, PA 17837. *Infinitely divisible weighted shifts.* Preliminary report.

A weighted shift W_α on Hilbert space with weight sequence $\alpha : \alpha_0, \alpha_1, \ldots$ (the α_n assumed positive) is said to be moment infinitely divisible if the shift with weights $\alpha^t : \alpha_0^t, \alpha_1^t, \ldots$ is subnormal for each $t > 0$. We show that a shift is moment infinitely divisible if and only if the sequence of weights is log completely alternating, motivate the choice of terminology, recapture some old results, and produce new results and examples. (Received September 09, 2015)

1116-47-692 **John E McCarthy*** (mccarthy@math.wustl.edu), Dept. of Mathematics, Washington University, 1 Brookings Drive, St. Louis, MO 63130, and **Jim Agler**. *Non-commutative Function Theory for Operators.*

Non-commutative function theory, as developed in the book [1], is the study of functions whose input is a d-tuple of n-by-n matrices and whose output is an n-by-n matrix, with the idea that it should somehow be independent of n. Nc-functions f are required to respect intertwining: if $Lx_j = y_j L$ for $1 \leq j \leq d$, then $Lf(x) = f(y)L$. Notice that all non-commuting polynomials respect intertwining.

Even though the original domains of nc-functions are sets of d-tuples of matrices, the functions often make sense on d-tuples of operators on an infinite dimensional Hilbert space $\mathcal{H}$. We shall discuss when nc-functions have unique extensions to domains in $B(\mathcal{H})^d$.

References

1. Dmitry S. Kaliuzhnyi-Verbovetskyi and Victor Vinnikov. *Foundations of free non-commutative function theory.* AMS, Providence, 2014.

(Received September 10, 2015)

1116-47-826 **Benjamin Peter Russo*** (russo5@ufl.edu). *Sub-Jordan Operator Tuples.*

An operator T is called a *3-isometry* if there exists a $B_1(T^*, T)$ and $B_2(T^*, T)$ such that

$$Q_T(n) = T^{*n}T^n = I + nB_1(T^*, T) + n^2 B_2(T^*, T)$$

for all natural numbers n. A related class of operators, called *3-symmetric* operators, have a similar definition. These operators have a connections with Sturm-Liouville theory and are natural generalizations of isometries and self-adjoint operators. We call an operator J a *Jordan* operator of order 2 if $J = A + N$, where A is either unitary or self-adjoint, N is nilpotent order 2, and A and N commute. As shown in the work of Agler, Ball and Helton, and joint work with McCullough, 3-symmetric and 3-isometric operators can be modeled as Sub-Jordan operators. In this talk we discuss the extension of these theorems to the multi-variable case in relation to a conjecture of Ball and Helton. More specifically, we cover connections between the lifting theorems via spectral theory and the necessity of an extra condition unique to the multi-variable case. (Received September 13, 2015)

1116-47-888 **Yunxiang Ren*** (yunxiang.ren@vanderbilt.edu), 1326 Stevenson Center, Vanderbilt University, Nashville, TN 37240. *Singly generated planar algebras by a 3-box.*

Subfactor planar algebra generated by a 2-box with Yang-Baxter relation has been classified by Bisch, Jones and Liu. We give a classification of singly generated planar algebra by a 3-box with 'I=H' relation. The above part is joint work with C.Jones, Z.Liu. Later, we observe a Z/2Z symmetry on the subfactor arising from $SU(N)_N$ which produces a family of subfactors singly generated by a 4-box. (Received September 14, 2015)

1116-47-974 **Waleed Al-Rawashdeh*** (walrawashdeh@mtech.edu), Montana Tech, 1300 West Park Street, Butte, MT 59701. *Compact Composition Operators on Weighted Hilbert Spaces.*

Let φ be an analytic self-map of open unit disk $\mathbb{D}$. A composition operator is defined as $(C_\varphi f)(z) = f(\varphi(z))$, for $z \in \mathbb{D}$ and f analytic on $\mathbb{D}$. Given an admissible weight ω, the weighted Hilbert space $\mathcal{H}_\omega$ consists of all analytic functions f such that $\|f\|^2_{\mathcal{H}_\omega} = |f(0)|^2 + \int_{\mathbb{D}} |f'(z)|^2 w(z) dA(z)$ is finite. In this talk, we study composition operators acting between weighted Bergman space A^2_α and the weighted Hilbert space $\mathcal{H}_\omega$. (Received September 15, 2015)

1116-47-978 **Kelly Bickel*** (kelly.bickel@bucknell.edu) and **Constanze Liaw**. *Compressed Shift Operators on Two-Variable Model Spaces.*

In this talk, we will discuss the operator-theoretic properties of compressed shift operators on model spaces of the Hardy space on the bidisk. Results include characterizations (in terms of an associated inner function) of when a commutator of a compressed shift with its adjoint has rank n and when subspaces associated to Agler decompositions are reducing for compressed shift operators. Time permitting, we will consider partial generalizations to model spaces of vector-valued functions. (Received September 15, 2015)

1116-47-1061 **Greg Knese*** (geknese@wustl.edu), Washington University in St. Louis, One Brookings Drive, Department of Mathematics, St. Louis, MO 63130. *The 3x3 von Neumann inequality.*

We will explain how recent results of Kosinski on the three point Pick interpolation problem on the polydisc can be used to prove the von Neumann inequality for d-tuples of 3x3 contractive matrices. (Received September 16, 2015)

1116-47-1131 **Robert F. Allen** (rallen@uwlax.edu), 1725 State St., La Crosse, WI 54601, and **Isaac M. Craig*** (craig.isaa@uwlax.edu), 1725 State St., La Crosse, WI 54601. *Multiplication Operators on Weighted Banach Spaces of an Infinite Tree.* Preliminary report.

We study multiplication operators on the weighted Banach spaces H^∞_μ of an infinite tree T. We characterize the bounded and the compact operators, as well as determine the operator norm. In addition, we determine the spectrum of the bounded multiplication operators and characterize the isometries. Finally, we study the multiplication operators between the weighted Banach spaces and the Lipschitz space $\mathcal{L}$ on T by characterizing the bounded and the compact operators, determine estimates of the operator norm, and show there are no isometries. (Received September 17, 2015)

1116-47-1163 **Caixing Gu*** (cgu@calpoly.edu), Department of Mathematics, California Polytechnic State University, San Luis Obispo, CA 93407. *Common reducing subspaces of several weighted shifts with operator weights.* Preliminary report.

We characterize common reducing subspaces of several weighted shifts with operator weights. As applications, we study the common reducing subspaces of the multiplication operators by powers of coordinate functions on Hilbert spaces of holomorphic functions in several variables. The identification of reducing subspaces also leads to structure theorems for the commutants of von Neumann algebras generated by these multiplication operators. This general approach applies to the weighted Hardy spaces, weighted Bergman spaces, Drury-Arveson space and Dirichlet spaces of unit ball or polydisk uniformly. (Received September 17, 2015)

1116-47-1175 **Ronald G Douglas*** (rdouglas@math.tamu.edu), Dept of Mathematics, College Station, TX 778433368. *On Hilbert modules.* Preliminary report.

In the study of multivariable operator theory, one approach is using methods from algebra and in particular studying Hilbert spaces, which are modules over them; that is, actions of the algebra as bounded linear operators on the Hilbert space, where the algebra acts via bounded linear operators on the Hilbert space. One advantage in this approach is the possiblity of bringing results and intuition from algebra into the subject.

In lecture notes by Paulson and myself, we attempted to introduce a notion of projective resolutions into this study. Since then, it was found that the only example for where this is successfuly is appropopate is the Hardy space on the unit disc.

In this talk we explore a somewhat different approach to projective resolutions, where the basic building blocks are "nice reproducing kernel Hilbert spaces" on which the algebra acts as multiplication operators. For the most part, we will raise questions and suggest topics for further study. (Received September 17, 2015)

1116-47-1225 **Ilya M Spitkovsky*** (imspitkovsky@gmail.com). *On Toeplitz operators with matrix almost periodic symbols.*

Toeplitz operators are invertible if and only if their symbols are canonically factorable. In its turn, factorability criteria are well known for continuous or piecewise continuous symbols, in which case they are similar in scalar and matrix settings. Scalar almost periodic symbols, modulo natural adjustments, behave as their continuous counterpart. The situation changes dramatically when passing to matrix almost periodic symbols, for which the factorability criterion is still unknown. We will discuss some particular cases settled by now, including those arising from convolution type equations on finite intervals. (Received September 18, 2015)

1116-47-1280 **Rachael M. Norton*** (rachael-norton@uiowa.edu). *Displacement Theory and W^*-correspondences.*

We show how the so-called displacement equation can be formulated in the context of W^*-correspondences and used to prove a generalization of the Nevanlinna-Pick theorem following the arguments of Constantinescu and Johnson in 2003. We present an outline of our proof and discuss connections between our result and a similar-looking theorem proved by Muhly and Solel in 2004. (Received September 18, 2015)

1116-47-1362 **Rene Ardila*** (rene-ardila@uiowa.edu), 14 MacLean Hall, University of Iowa, Iowa City, IA 52240. *Morita Equivalence and Hardy Algebras.*

We extend the notion of Morita equivalence of C^*-correspondences, developed by Muhly and Solel, to the setting of W^*-correspondences and show that if two W^*-graph correspondences, E and F, are (weakly) Morita equivalent, then their Hardy algebras, $H^\infty(E)$ and $H^\infty(F)$, are weakly Morita equivalent as dual operator algebras in the sense of Blecher and Kashyup. We use this result to study the induced representations of Hardy algebras of W^*-correspondences. Special attention is given to graph correspondences. (Received September 18, 2015)

1116-47-1395 **Erin Griesenauer*** (erin-griesenauer@uiowa.edu), Department of Mathematics, 14 MacLean Hall, Iowa City, IA 52242, and **Paul Muhly** (paul-muhly@uiowa.edu) and **Baruch Solel** (mabaruch@techunix.technion.ac.il). *Matrix Bundles, Function Algebras, and Azumaya Algebras.*

We study algebras of cross sections of holomorphic matrix bundles. Our work is inspired by certain matrix bundles that arise naturally in geometric invariant theory and noncommutative function theory. These algebras of cross sections may be viewed as noncommutative analogues of function algebras. We describe in detail how our algebras arise and show that they are Azumaya algebras. (Received September 19, 2015)

1116-47-1576 **Raul E Curto*** (raul-curto@uiowa.edu). *Hyponormality of commuting pairs of Toeplitz operators with matrix-valued symbols.*

In joint work with In Sung Hwang and Woo Young Lee, we consider commuting pairs of Toeplitz operators on the Hardy space of the unit circle, whose symbols are matrix-valued. We obtain a complete characterization of (joint) hyponormality when the symbols are of bounded type. As in the scalar case (cf. R.E. Curto and W.Y. Lee, Joint hyponormality of Toeplitz pairs, Memoirs AMS 150, no. 712(2001)), we reduce joint hyponormality to the hyponormality of single Toeplitz operators. As a corollary, we obtain a simple description of (joint) hyponormality when the symbols are rational matrix-valued. Along the way we study the self-commutators of Toeplitz pairs with matrix-valued rational symbols, and derive the associated rank formulae. (Received September 20, 2015)

1116-47-1599 **Brittney R. Miller*** (mille753@purdue.edu). *Classifying Functions in the Kernel of the Adjoint of a Composition Operator on the Hardy Space.* Preliminary report.

Let φ be an analytic function mapping the complex unit disk $\mathbb{D}$ to itself. The composition operator C_φ, with symbol φ, is defined by $C_\varphi f = f \circ \varphi$ for f in a Hilbert space of analytic functions on $\mathbb{D}$. Results in the Hardy space relate the kernel, spectrum, and adjoint of C_φ to its symbol φ. In this talk, I will give a classification of functions in the kernel of the adjoint of C_φ for certain classes of symbols φ using the adjoint formula in the Hardy space from Hammond, Moorhouse, and Robbins's 2008 paper. (Received September 21, 2015)

1116-47-1661 **J E Pascoe*** (pascoej@math.wustl.edu). *Monotonicity in free analysis.*

Let $f : (a,b) \to \mathbb{R}$. The function f is said to be *matrix monotone* if $A \leq B \Rightarrow f(A) \leq f(B)$ for all pairs of like-sized self-adjoint matrices with spectrum in (a,b). Classically, Charles Löwner showed that a bounded Borel function is matrix monotone if and only if it is analytic and extends to be a self-map of the upper half plane. The theory of matrix montonicity has profound consequences for any general theory of matrix inequalities. For example, it might seem surprising that $X \leq Y$ does not imply that $X^2 \leq Y^2$, which is a consequence of Löwner's theorem. We will discuss commutative and noncommutative generalizations to several variables of Löwner's theorem. (Received September 21, 2015)

1116-47-1672 **John D. Williams*** (williams@math.uni-sb.de), Universität des Saarlandes, Fachrichtung Mathematik, Postfach 151150, 66041 Saarbrücken, Germany. *$\mathcal{B}$-valued Free Convolution for Unbounded Operators.*

Consider the $\mathcal{B}$-valued probability space $(\mathcal{A}, E, \mathcal{B})$, where $\mathcal{A}$ is a tracial von Neumann algebra. In this talk, we will present recent results that extend the theory of operator valued free probability to the algebra of affiliated operators $\tilde{\mathcal{A}}$. For a random variable $X \in \tilde{\mathcal{A}}^{sa}$ we study the Cauchy transform G_X and show that the operator algebra $(\mathcal{B} \cup \{X\})''$ can be recovered from this function. In the case where $\mathcal{B}$ is finite dimensional, we show that, when $X, Y \in \tilde{\mathcal{A}}^{sa}$ are assumed to be $\mathcal{B}$-free, the $\mathcal{R}$-transforms are defined on universal subsets of the resolvent and satisfy

$$\mathcal{R}_X + \mathcal{R}_Y = \mathcal{R}_{X+Y}.$$

Examples indicating a failure of the theory for infinite dimensional $\mathcal{B}$ are provided. Lastly, we show that the class of functions that arise as the Cauchy transform of affiliated operators is, in a natural way, the closure of the set of Cauchy transforms of bounded operators. Time permitting, we will utilize these results to provide new examples of non-commutative convolution operations. (Received September 21, 2015)

1116-47-1737 **Scott A. Atkinson*** (saa6uy@virginia.edu). *Convex Sets Associated to C*-Algebras.*
Given a separable C*-algebra $\mathfrak{A}$, we can associate to it an invariant given by weak approximate unitary equivalence classes of certain $*$-homomorphisms on $\mathfrak{A}$. One can show that this object takes the form of a closed, bounded, convex subset of a separable Banach space. This can be thought of as a convex version of the semigroup Ext($\mathfrak{A}$). This invariant is closely related (and sometimes affinely homeomorphic) to the trace space of $\mathfrak{A}$, but its data is different from that of the trace space in general. We will discuss structure and properties of this object along with some related consequences and open problems. (Received September 21, 2015)

1116-47-1910 **Joseph C Noles*** (jnoles@math.tamu.edu). *On Upper Triangular Forms in Finite von Neumann Algebras.*
For any operator T in a finite von Neumann algebra, Dykema, Sukochev and Zanin showed that T has an upper triangular form, $T = N + Q$, with N normal, Q sot-quasinilpotent and N and T having the same Brown measure. We discuss recent results in the analysis of such upper triangular forms. (Received September 21, 2015)

1116-47-2069 **Christopher R. Felder***, cfelder@butler.edu. *Zero Inclusion for the Numerical Range of a Composition Operator.* Preliminary report.
This presentation answers a question posed by P. S. Bourdon and J. H. Shapiro, namely, that zero is always in the numerical range of a composition operator C_ϕ acting on $H^2(\mathbb{D})$ when ϕ is any parabolic-type self-map of the unit disk $\mathbb{D}$. (Received September 21, 2015)

1116-47-2098 **Y Shen*** (yshen2@math.fsu.edu), Tallahassee, FL 32306. *motives of noncommutative tori.*
In this article, we propose a way of seeing the noncommutative tori in the category of noncommutative motives. As an algebra, the noncommutative torus is lack the smoothness property required to define a noncomutative motive. Thus, instead of working with the algebra, we work with the category of holomorphic bundles. It is known that these are related to the coherent sheaves of an elliptic curve. We describe the cyclic homology of the category of holomorphic bundle on a noncommutative torus. We then introduce a notion of (weak) t-structure in dg categories. By applying the t-structure to a noncommutative torus, we show that it induces a decomposition of the motivic Galois group of the Tannakian subcategory generated by the auxiliary elliptic curve. (Received September 21, 2015)

1116-47-2306 **David Milan*** (dmilan@uttyler.edu) and **Scott LaLonde** (slalonde@uttyler.edu). *Amenability and uniqueness for groupoids associated with inverse semigroups.* Preliminary report.
We investigate recent uniqueness theorems for reduced C^*-algebras of Hausdorff étale groupoids in the context of inverse semigroups. In many cases the distinguished subalgebra is closely related to the structure of the inverse semigroup. In order to apply our results to full C^*-algebras we also investigate amenability. (Received September 22, 2015)

1116-47-2417 **Victor Vinnikov*** (vinnikov@math.bgu.ac.il), Department of Mathematics, Ben Gurion University of the Negev, P.O.B. 653, 8410501 Beer Sheva, Israel. *Higher order noncommutative functions and the universal skew field of fractions of a tensor product of free algebras.*
Higher order free noncommutative functions relate to usual free noncommutative functions much like usual commutative functions of several variables relate to functions of a single variable. They appear naturally in noncommutative function theory as the range of the noncommutative difference-differential operator. In this talk, I will first review higher order noncommutative functions and some of their properties. I will then show how these ideas can be used in the context of noncommutative rational functions to construct the universal skew field of fractions, in the sense of P.M. Cohn, of a tensor product of free algebras (which is not a fir nor even a Sylvester domain). The talk is based on joint work with Dmitry Kalyuzhnyi-Verbovetskii, and with Igor Klep and Jurij Volcic. (Received September 22, 2015)

1116-47-2435 **John H. Clifford*** (jcliff@umich.edu), Mathematics and Statistics, 4901 Evergreen Road, Dearborn, MI 48128-1491, and **Michael Dabkowski**. *Numerical Range of the product of a composition operator with the adjoint of a composition operator.* Preliminary report.

In this talk, we will consider the numerical range of the product of a composition operator with the adjoint of a composition operator, $W(C_\psi^* C_\varphi)$ and $W(C_\varphi C_\psi^*)$, on the Hardy space. We completely characterize the numerical range when ψ and φ are inner functions. (Received September 22, 2015)

1116-47-2438 **Joseph A Ball*** (joball@math.vt.edu), Department of Mathematics, 225 Stanger Street, McBryde Hall, Blacksburg, VA 24061-0123. *Interpolation and transfer-function realization for the noncommutative Schur-Agler class.*

The Schur-Agler class consists of functions over a domain satisfying an appropriate von Neumann inequality. Originally defined over the polydisk, the idea has been extended to general domains in both commutative and noncommutative settings with polynomial defining function. More recently there has emerged a free noncommutative function theory (functions of noncommuting matrix variables respecting direct sums and similarity transformations). We discuss extensions of the Schur-Agler-class theory to the free noncommutative function setting. This includes the positive-kernel-decomposition characterization of the class, transfer-function realization and Pick interpolation theory. A special class of defining functions is identified for which the associated Schur-Agler class coincides with the contractive-multiplier class on an associated noncommutative reproducing kernel Hilbert space; in this case, solution of the Pick interpolation problem is in terms of the complete positivity of an associated Pick matrix which is explicitly determined from the interpolation data. The talk is based on joint work with Gregory Marx and Victor Vinnikov. (Received September 22, 2015)

1116-47-2678 **Jennifer R Good*** (goodje@uwplatt.edu), Department of Mathematics, University of Wisconsin - Platteville, 435 Gardner Hall, 1 University Plaza, Platteville, WI 53818. *Weighted Nevanlinna-Pick Interpolation over W^*-Algebras.* Preliminary report.

Inspired by Popescu's work with noncommutative varieties, Muhly and Solel recently extended their study of the Hardy algebras that arise from W^*-correspondences to accommodate operator-valued weights. We will consider several classical notions that generalize to this setting, for instance the interpolation results of Nevanlinna and Pick. (Received September 22, 2015)

1116-47-2776 **J. A. Ball**, **G. Marx*** (marxg@vt.edu) and **V. Vinnikov**. *Completely Bounded Noncommutative Kernels.*

We introduce completely bounded noncommutative kernels and investigate when completely bounded noncommutative kernels can be decomposed as a sum of completely positive noncommutative kernels. In the process, we develop an analogue to the Arveson-Wittstock extension theorem. This work extends the theory of noncommutative kernels found in [1], and its development is motivated by the completely bounded kernels found in [2].

[1] J. A. Ball, G. Marx, and V. Vinnikov, *Noncommutative reproducing kernel Hilbert spaces*, to appear.

[2] T. Bhattacharyya, M. A. Dritschel, and C. S. Todd. *Completely bounded kernels*, Acta Sci. Math. (Szeged) **79** (2013), 191-217. (Received September 22, 2015)

1116-47-2781 **Snehalatha Ballamoole*** (sb1244@msstate.edu), Visiting Assistant Professor, Department of Mathematics and Statistics, Mississippi State University, Starkville, MS 39762, **Thomas Len Miller** (miller@math.msstate.edu), Professor, Department of Mathematics and Statistics, Mississippi State University, Starkville, MS 39762, and **Vivien Glass Miller** (vivien@math.msstate.edu), Professor, Department of Mathematics and Statistics, Mississippi State University, Starkville, MS 39762. .

We consider a class of integral operators $T_{\mu,\nu}f(z) := z^{\mu-1}(1-z)^{-\nu}\int_0^z w^{-\mu}(1-w)^{\nu-1}f(w)dw$ on the Zygmund space $\mathcal{Z}$ of the unit disk. Specifically, we obtain the boundedness, spectrum and the point spectrum of $T_{\mu,\nu}$ on the Zygmund space $\mathcal{Z}$. We also obtain boundedness and boundedness from below of the multiplication operator $M_u f(z) = u(z)f(z)$ on the Zygmund space which is a crucial in the proof of spectrum of $T_{\mu,\nu}$.
(Received September 22, 2015)

49 ► Calculus of variations and optimal control; optimization

1116-49-97 **Tan Hoang Cao*** (tan.cao@wayne.edu), 641 Prentis Street, apt 111, Detroit, MI 48201.
Optimal control of the perturbed sweeping process over polyhedral controlled set. Preliminary report.

The paper addresses a new class of optimal control problems governed by the dissipative non-Lipschitzian differential inclusion of the perturbed sweeping/Moreau process over a moving controlled polyhedral set. Besides the highly non-Lipschitzian nature of the unbounded differential inclusion of the controlled perturbed sweeping process, the optimal control problems under consideration contain intrinsic state constraints of the inequality and equality types. All of this creates serious challenges for deriving necessary optimality conditions. We first establish the strong convergence of optimal solutions of discrete approximations to a local minimizer of a continuous-time system and obtain necessary conditions for discrete counterparts of the controlled sweeping process under consideration. And then we derive constructive necessary conditions for the original perturbed sweeping process problem expressed entirely in terms of the data and the reference trajectory. Our approach to necessary optimality conditions is based on the method of discrete approximations and generalized differential tools of variational analysis. The established necessary optimality conditions for the perturbed sweeping process are illustrated by some nontrivial examples. (Received July 22, 2015)

1116-49-195 **Minh Ngoc Dao*** (minhdn@hnue.edu.vn), 3333 University Way, Kelowna, BC V1V 1V7, Canada. *On the Douglas-Rachford algorithm: inconsistency and finite convergence.*

The Douglas-Rachford algorithm is one of the most successful methods for solving optimization and feasibility problems. In this talk, we present convergence results when the underlying constraints are possibly inconsistent but one constraint is an affine subspace. We also provide novel conditions sufficient for finite convergence in the context of convex feasibility problems. (Received August 12, 2015)

1116-49-326 **Messaoud Bounekhel*** (bounkhel@ksu.edu.sa), King Saud University, Department of, Mathematics, college of Science, Riyadh 11451, Saudi Arabia, Riyadh, 11451, Saudi Arabia.
Existence of equilibria and fixed points of set-valued mappings on epi-Lipschitz sets with weak tangential conditions.

In this paper we prove a new result of existence of equilibria for an u.s.c. set-valued mapping F on a compact set S of finite dimensional space which is epiLipschitz and satisfies a weak tangential condition. Equivalently this provides existence of fixed points of the set-valued mapping F(x) → x. The main point of our result lies in the fact that we do not impose the usual tangential condition in terms of the Clarke tangent cone. Illustrative examples are stated showing the importance of our results and that the existence of such equilibria does not need necessary such usual tangential condition. (Received August 25, 2015)

1116-49-403 **Yuan Tian*** (tiany7@miamioh.edu), 301 S. Patterson Ave., BAC 230, Oxford, OH 45056, and **Boris Mordukhovich**. *Runge-Kutta Approximation and Optimization of Differential Inclusions.*

This talk concerns the Runge-Kutta approximation of the generalized Bolza type problem for dynamic systems governed by constrained differential inclusions. We construct an approximating Runge-Kutta sequence and prove that this sequence converges to the optimal solution. First we establish well-posedness of the Runge-Kutta discrete approximations in the sense of $W^{1,2}$ norm convergence to the trajectory for differential inclusions. Moreover, we build a Runge-Kutta discrete sequence of finite-dimensional optimization problems with a strong convergence of optimal solution. Finally, we derive necessary optimality conditions for the discretized Bolza problems via suitable generalized differential constructions of variational analysis. (Received August 30, 2015)

1116-49-427 **Ebrahim Sarabi*** (ebrahim.sarabi@wayne.edu), Department of Mathematics, 1264 Faculty/Administration Building, 656 W. Kirby, Detroit, MI 48202. *Stability analysis of composite optimization problems with applications to critical multipliers.*

In this talk, we consider a composite optimization problem and present a second-order characterization of full stable local minimizers of this problem. Finally, we show that how full stability can rule out the existence of critical multipliers of the latter problem. (Received August 31, 2015)

1116-49-738 **R. Blake Rector*** (r.b.rector@pdx.edu) and **Nguyen Mau Nam** (mau.nam.nguyen@pdx.edu). *Geometric Approach to Convex Analysis in Locally Convex Topological Vector Spaces.*

We use a geometric approach to study generalized differentiation of convex functions and set-valued mappings in infinite dimensions. This approach provides easy access to basic subdiffrential formulas as well as new calculus results on subgradients of optimal value functions and coderivatives of set- valued mappings in locally convex topological vector spaces. (Received September 11, 2015)

1116-49-891 **Piotr Hajlasz*** (hajlasz@pitt.edu) and **Soheil Malekzadeh**. *Unrectifiability of metric spaces and mappings of bounded length distortion.*

I will discuss some results about unrectifiability of metric spaces and a related new characterization of mappings of bounded length distortion. (Received September 14, 2015)

1116-49-967 **Aden O Ahmed*** (aden.ahmed@tamuk.edu), Department of Mathematics MSC 172, 700 University BLVD, Kingsville, TX 78363-8202. *Optimal Strategies in a Quantum Three-Player Dilemma Game.*

This presentation explores an octonionic representation of the payoff function in generic three-player maximally entangled quantum games. This fresh computational framework is then utilized to identify certain family of optimal strategies in a quantized version of a three-player dilemma game. (Received September 15, 2015)

1116-49-1309 **Enrique Alvarado*** (ealvarado9611@gmail.com). *The multi-scale flat norm and applications: an introduction.*

In geometric measure theory, the flat norm has been used as a metric in the space of currents since its introduction by Hassler Whitney in 1957. In 2007 it was noticed that the L^1TV functional that is used in image analysis was calculating a multi-scale generalization of the flat norm. As an introduction to the talks of Ibrahim and Hu, we will explain the multi-scale flat norm and the space of currents, and show an example of how it applies to image analysis. (Received September 18, 2015)

1116-49-1348 **Yunfeng Hu*** (yhu@math.wsu.edu), **Bala Krishnamoorthy**, **Altansuren Tumurbaatar** and **Kevin R. Vixie**. *Median shapes and minimal varifolds.* Preliminary report.

Using the variational definitions for mean and median one can use any distance on a space to get means and medians in those spaces. In this work, we represent shapes as currents and use the multiscale flat norm to measure distance, and we define mean and median currents variationally. Because of computational issues, we focus on medians, in which case the simplicial versions of the problem can be easily solved with linear programming. This talk will focus primarily on the the theoretical properties of the problem. We will discuss existence and uniqueness of medians, both in the unregularized and mass regularized forms. We will also discuss results on the regularity of minimizers in the case in which we look for varifold solutions related to medians of shapes that share boundaries. (Received September 18, 2015)

1116-49-1428 **Ahmad R Almomani*** (almomaar@clarkson.edu), 8 Clarkson Ave. Box 5815, Mathematics Department, Clarkson University, Potsdam, NY 13699. *Constraint Handling for Water Resources Application with Filter Particle Swarm Optimization.*

When the derivative is hard to compute or unavailable in most real-world, then we use Derivative-Free Optimization(DFO) solvers. The presence of constraints brings difficulties in searching step since the search space has to be restricted to a feasible region. We introduce new algorithm for global method that combine filter method for constraints with Particle Swarm Optimization (PSO) method. We apply the new algorithm on water resources policy and compare it with current solvers using performance and data profiles. (Received September 19, 2015)

1116-49-1486 **Isabelle Kemajou-Brown*** (isakema@gmail.com). *Brief history of optimal control theory and some recent developments.*

Optimal control theory has been very well developed in the past years out of the need to derive a control policy such that a certain optimality criterion is reached. After a brief introduction on the starting point and evolution of this topic, we discuss some formulations in both deterministic and stochastic cases. We present the main approaches of solving optimal control problems. We formulate a stochastic control problem under regime switching model using the maximum principle approach. The shadow price of a resource with some specific consideration is the key to understanding the economic interpretation of optimal control theory. We also discuss an example of connection between optimal control and shadow price. (Received September 20, 2015)

1116-49-1524 **R N MOHAPATRA** (ram.mohapatra@ucf.edu), Department of Mathematics, University of Central Florida, 4000 Central Floida Blvd., Orlando, FL 32816, and **Rachid Ait Maalem Lahcen*** (rachid@ucf.edu), Department of Mathematics, University of Central Florida, Orlando, FL 32816. *A study of Mathematical Programming Problems under different types of invexity.* Preliminary report.

Convexity, Invexity and Univexity have been used to study multi-objective mathematical programming problems. In this talk we will discuss some of these topics and their relationships. The intent of this talk is to seek methods that can handle smooth and mon-smooth mathematical programming problems under generalized invexity. The research is at its explorative stage. (Received September 23, 2015)

1116-49-1560 **Dominique Zosso*** (zosso@math.ucla.edu), **Braxton Osting** and **Stanley J. Osher**. *A Dirichlet energy criterion for graph partitioning and image segmentation.*

We consider the graph partitioning problem using a criterion based on the sum of the minimal Dirichlet energies of partition components. This is a bi-level optimization problem; we propose an efficient primal-dual method for computing the Dirichlet energy ground state of partition components (inner problem), and a rearrangement algorithm is used to improve graph partitions (outer problem).

We demonstrate the graph partitioning method on the five-moons toy problem, the MNIST data set, as well as 2D and 3D domain partitioning. We also extend it to a graph-based approach for image segmentation. To this end, we introduce several novel graph construction models which are based on graph-based segmentation criteria extending beyond—and bridging the gap between—segmentation approaches based on edges and homogeneous regions alone.

The method is applied to a number of example segmentation problem. We illustrate the various image-based graph constructions, before successfully running a variety of region-, edge-, hybrid, and texture-based image segmentation experiments. Our method seamlessly generalizes region- and edge-based image segmentation to the multi-phase case and can intrinsically deal with image bias as well as more interesting image features such as texture descriptors. (Received September 20, 2015)

1116-49-1750 **Roberto Paroni*** (rob.paroni@gmail.com), DADU, Palazzo Pou Salit, 33100 Alghero, SS, Italy. *The energy of a Möbius band.*

In 1929 Sadowsky gave a constructive proof for the existence of a developable Möbius band and posed the problem of determining the equilibrium configuration of a Möbius strip formed from an unstretchable material. He tackled this latter problem variationally and he deduced the bending energy for a strip whose width is much smaller than the length. This energy, now known as Sadowsky's energy, depends on the curvature and torsion of the centerline of the band and it is singular at the points where the curvature vanishes.

In this talk, we re-examine the derivation of the Sadowsky's energy by means of the theory of Gamma-convergence. We obtain an energy that is never singular and agrees with the classical Sadowsky functional only for "large" curvature of the centerline of the strip.

The talk is based on ongoing joint work with L. Freddi, P. Hornung, and M.G. Mora. (Received September 21, 2015)

1116-49-1892 **Robert J Kipka*** (kipka@mast.queensu.ca), Robert Kipka, Department of Math & Stats, Jeffery Hall, University Ave., Kingston, Ontario K7L 3N6, Canada, and **Yuri S. Ledyaev**. *A generalized multi-directional mean value inequality.*

Since the appearance of the first multi-directional mean value inequality in 1994, theorems of this type have proven their utility through nontrivial applications in the areas of optimization and control theory. Stated in terms of nonsmooth or variational analysis, such theorems nonetheless provide novel and important information even for smooth problems. Among the applications of the original theorem is a short proof of Subbotin's theorem, which provides an important connection between subgradients and Dini subderivates.

Certain recent problems in dynamic optimization have required a mean value inequality that incorporates variations originating in topological vector spaces. In this talk we show how such an extension can be obtained in a general setting, derive a corresponding Subbotin-type theorem, and point out applications of these general theorems to problems in the areas of optimal control and calculus of variations. (Received September 21, 2015)

1116-49-1940 **John V Matthews*** (matt-matthews@utc.edu), 615 McCallie Ave, Dept 6956, Chattanooga, TN 37363, and **Boris P Belinskiy** and **Don B Hinton**. *The leading mode in an ice-covered ocean wave guide.* Preliminary report.

Wave propagation is studied for a layered ocean wave guide covered by pack ice. The standard separation of variables leads to a Sturm–Liouville problem in the cross–section of the wave guide. We find the leading mode that is the separated solution for the maximal eigenvalue. Assuming that the speed of propagation varies within the given physical limits, we identify the minimum and maximum wave numbers of that leading mode. A numerical study of the problem allows us to evaluate the leading wave number (eigenvalue) and comment on physical properties of the system. (Received September 21, 2015)

1116-49-1959 **João Gouveia*** (jgouveia@mat.uc.pt), Departamento de Matemática, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, 3001-501 Coimbra, Portugal. *Slack ideals and semidefinite representations of polytopes.*

In this talk, we will introduce the concept of slack ideal, an algebraic object that codifies the geometry of a polytope. This notion is motivated by our study of psd minimality.

A d-polytope is said to be psd minimal if it can be written as a projection of a slice of the cone of $d+1$ by $d+1$ positive semidefinite matrices, the smallest possible size for which this may happen. We will show how the slack ideal can be used to extract conditions on psd minimality, and use it to complete the classification of psd minimal 4-polytopes, settling some open questions and creating new ones.

Joint work with Kanstantsin Pashkovich, Richard Robinson and Rekha Thomas. (Received September 21, 2015)

1116-49-1978 **Xin Luo*** (xluo10@crimson.ua.edu) and **Min Sun**. *An Improved Modal Interval Algorithm for Unconstrained Continuous Minimax Problems.*

Continuous minimax problems can be applied to engineering, finance and other fields. Based on Miguel Á. Sainz [Journal of Mathematical Analysis and Applications. 339(2008) 18-30], we introduced a new definition of semantic extensions and developed an improved algorithm using modal intervals to solve unconstrained continuous minimax problems. The convergence of the algorithm and more deletion conditions are proposed in this paper. Numerical results of several typical examples show that the algorithm is reliable and efficient. (Received September 21, 2015)

1116-49-2078 **Arjuna Flenner*** (arjuna.flenner@navy.mil). *Exploitation of Graphical Models to Guide Deep Representations.* Preliminary report.

Recently, the graph theory, PDE, and optimization communities have generated algorithms to analyze pairwise relationships between high dimensional data samples using graph segmentation and clustering algorithms. Concurrently, the machine learning community has developed a representation learning strategy, deep learning, that obtains human levels of performance for many image and voice classification data sets. These deep architectures learn a multi-layer collection of representations where a representation at a higher layer is related to the lower layer through a nonlinear pooling operator, which results in down-sampling and dimensionality reduction. The pooling strategy is chosen to create a final representation that is robust to deformations along a pre-specified group operation, such as the translation group, and much of the success of the deep architectures is attributed to this pooling step. This work devises a framework that incorporates the pairwise relationships of graphical data, which may be difficult to describe using a distance or metric, into the deep learning architecture that is consistent with the pooling structure. We demonstrate this framework in three tasks: database organization, regression, and classification. (Received September 21, 2015)

1116-49-2082 **Julia Eaton*** (jreaton@uw.edu), SIAS, UWT, 1900 Commerce Street, Box 358436, Tacoma, WA 98402, and **James V Burke**. *A chain rule for spectral functions.* Preliminary report.

Spectral functions are functions of the form $\psi := H \circ \Lambda$, where $H : \mathbb{C}^n \to \mathbb{R}$ is permutation invariant and $\Lambda : \mathbb{C}^{n\times n} \to \mathbb{C}^n$ takes a matrix to its vector of eigenvalues. If H returns the maximum of the real parts of its argument we recover spectral abscissa. If H returns the maximum modulus of its arguments we recover the spectral radius. Spectral functions can be viewed through polynomial root functions. Let $\Phi : \mathbb{C}^{n\times n} \to \mathcal{P}^n$ take a matrix to its characteristic polynomial, where $\mathcal{P}^n$ denotes degree n polynomials, let $\zeta : \mathcal{P}^n \to \mathbb{C}^n$ take a degree n polynomial to its vector of roots, and let $\mathfrak{h} : \mathcal{P}^n \to \mathbb{R}$ be given by $\mathfrak{h} := H \circ \zeta$. Then there is a one-to-one correspondence between spectral functions ψ and polynomial root functions $\mathfrak{h}$. An eigenvalue is nonderogatory if its geometric multiplicity is one. By applying a subdifferential chain rule formula, we formalize a long-standing intuition that nonderogatory matrices behave like polynomials, at least from a variational perspective. (Received September 21, 2015)

1116-49-2090 **Akhtar A. Khan*** (aaksma@rit.edu), Center for Applied and Computational Mathemat, School of Mathematical Sciences, Rochester, NY , and **Dumitru Motreanu**. *Existence Theorems for Elliptic and Evolutionary Variational and Quasi-Variational Inequalities.*

This talk gives new existence results for elliptic and evolutionary variational and quasi-variational inequalities. Specifically, we give an existence theorem for evolutionary variational inequalities involving different types of pseudo-monotone operators. Another existence result embarks on elliptic variational inequalities driven by maximal monotone operators. We propose a new recessivity assumption that extends all the classical coercivity conditions. We also obtain criteria for solvability of general quasi-variational inequalities treating in a unifying way elliptic and evolutionary problems. Two of the given existence results for evolutionary quasi variational inequalities rely on Mosco-type continuity properties and Kluge's fixed point theorem for set-valued maps. We also focus on the case of compact constraints in the evolutionary quasi-variational inequalities. Here a relevant feature is that the underlying space is the domain of a linear, maximal monotone operator endowed with the graph norm. Applications are also given. (Received September 21, 2015)

1116-49-2128 **Ekaterina Merkurjev*** (kmerkurjev@gmail.com). *Modified Cheeger and Ratio Cut Methods Using the Ginzburg-Landau Functional for Classification of High-Dimensional Data.*

Recent advances in clustering have included continuous relaxations of the Cheeger cut problem and those which address its linear approximation using the graph Laplacian. In this talk, we show how to use the graph Laplacian to solve the fully nonlinear Cheeger cut problem, as well as the ratio cut optimization task. For the derivation, the Ginzburg-Landau functional is used. The resulting algorithms are efficient ways to cluster the data into two classes, and they can be easily extended to case of multiple classes, or used on a multi-class set via recursive bipartitioning. In addition to showing results on benchmark data sets, we also show an application of the algorithm to hyperspectral video data. (Received September 21, 2015)

1116-49-2225 **Kehinde Rilwan Salau***, 617 N Santa Rita Ave., Tucson, AZ 85719, and **David W Shanafelt** and **Richard T Melstrom**. *The optimal timing of reintroduction: The case of the endangered black-footed ferret.* Preliminary report.

Species reintroduction into the wild is a popular conservation tool. One of the flagship species for reintroduction is the black-footed ferret (Mustela nigripes), which is endangered due to declines in its primary food source, prairie dogs. Reintroduction programs are expensive, incurring costs to grow captive populations as well as to manage wild ones, but most recovery studies ignore these costs and focus on the biological complexities of the problem. We conduct a bioeconomic analysis of a stylized ferret reintroduction program, where the objective is to minimize the costs of reintroduction while providing a suitable number of ferrets to establish a viable wild population. This analysis accounts for the fact that reintroduction requires jointly managing (1) ferrets in captivity and (2) ferrets and prairie dogs in the wild. Under scrutiny is the period when a wild ferret population should be established, so the control variable is the timing of reintroduction. This distinguishes the paper from prior work in bioeconomics, which largely examine problems involving adjustable controls. The simplicity and realism of this control means that the ferret application can provide insights into efficient management for a wide range of reintroduction programs. (Received September 22, 2015)

1116-49-2309 **James A Matuk*** (matukj@duq.edu). *Adaptations to Curvature Based Denoising.*

Image denoising techniques include tools from a number of fields of mathematics including partial differential equations, probability, linear algebra, and both convex and non-convex optimization. Recent work by Bertalmio and Levine has demonstrated that it might be more effective to denoise the curvature of the level lines of a noisy image and then use this 'denoised' curvature information to reconstruct an estimate of the original image. The goal of this research is to statistically analyze image curvature data in order to develop better denoising methods for this new framework. In this talk I will give a brief description of the problem: image noise. An analysis of the curvature noise distribution which motivates new techniques for denoising curvature data will follow. We use this information to generate a denoised image using a variational model that incorporates the smoothed level line curvature data while preserving level line contrast. Numerical results using this approach show improvement upon state-of-the art denoising methods. (Received September 22, 2015)

1116-49-2312 **Kinardi Isnata*** (isnatak@duq.edu). *A Variational Approach for High Dynamic Range Imaging (HDR).* Preliminary report.

In this talk, we present a variational approach for fusing information from a stack of image data consisting of short and long exposure images into a High Dynamic Range (HDR) image. The varying range of exposures allow for an HDR that possesses the desired visual information in all regions in the image (e.g. vibrant colors, sharp details, and a greater dynamic range of luminosity), which a regular camera cannot capture. Based on the variational approach proposed by Bertalmio and Levine (2013) for fusing an exposure bracketed image pair, we develop a method that can fuse any number of images of the same field of view. The framework is capable of attenuating spatially varying nonlinear blur, reducing noise, preserving details, and correcting color information. In addition to the ordinary HDR problems, we demonstrate how this framework can be used to fuse medical image data, such as MRI and CAT scans. (Received September 22, 2015)

1116-49-2436 **Norma Ortiz-Robinson*** (nlortiz@vcu.edu) and **Vinicio R Rios** (vrios@demat-fecluz.org). *Invariance properties of time delayed differential inclusion systems.*

Necessary and sufficient conditions of invariance for dynamical systems described by differential inclusions with time delay will be discussed. In addition, we present properties of new versions of the minimal time function and reachable set under these delayed dynamics. (Received September 22, 2015)

1116-49-2521 **Doug E. Ward*** (wardde@miamioh.edu), Miami University, Dept of Mathematics, 301 S. Patterson Ave, Oxford, OH 45056. *Generalized Directional Derivatives of the Perturbation Map in Parametric Set-Valued Optimization.* Preliminary report.

In parametric nonlinear programming, there are well known bounds on the upper and lower Dini directional derivatives of the value function. We look at the possibility of extending such results from a scalar optimization setting to a set-valued optimization setting. (Received September 22, 2015)

1116-49-2632 **Andrea Bertozzi*** (bertozzi@math.ucla.edu), 520 Portola Plaza, Los Angeles, CA 90095. *Geometric graph-based methods for high dimensional data.*

We present recent methods for segmentation of large datasets with graph based structure. The method combines ideas from classical nonlinear PDE-based image segmentation with fast and accessible linear algebra methods for computing information about the spectrum of the graph Laplacian. The goal of the algorithms is to solve semi-supervised and unsupervised graph cut optimization problems. (Received September 22, 2015)

1116-49-2634 **Noemi Petra*** (npetra@ucmerced.edu). *A Fast and Scalable Method for A-Optimal Design of Experiments for Infinite-dimensional Bayesian Nonlinear Inverse Problems with Application to Porous Medium Flow.*

We address the problem of optimal experimental design (OED) for Bayesian nonlinear inverse problems governed by partial differential equations (PDEs). The inverse problem seeks to infer a parameter field (e.g., the log permeability field in a porous medium flow problem) from experimental data observed at a set of sensor locations. The goal of the OED problem is to find an optimal placement of sensors so as to minimize the uncertainty in the inferred parameter field. We formulate the OED objective function by generalizing the classical A-optimal experimental design criterion using the expected value of the trace of the posterior covariance. This OED problem includes as constraints the system of PDEs characterizing the maximum a posteriori probability (MAP) point, and the PDEs describing the action of the covariance (of the Gaussian approximation to the posterior) to vectors. We control the sparsity of the sensor configurations using sparsifying penalty functions, and solve the resulting bilevel optimization problem via an interior-point quasi-Newton method. Numerical results show that the number of PDE solves required for the evaluation of the objective function and its gradient is independent of both the parameter and the sensor dimensions. (Received September 22, 2015)

1116-49-2702 **Luciano Stefanini** (lucste@uniurb.it), University of Urbino "Carlo Bo", Via A. Saffi 42, 61029 Urbino, PU, Italy, and **Barnabas Bede*** (bbede@digipen.edu), Department of Mathematics, DigiPen Institute of Technology, Redmond, WA 98052. *A new difference for compact convex sets.*

The concept of difference of two compact convex subsets in $\mathbb{R}^n$ plays a central role in optimization theory and in particular in quasidifferential calculus. There are various difference concepts defined by various authors, as e.g., Pontryagin, Demyanov, Rubinov, etc. We define a new difference in the space of compact convex subsets of $\mathbb{R}^n$, based on a generalization of the Hukuhara difference for intervals. Based on the support function and the dual support function we construct a family of support intervals of a given compact convex set. We consider the family of intervals obtained as generalized Hukuhara differences of the support intervals of the two sets, and we construct a minimal, compact convex set that contains this family of intervals. This construction leads to a novel difference concept between compact convex sets. We study this new difference in comparison with various other similar concepts as e.g., Pontryagin difference and Demyanov difference. (Received September 22, 2015)

1116-49-2751 **Mau Nam Nguyen*** (mnn3@pdx.edu), Department of Mathematics and Statistics, Portland State University, Portland, OR 97201, and **Daniel Giles**, Department of Mathematics and Statistics, Portland State University, Portland, OR 97201. *Minimizing Differences of Convex Functions and Applications to Multifacility Location.*

In this talk we present a number of optimization methods for minimizing differences of convex functions. Then we introduce an algorithm based on differences of convex functions for solving some multi-facility location problems that involve distances generated by different norms and Minkowski gauges. We also discuss results of convergence as well as numerical tests to show the effectiveness of the algorithm. (Received September 22, 2015)

1116-49-2777 **Baasansuren Jadamba*** (bxjsma@rit.edu), Center for Applied and Computational Math, Rochester Institute of Technology, Rochester, NY 14623. *Efficient second-order methods for an elastography inverse problem.*

This work is on a computational framework for an inverse problem of detecting cancerous tumors in the human body using an output least-squares (OLS) approach. The proposed framework is based on employing second-order methods. One of the main contributions of this work is a thorough derivation of an efficient computation of the hessian of the OLS functional. Joint work with Akhtar Khan and Miguel Sama. (Received September 22, 2015)

1116-49-2902 **Drew P Kouri*** (dpkouri@sandia.gov), PO Box 5800, MS 1320, Sandia National Laboratories, Albuquerque, NM 87125. *A Data-Driven Approach to PDE-Constrained Optimization Under Uncertainty.* Preliminary report.

In engineering optimization problems the true physical parameters are often unknown and estimated from data. For many applications it is critical that the optimal solutions are, in some sense, robust to this uncertainty. In this talk, I will present a distributionally robust approach that incorporates data in PDE-constrained optimization. First, I will develop a data-driven discretization for the unknown probability measures of PDE parameters and prove rigorous error bounds for this discretization. I will then formulate a robust optimization problem which accounts for the uncertainty in the estimated probability measures. I will conclude with a discussion of potential algorithms and preliminary numerical results. (Received September 23, 2015)

1116-49-2910 **M. Zuhair Nashed*** (m.nashed@ucf.edu), Professor Zuhair Nashed, Department of Mathematics, University of Central Florida, Orlando, FL 32816. *Variational gradients in function spaces.*

In a series of papers (see [1] and [2] and refereces therin), Hamilton and Nashed introduced and studied new notions of (locally defined) regualar and singular variational derivatives, ans singular bivariational derivatives. General representation theorems for the Gateaux variation of a functional are established in terms of these notions. . These notions and results resolve difficulties inherent in what Volterra called ""exceptional points"'and in the classical treatment of functional (or Volterra) derivative. In this talk, weintroduce notions of regular gradients and singular gradients in function spaces that resolve these difficulties, and apply them to examples in the calculus of variations and variational problenms. (Received September 23, 2015)

1116-49-2956 **Pando Georgiev*** (pandogeorgiev@gmail.com), Department of Mathematics, University of Central Florida, 4393 Andromeda Loop N, Orlando, FL 32816, and **Zuhair Nashed** (zuhair.nashed@ucf.edu), Department of Mathematics, University of Central Florida, 4393 Andromeda Loop N, Orlando, FL 32816. *Sampling from several functions and simultaneous reconstruction.* Preliminary report.

Assume that we have samples (point values) from several functions, however we do not know which samples to which function belong. We develop sufficient conditions for reconstruction of all functions from the given point values, using the theory of reproducing kernel spaces. We present algorithms for this functions reconstruction problem and discuss connections with the statistical learning theory. (Received September 23, 2015)

51 ► Geometry

1116-51-231 **Derege H Mussa*** (derege.mussa@utdallas.edu), 800 West Campbell Road, Richardson, TX 75080. *Generating Tetrahedra from a Monotonic series.* Preliminary report.

Derege Mussa(derege.mussa@utdallas.edu),800 West Campbell Road , Richardson, TX 75080. Generating Tetrahedra from a Monotonic series Tetrahedron (plural Tetrahedra) is a three dimensional solid having four vertices, four triangular faces and six edges which don't lie in a single plane. Each of the four faces of a tetrahedron form a triangle so a six tuple S = (a, b, c, d, e, f) exists if the tetrahedron is facial and that the McCrean determinant is positive. Using only the partition information tetrahedron would lie in one of the 11 classes. These 11 classes exist as 3D type but not as a degenerate 2D type because it doesn't exist in the plane. According to Derege Mussa Theorem: There are 25 different partition classes of Tetrahedra taking into account graph theoretical aspects of the position of the edges, and all 25 types exist. if we take {1,1,1,1,1,1} partition type one can construct a total of 30 incongruent Tetrahedra. The question is can we generate a legal Tetrahedra from a six tuple S = (a, b, c, d, e, f) using monotonic series in a natural way? This paper discusses 1.Reconstruction of Tetraheda 2. Monotonic series of Tetrahedra 3. Generating of Tetrahedra using monotonic series (Received August 15, 2015)

1116-51-398 **Mamoun Sakkal*** (`mamoun@sakkal.com`), Sakkal Design, 1523 175th place SE, Bothell, WA 98012. *Intersecting Squares: Geometric Compositions of Square Kufic Calligraphy in Bibi Khanum Mosque, Samarkand.*

The colossal Bibi Khanum mosque built by Timur in Samarkand is a showcase of Square Kufic calligraphy at the beginning of the 15th century. Its exterior walls are covered with multiple designs that demonstrate geometric concepts used as basis for constructing calligraphic surface patterns. In this paper, I will present designs based on different arrangements of squares, and will detail one of these schemes, the Double Square, where two squares intersect each other on their diagonal axes.

After a brief historical overview of Square Kufic and the geometric principles of its square designs, the Square Kufic patterns in Bibi Khanum mosque are presented in a catalogue of compositions. Although the octagon-based designs seem to follow already established and commonly used patterns, several of those based on squares are original schemes uniquely appropriate for Square Kufic calligraphy. The square-based compositions can result from placing the squares adjacent to each other, or intersecting the squares on their sides or their diagonals.

A versatile and widely used pattern in Timurid architecture is the Double Square design, which will be analyzed in detail. This design is an exceptional case of union between calligraphy and geometry in the arts of medieval Islam. (Received September 01, 2015)

1116-51-439 **Robert J Lang*** (`robert@langorigami.com`) and **Roger Alperin** (`roger.alperin@sjsu.edu`). *Counterrotating Twist Tessellations and Brocard Polygons.*

Previous work by Lang and Bateman showed that a tiling of convex polygons could be converted to a flat-foldable origami tessellation via the "shrink-rotate" algorithm if and only if the tiling satisfied the Spiderweb condition, i.e., it possessed a non-crossing reciprocal diagram. In such origami tessellations, the twists all rotate the same direction, i.e., all clockwise or all counterclockwise.

There is another family of flat-foldable twist tessellations in which adjacent twists rotate in opposite directions. Such tessellations have been known in the origami world for many years, but no general algorithm has previously been described for their construction. In this work, we describe an algorithm for the construction of a general class of flat-foldable twist tessellations in which each tiling gives rise to a 2-D parameterized family of tessellations. We show that a sufficient condition for the existence of such a family is that each tile in the tiling is a cyclic Brocard polygon and show several new examples of such tessellations. (Received September 01, 2015)

1116-51-441 **Denise M Halverson*** (`halverson@math.byu.edu`), 263 TMCB, Brigham Young University, Provo, UT 84602. *Kaleidocycles, Rigid Reachability, and Huffman Grids.* Preliminary report.

In this presentation, we will look at the interplay between geometric and analytical methods in solving problems in origami mathematics. (Received September 01, 2015)

1116-51-574 **Jonas Azzam***, Universitat Autònoma de Barcelona, Departament de Matemàtiques, Edifici C, Faculta de Ciències, Bellaterra, Spain, and **Xavier Tolsa**. *A characterization of rectifiable measures in Euclidean space.*

We show that a Radon measure μ in R^d which is absolutely continuous with respect to n-dimensional Hausdorff measure H^n is n-rectifiable if the so called Jones' square function is finite μ-almost everywhere. The converse of this result is proven in a companion paper by Xavier Tolsa, and hence these two results give a classification of all n-rectifiable measures which are absolutely continuous with respect to H^n. (Received September 07, 2015)

1116-51-641 **Ryuhei Uehara*** (`uehara@jaist.ac.jp`), School of Information Science, JAIST, Nomi 1-1, Ishikawa 923-1292, Japan. *Recent results on common developments of tetramonohedron and other solids.*

In general, it is not known the relationship between a polygon P and a polyhedron Q that can be folded from P. Only exception is that P is a kind of p2 tiling if and only if Q is a tetramonohedron which consists of four congruent triangles. We have investigated polygons P that can be folded into two or more convex polyhedra. In this talk, we focus on the polyhedra that can be folded from a p2 tiling which is a development of a tetramonodedron. We summarize recent results: (1) We classify Johnson solids whether whose edge developments can fold into regular tetrahedra or not. Some Johnson solids have edge developments that can fold into regular tetrahedra in two or more different ways. We also give the proof that states the other Johnson solids have no such edge developments. (2) We proposed an algorithmic way that generates a polygon that can fold into regular cube and "almost regular" tetrahedron. The error of this almost regular tetrahedron can be bounded above by $2.89200 \times 10^{-1796}$. Some open problems will be also presented. (Received September 09, 2015)

1116-51-787 **J Mealy*** (jmealy@austincollege.edu) and **Ryan Hood** (rhood13@austincollege.edu). *Spiraling geodesics (II) in staircase metric geometries.*

Further results in the category, staircase metric geometry. After providing a brief introduction to our category of geometric systems, we report on the continued investigation of geodesics in these systems that exhibit a spiraling characteristic. The construction of new examples of semi-complete geodesics of this type utilizes a dilation factor boundary scheme 'orthogonal' to that featured in our earlier constructions. The constructed parameter space features other differences from those earlier examples, and suggests new directions in the work. Finally, on a broader note, we discuss a form of the angle change law governing df-boundary crossings of geodesics in very general 2-dimensional (positive definite) SMG systems. (Received September 12, 2015)

1116-51-807 **Dylan G.L. Allegretti*** (dylan.allegretti@yale.edu), Department of Mathematics, Yale University, 10 Hillhouse Ave., New Haven, CT 06511. *A q-deformation of Fock and Goncharov's canonical basis for moduli spaces of local systems on surfaces.*

In a famous paper from 2003, Fock and Goncharov defined a version of the space of flat $PGL_2(\mathbb{C})$-connections on a surface and showed that the algebra of functions on this space has a canonical basis parametrized by points of a dual moduli space. This algebra of functions can be canonically quantized, and Fock and Goncharov conjectured that their canonical basis could be deformed to a canonical set of elements of the quantized algebra. In this talk, I will describe my recent work with Hyun Kyu Kim proving Fock and Goncharov's conjecture. (Received September 13, 2015)

1116-51-859 **Dylan G.L. Allegretti***, Department of Mathematics, Yale University, 10 Hillhouse Ave., New Haven, CT 06511. *New results on the structure of quantum Teichmüller space.*

In 1999, Chekhov and Fock showed that the Teichmüller space of a punctured surface admits a canonical quantization. It is generally believed that quantum Teichmüller theory should play an important role in the formulation of pure (2+1)-dimensional quantum gravity with negative cosmological constant and its holographic dual theory. In this talk, I will report on my recent work with Hyun Kyu Kim on the structure of quantum Teichmüller space. Our results describe a canonical set of elements of the deformed algebra of functions on the Teichmüller space with many remarkable properties conjectured by Fock and Goncharov. (Received September 14, 2015)

1116-51-1237 **Ga Yee Park*** (gpark@smith.edu), **Vivian Li** (xili@smith.edu), **Rebecca Roberts** (rmroberts@smith.edu) and **Lisa Wang** (lwang76@smith.edu). *Number Theory on Square-tiled Surfaces I.* Preliminary report.

We study geodesics on square-tiled surfaces that are composed of diagonals of the squares. The dimensions of a surface are "relatively prime" if there are no geodesic loops. The "gcd" is related to the number of loops and the "lcm" is related to the lengths of loops and paths between vertices. We have results for a number of surfaces. (Received September 18, 2015)

1116-51-1240 **Elizabeth McGrady*** (emcgrady@smith.edu), **Rose Goueth** (rgoueth@smith.edu), **Alyssa Kaplan** (akaplan@smith.edu), **Claire Kerper** (ckerper@smith.edu) and **Gillian Tisdale** (gtisdale@smith.edu). *Number Theory on Square-tiled Surfaces II.* Preliminary report.

This is a continuation of "Number Theory on Square-tiled Surfaces I". We study geodesics on square-tiled surfaces that are composed of diagonals of the squares. The dimensions of a surface are"relatively prime" if there are no loops. The"gcd" is related to the number of loops and the "lcm" is related to the lengths of loops and paths between vertices. We have results for additional surfaces. (Received September 18, 2015)

1116-51-1347 **Robert T. Arn*** (arn@math.colostate.edu), **Bruce Draper**, **Michael Kirby** and **Chris Peterson**. *Formulation of Generalized Curvature Values from the Singular Value Decomposition and the use on Human Action Data.*

In examining the local singular value decomposition (LSVD) on a curve in $\mathbb{R}^n$, we recognize a relationship between the Frenet-Serret Frame and local singular vectors. Expanding on this, we derive equations to compute generalized curvature values at a given point on the curve in terms of the local singular values. We apply this characterization to curves in 75 dimensions generated by the Microsoft Kinect 2 device. In particular, we create a feature vector of generalized curvatures which evolves along the curve. This approach produces a time-series representation of human action data that we propose to apply to segment human actions in an open world environment. (Received September 18, 2015)

1116-51-1385 **Catrice Chong*** (cachong@smith.edu), **Cheryl Holmes** (cholmes@smith.edu), **MyVan Vo** (mvo@smith.edu) and **Lauren White** (lmwhite@smith.edu). *Pinpointing unknown objects by their reflected light rays.* Preliminary report.

Suppose a square S of a known size $s = 1/n$, $n > 1$, is inside a bounding unit square B at an unknown location. We shoot a light ray into B and notice where it emerges, reflecting off S (if it hits it) with perfect reflection. We prove that $n + 1$ light-ray probes are sufficient and sometimes necessary to locate S. We then generalize this result to more general situations, with special attention to multiple objects, all mirrored, so there may be complex inner reflections before the ray emerges. (Received September 19, 2015)

1116-51-1517 **Alex D Austin*** (alexander.austin@gmail.com). *Logarithmic Potentials and Quasiconformal Flows on the Heisenberg Group.* Preliminary report.

The Heisenberg group $\mathbb{H}$ is an important example in analysis (e.g. several complex variables), geometry (e.g. complex hyperbolic), algebra (e.g. nilpotent groups), and applications (e.g. math biology). It is therefore imperative that, given a metric space X, we are able to say when it is essentially the same as $\mathbb{H}$ in that there exists a bi-Lipschitz mapping $f : X \to \mathbb{H}$.

I exhibit a family of metric doubling measures on $\mathbb{H}$, weighting Lebesgue measure with (the exponential of) certain logarithmic potentials. Each associated metric is shown to be bi-Lipschitz equivalent to the usual sub-Riemannian metric on $\mathbb{H}$ by constructing a quasiconformal mapping of $\mathbb{H}$ with Jacobian comparable to the weighting. To do this I establish results of independent interest in the theory of quasiconformal flows on $\mathbb{H}$, building on the work of Korányi and Reimann. The scheme follows analogous work of Bonk, Heinonen and Saksman in the Euclidean setting.

Along the way I confront the limitations of conformal mappings of $\mathbb{H}$, explain how the radial stretch mappings of Balogh, Fässler and Platis inspired a key step, and mention future work on a possible connection to the CR notion of Q-curvature. (Received September 20, 2015)

1116-51-1537 **Zhengyi Zhou*** (zhengyizhou@berkeley.edu), Univ of Calif, Berkeley, Dept of Math Suite 3840, 951 Evans Hall, Berkeley, CA 94720-3840. *Quotient of polyfold and applications to equivariant transversality.* Preliminary report.

Hofer, Wysocki and Zehnder developed polyfold theory to regularize moduli spaces of pseudoholomorphic curves by transverse perturbations of a single section. We extend this theory to obtain equivariant regularizations of moduli spaces with a global compact group action, that is we construct an equivariant fundamental class(EFC). We moreover prove a localization theorem for the equivariant fundamental class for torus actions.

The main tool is a general quotient theorem for polyfold Fredholm sections that are equivariant under a free scale smooth action.

While equivariant transversality may fail – even in finite dimensional cases, when the action has nontrivial stabilizers – we can use our quotient construction to analyze the obstructions in the case of S^1 action. If these vanish, we construct an equivariant transverse perturbation, so that the equivariant fundamental class is represented by the quotient of its zero set as a S^1 space.

As an example of obstructions to equivariant transversality, we show the existence of a rigid curve of negative Fredholm index in a Hirzebruch surface with S^1-action, even under S^1-equivariant polyfold perturbations. We moreover use EFC to explain how this curve should contribute to equivariant Gromov-Witten theory. (Received September 21, 2015)

1116-51-1660 **Tomohiro Tachi*** (tachi@idea.c.u-tokyo.ac.jp). *Overconstrained Rigid Origami Mechanisms.*

Rigid origami mechanisms, rigid plate and hinge mechanisms, are applied for the design of deployable and transformable structures. Normally, rigid origami structures are flexible when the number of variables (the fold angle for each interior edge) exceeds the number of constraints (three rotational constraints for each interior vertex). However, there are known families of rigid origami that are transformable even if they have smaller number of variables than that of constraints. This is due to the degenerate constraints originating from local and global symmetry of the crease pattern. A well-known example of such mechanisms, i.e., overconstrained mechanisms, is Miura-ori.

The speaker talks about recent studies on shape and topology generalizations of overconstrained rigid origami mechanisms and their uses for designing unusual structural systems. Computational methods are also introduced for solving the design problem with geometric constraints to obtain non-trivial degeneracy. By combining compatible mechanical in a non-trivial way, we are able to obtain deployable systems with high stiffness against undesirable deformation modes and unusual flexibility against the pre-designed deployment mode. (Received September 21, 2015)

1116-51-1742 **Andrea Arauza*** (arauza@math.ucr.edu), Univ of Calif, Riverside, Dept of Math 208 Surge, 900 University Ave, Riverside, CA 92521. *Noncommutative Fractal Geometry.*

Tools from noncommutative geometry can be used to study fractal geometry. Here the spectral triple arises as the key tool. Examples, such as the triple for the circle, the Sierpinski gasket, and the harmonic Sierpinski gasket, illustrate the power of the spectral triple. Also, noncommutative geometry can provide a different perspective from which to view analysis on fractals and a notion of a fractal manifold. The talk will be based on papers by Erik Christensen, Cristina Ivan, and Michel L. Lapidus and by Michel L. Lapidus and Jonathan J. Sarhad. (Received September 21, 2015)

1116-51-2578 **Stephen Lewis*** (iam@stephen-lewis.net). *Local Set Approximation, Psuedo.*

Local Set Approximation (LSA) and tangents provide a framework for describing the small scale and infinitesimal behavior of a set. In this talk, we'll introduce LSA from a top-down perspective and give a theorem on the "Connectedness of the Tangent Cone at Infinity," which is a first step in understanding the structure of tangent sets. (Received September 22, 2015)

1116-51-2672 **Aaron Fenyes*** (afenyes@math.utexas.edu). *Deflating hyperbolic surfaces.*

Moving around on a hyperbolic surface feels very different, both geometrically and dynamically, from moving around on a flat one. However, there is a startling correspondence between hyperbolic and flat surfaces, which I think deserves to be more widely known. When a hyperbolic surface is equipped with some extra structure—a geodesic lamination of a certain kind—it can be "deflated" to a flat surface, which can later be "reinflated" to recover the original surface. This construction gives a very concrete way of looking at some classic geometric facts, like the correspondence between measured laminations and measured foliations. It can also be seen as a baby case of *abelianization*, a powerful technique for studying nonabelian character varieties by mapping them onto abelian ones. (Received September 22, 2015)

1116-51-2911 **Tyler Hoffman*** (tsh002@mcdaniel.edu) and **Benjamin Steinhurst** (bsteinhurst@mcdaniel.edu). *Hausdorff dimension of generalized Fibonacci word fractals.*

The Fibonacci word fractals are a class of fractals that have been studied recently, though the word they are generated from is more widely studied in combinatorics. The Fibonacci word can be used to draw a curve which possesses self-similarities determined by the recursive structure of the word. The Hausdorff dimension of the scaling limit of the finite Fibonacci word curves is computed and these computations are generalized to a larger family of fractals. (Received September 23, 2015)

1116-51-2975 **Caleb J. Ashley*** (caleb.ashley@morehouse.edu), Department of Mathematics, Morehouse College, 830 Westview Dr. S.W., Atlanta, GA 30314. *Gearing Up; Algorithms For Discreteness.*

Determining whether a given finitely generated group of isometries is discrete is a formidable problem. Furthermore discreteness occupies a central position in many venerable mathematical theories. Let Γ be a rank 2 non-elementary subgroup of $PSL(2,R)$; J. Gilman and B. Maskit developed a discreteness algorithm which codified all previously existing algorithms. I intend to share motivation, tools, and efforts for pursuing sufficient conditions for a discreteness algorithm for $\Gamma < PSL(2,R)$ of rank 3. A discreteness algorithm for Γ generated by 3 parabolic elements will be presented. (Received September 23, 2015)

52 ► Convex and discrete geometry

1116-52-148 **Yves Nievergelt*** (ynievergelt@ewu.edu), Eastern Washington University, Department of Mathematics, 216 Kingston Hall, Cheney, WA 99004-2418. *The Probability that Two Samples on a Convex Curve Have Disjoint Convex Hulls.*

While researching the rate of chemical reactions between acids and methyl acetate, Wilh. Ostwald (*J. Praktische Chemie*, 1883) conducted two identical experiments in parallel, and measured their equilibrium concentrations several times in each experiment. In experiments with trichloroacetic acid, both values in one sample x_1, x_2 exceed all three values in the other sample ξ_1, ξ_2, ξ_3 [mL/100]:

$$\xi_1 = 1358, \qquad \xi_1 = 1361, \qquad \xi_3 = 1362; \qquad x_1 = 1367, \qquad x_2 = 1367.$$

How likely will all the values in one sample exceed all the values in the other sample? Regardless of their probability measure, the probability that two mutually stochastically independent identically distributed samples with respectively j points and k points have disjoint convex hulls is $2(j!)(k!)/(j+k)!$ on the line and $(j!)(k!)/(j+k-1)!$ on any convex curve in the plane, which generalizes the same formula proved by L. C. G. Rogers (*J. Appl. Probab.*, 1978) for two samples *uniformly* distributed on the *circle*. (Received August 06, 2015)

1116-52-168 **Satyan L Devadoss*** (satyan.devadoss@williams.edu) and **Samantha Petti**. *A space of phylogenetic networks.* Preliminary report.

A classic problem in computational biology is constructing a phylogenetic tree given a set of distances between species. We consider a *split network*, a generalization of a tree in which multiple parallel edges signify divergence. A geometric space of such networks is introduced, forming a natural extension of the work by Billera, Holmes, and Vogtmann on tree space. We explore geometric and topological properties of this space, and show an unexpected embedding of the real moduli space of curves within it. (Received August 11, 2015)

1116-52-171 **Satyan L Devadoss*** (satyan.devadoss@williams.edu) and **Stefan Forcey**. *Poset Associahedra.*

Motivated by the *associahedron* polytope, we consider the generalization of associativity and nestings to posets. This leads to a new family of simple convex polytopes obtained by iterated truncations, generalizing graph associahedra and nestohedra, even encompassing notions of associativity on CW-complexes. (Received August 11, 2015)

1116-52-206 **Carl W. Lee** (lee@uky.edu), University of Kentucky, Department of Mathematics, 715 Patterson Office Tower, Lexington, KY 40506, and **Sarah A. Nelson*** (sarah.nelson@uky.edu), University of Kentucky, Department of Mathematics, 715 Patterson Office Tower, Lexington, KY 40506. *Toric g-Vectors of Convex Polytopes from Gale Diagrams.* Preliminary report.

If P is a convex d-polytope with n vertices, then the combinatorial structure of P can be represented by a certain set of n points in $\mathbf{R}^e$ (a Gale diagram), where $e = n - d - 1$. Associated with P is its flag-f-vector, which enumerates the numbers of chains of faces of the various possible types. The toric g-vector is a certain linear transformation of this vector. For simplicial polytopes, Lee defined the winding number w_k in a Gale diagram corresponding to a given polytope. He showed that w_k in the Gale diagram equals g_k of the corresponding polytope. We will extend these results to many non-simplicial cases by explaining how to determine g_k of the polytope by only considering the corresponding Gale diagram. In particular, we determine g_k for every possible Gale diagram in dimension 2. (Received September 22, 2015)

1116-52-433 **Joseph O'Rourke*** (orourke@cs.smith.edu), Dept. Computer Science, Smith College, Northampton, MA 01063. *Spiral Unfoldings of Convex Polyhedra.* Preliminary report.

The notion of a spiral unfolding of a convex polyhedron, resulting by flattening a special type of Hamiltonian cut-path, is explored. `http://cs.smith.edu/~orourke/SpiralUnf/` (Received September 01, 2015)

1116-52-768 **John Christopher Bowers*** (bowersjc@jmu.edu) and **Ileana Streinu** (istreinu@smith.edu). *Geodesic Universal Molecules.*

The universal molecule is a well-known origami crease pattern which allows a convex polygon to be folded into a 3D structure having certain tree-like properties. In this talk we introduce geodesic universal molecules, which generalize the universal molecule to non-convex polygons. This includes non-convex polygons drawn on the surface of intrinsically flat, piecewise-linear surfaces that may have self-overlap when laid open, flat in the plane and may have negative curvature along its boundary. We also generalize Lang's universal molecule algorithm to produce the geodesic universal molecule for any such non-convex polygon. (Received September 12, 2015)

1116-52-1013 **Alan Haynes*** (alan.haynes@york.ac.uk), **Henna Koivusalo** and **James Walton**. *Characterization of perfectly ordered mathematical quasicrystals.*

In this talk we will explain a duality between the problems of understanding patterns in cut and project sets, which are mathematical models for quasicrystals, and understanding the dynamics of certain linear actions on the internal spaces which define them. We will show how this point of view can be used to give a simple characterization of the collection of linearly repetitive cut and project sets (models for perfectly ordered quasicrystals), answering a question of Lagarias and Pleasants. (Received September 16, 2015)

1116-52-1047 **Florian Frick*** (ff238@cornell.edu). *Counterexamples to the topological Tverberg conjecture.*

We will combine recent work of Mabillard and Wagner with a "cheap trick" (joint work with P. Blagojević and G. M. Ziegler) to obtain counterexamples to the topological Tverberg conjecture due to Bárány from 1976. The conjecture states that any continuous map of a simplex of dimension $(r-1)(d+1)$ to Euclidean d-space maps points from r disjoint faces of the simplex to the same point. This conjecture is true precisely for r a power of a prime. (Received September 16, 2015)

1116-52-1146 **Anna Lubiw*** (alubiw@uwaterloo.ca). *Star Unfoldings of Convex Polyhedra.*

Unfolding a polyhedron means cutting its surface so that the result unfolds to a planar polygon that does not overlap itself. For convex polyhedra, although it is an open question to unfold with edge cuts, there are two main unfolding methods that work: the star unfolding and the source unfolding. Both methods use shortest paths from vertices to a point p on the polyhedron surface. Non-overlap of the source unfolding is straightforward; non-overlap of the star unfolding was proved by Aronov and O'Rourke in 1992. I will give a much simpler proof of non-overlap of the star unfolding (joint work with Stephen Kiazyk). Our proof extends to some cases of the more general star unfolding from a geodesic curve, where we cut a geodesic curve and cut a shortest path from each vertex to the curve. I will discuss questions of optimizing unfoldings, e.g. to minimize perimeter, or maximize minimum angle. (Received September 17, 2015)

1116-52-1213 **B. Grunbaum***, Department of Mathematics, University of Washinton, Seattle, WA 98195. *Generating the symmetries of medieval Islamic ornaments.*

For better part of a century there have been frequent discussions regarding the number of crystallographic groups that can be found in medieval Islamic decorations. While this may be of some interest to present day mathematicians, this is largely irrelevant to the understanding of the Islamic decorative arts. Two questions that may be more relevant are: (i) What were the motivations for the artists and artisans in widely separated lands to create this specific type of ornament? (ii) How did they actually do it? There seems to be more information available on the second question than on the first, and my intention is to contribute to understanding the possible methods used in practice. In particular, for tilings or interlace ornaments that have 4-fold or 6-fold symmetries it is easy to show a construction method that would have been appropriate for the creators of these kinds of ornaments. The construction is based on repeated reflections of the design given in a triangle in the sides of the triangle. Mathematically, this triangle is a fundamental region for the corresponding reflection group. (Received September 17, 2015)

1116-52-1726 **Andrea Young***, younga@ripon.edu. *Canonical metrics on the Pentachoron.*

In this talk, we will discuss canonical metrics on the pentachoron, or 5-cell, which can be given the structure of a triangulated piecewise-flat 3-manifold. In particular, we will discuss a notion of conformal equivalence of metrics with the goal of providing numerical evidence that a discrete Yamabe problem can be solved on this manifold. (Received September 21, 2015)

1116-52-2006 **Zachary Abel*** (zabel@math.mit.edu), **Erik D. Demaine**, **Martin L. Demaine**, **Sarah Eisenstat**, **Jason Lynch** and **Tao B. Schardl**. *Who Needs Crossings? Hardness of Plane Graph Rigidity.* Preliminary report.

Despite initial motivation from mechanical linkages such as those used to power steam engines, Kempe's celebrated Universality Theorem—informally, "there is a linkage to sign your name"—does not account for bar intersections in the linkages it describes. Indeed, all known constructions for this Theorem (and its various strengthenings) critically rely on allowing bars to cross each other. What is lost by forbidding crossings? Non-crossing linkages can be physically realized without concern for extraneous obstructions, e.g., with edge-hinged panels as in rigid origami or pop-up cards. But are linkages as expressive when crossing is disallowed?

We settle this problem in the affirmative, by follow the spirit of Kempe's original proof of the Universality Theorem but with several new, delicately designed modular gadgets to forbid crossing between or within gadgets.

As a consequence of our construction (and some additional techniques), we also exactly settle the complexity of several graph-rigidity problems: The problems of testing rigidity or global rigidity of noncrossing linkages, or testing the rigidity of equilateral (but possibly crossing) linkages, are all complete for co-$\exists\mathbb{R}$, the complement of the class obtained from the Existential Theory of the Reals. (Received September 21, 2015)

1116-52-2200 **Casey Mann*** (cemann@uw.edu), University of Washington Bothell, School of STEM, 18115 Campus Way N.E., Box 358538, Bothell, WA 98011-8246, and **Jennifer McLoud-Mann** (jmcloud@uw.edu) and **David Von Derau** (davidvonderau@cobaltblue.us). *The Search for Convex Pentagons that Tile the Plane: Challenges in Computation and Dissemination.* Preliminary report.

Our search for convex pentagons admitting tilings of the plane presented several computational challenges, including problems of computational scale, algorithm implementation on a computing cluster, and analysis of the output. We will discuss how we approached these issues. Further, we are confronted with the challenge of disseminating the results of a massive computer search; how should the data be archived and presented? Lastly, we will discuss the media attention received by our discovery of a 15th type of pentagon and the challenges of communicating mathematical results to a lay audience though the fast-paced digital media. (Received September 23, 2015)

1116-52-2249 **Matthew J Dannenberg*** (mdannenberg@g.hmc.edu), 340 E. Foothill Blvd, Box 154, Claremont, CA 91711, and **John Berry**, **Jason Liang** and **Yingyi Zeng**. *The Convex Body Isoperimetric Conjecture.*

If a bubble with specific volume was placed in a convex container, what shape would it take and how little surface area could it have? What shape should the container be so as to maximize the required surface area of a bubble enclosing that volume? The Convex Body Isoperimetric Conjecture states that the least perimeter needed to enclose a given volume inside an open ball in $\mathbb{R}^n$ is greater than inside any other convex body with the same volume as the ball. The two-dimensional case has been proved by Esposito et al. for the case of exactly half the volume. In this talk, we unveil partial results toward a novel proof of the full conjecture in two dimensions. (Received September 22, 2015)

53 ► Differential geometry

1116-53-152 **Eric O. Korman*** (ekorman@math.utexas.edu). *Hyperholomorphic line bundles.*

We discuss a generalization of the hyperholomorphic line bundle constructed by Haydys and Hitchin that exists over hyperkähler manifolds admitting a special type of S^1 action. We will provide different descriptions, including a twistorial one. Examples will be drawn from the moduli space of parabolic Higgs bundles and adjoint orbits of complex semisimple Lie groups. Applications to physics may be discussed. (Received August 07, 2015)

1116-53-183 **Michael T. Lock***, Department of Mathematics, The University of Texas at Austin, 2515 Speedway, RLM 8.100, Austin, TX 78712. *Scalar-flat Kahler ALE metrics on minimal resolutions.*

Scalar-flat Kahler ALE surfaces have been studied in a variety of settings since the late 1970s. All previously known examples have group at infinity either cyclic or contained in SU(2). I will describe an existence result for scalar-flat Kahler ALE metrics with group at infinity G, where the underlying space is the minimal resolution of C^2/G, for all finite subgroups G of U(2) which act freely on S^3. I will also discuss a non-existence result for Ricci-flat metrics on certain ALE spaces, which is related to a conjecture of Bando-Kasue-Nakajima. This is joint work with Jeff Viaclovsky. (Received August 11, 2015)

1116-53-253 **Eleanor McNair Abernethy*** (abernethy@math.utk.edu), Department of Mathematics UTK, 227 Ayres Hall, 1402 Circle Drive, Knoxville, TN 37996. *Homotopy Critical Spectrum.* Preliminary report.

Spectra are a classical way to understand the geometry of compact Riemannian manifolds in Differential Geometry. Two well-known spectra are the Laplace spectrum and the length spectrum. A relatively new spectrum is the covering spectrum, developed by Sormani and Wei (2003), which utilizes delta covers of a compact geodesic space and singles out values of δ where the covering spaces $X^\delta \subsetneq X^{\delta'}$ for all $\delta' > \delta$. More recently, Plaut and Wilkins (2012) developed the homotopy critical spectrum which arises from a discrete analog of the fundamental group construction for a compact metric space. It is already known that the covering and homotopy critical spectra are essentially the same on compact geodesic spaces. However, the homotopy critical spectrum is defined in the more general setting of metric spaces. de Smit, Garnet and Sutton (2010) extended the notion of the covering spectrum to any metric space. I will present results of comparing the definitions of the homotopy critical spectrum and the de Smit/Garnet/Sutton formulation of the covering spectrum on general metric spaces. (Received August 18, 2015)

1116-53-263 **Ryad Ghanam*** (raghanam@vcu.edu), Doha, Qatar. *On the inverse problem of systems of second order differential equations.*

In this presentation, we go over the algorithm of solving the inverse problem for a system of second order differential equations. We then specialize in solving the problem for the geodesic equations of the canonical connection on low dimensional Lie groups. (Received August 19, 2015)

1116-53-313 **Benjamin Linowitz*** (linowitz@umich.edu) and **Jeffrey S Meyer**. *Can an orbifold be isospectral to a manifold?*

An old problem asks whether a Riemannian manifold can be isospectral to a Riemannian orbifold with nontrivial singular set. We show that under the assumption of Schanuel's conjecture in transcendental number theory, this is impossible whenever the orbifold and manifold in question are length commensurable compact locally symmetric spaces of nonpositive curvature associated to simple Lie groups. (Received August 24, 2015)

1116-53-404 **Junehyuk Jung*** (junehyuk@kaist.ac.kr), KAIST Department of Mathematical Sciences, 291 Daehak-ro , Yuseong-gu, Daejeon, 34141, South Korea. *Quantum Unique Ergodicity and the number of nodal domains of eigenfunctions.*

In this talk I'll first go over some problems and related results in spectral geometry. Then I'll explain how one can apply Quantum Ergodicity and Bochner's theorem to prove that the number of nodal domains of quantum ergodic sequence of even eigenfunctions tends to infinity as the eigenvalue $\lambda \to +\infty$. In particular, this implies that the number of nodal domains of Maass-Hecke eigenforms grows with the eigenparameter. This talk is based on the joint works with S. Zelditch and with S. Jang. (Received August 31, 2015)

1116-53-627 **Jason Cantarella*** (jason.cantarella@gmail.com), UGA Math Department, Boyd GSRC, Athens, GA 30602, and **Clayton Shonkwiler**. *Sampling random polygonal knot space.*

Consider the space of closed equilateral 17-gons in 3-space. What fraction of this space consists of knots? What is the topology of the component of the space consisting of trefoil knots? This talk discusses some recent advances on these kinds of questions using symplectic and algebraic geometry. In particular, we give a measure-preserving description of equilateral polygon space as the product of a convex polytope and a torus which allows to sample random polygons efficiently and to derive some bounds on simple knot probabilities. (Received September 09, 2015)

1116-53-649 **Angelynn Alvarez*** (aalvarez@math.uh.edu), **Ananya Chaturvedi** (ananya@math.uh.edu), **Gordon Heier** (heier@math.uh.edu) and **Fangyang Zheng** (zheng.31@osu.edu). *Metrics of Positive Holomorphic Sectional Curvature on Projectivized Vector Bundles.* Preliminary report.

In 1975, N. Hitchin proved that the Hirzebruch surfaces $\mathbb{F}_n = \mathbb{P}(\mathcal{O}_{\mathbb{P}^1}(n) \oplus \mathcal{O}_{\mathbb{P}^1})$, $n \geq 0$, admit (Hodge) metrics of positive holomorphic sectional curvature K. In this talk, I will determine explicit pinching constants c, C such that $c \leq K \leq C$ for these metrics. I will also discuss the curvature and pinching constants of projectivized vector bundles of arbitrary rank over compact Kähler manifolds, as well as some further generalizations. (Received September 10, 2015)

1116-53-868 **Lina Wu*** (lwu@bmcc.cuny.edu), 529 West 42nd Street, Apt. 5K, New York, NY 10036, and **Ye Li**. *Discovering Geometric and Topological and Physical Properties by Analytic Curvatures Properties on Convex Hyper-Surfaces from Spheres and Ellipsoids as A Starting Point.* Preliminary report.

Our aim is to find a way to study geometric, topological, and physical properties from the analytic curvature properties for a convex hyper-surface in the general setting. We begin with studying an ellipsoid and a sphere as a starting point. Calculating curvatures of a surface is at the threshold of a better understanding regarding geometric, topological, and physical properties on a surface. In order to calculate various curvatures, we demonstrate the way to compute the second fundamental form associated with curvatures by extending the calculation method from a sphere to an ellipsoid. Just as curvatures of a sphere are determined by its radius, curvatures of an ellipsoid are determined by its longest axis and its shortest axis. On an ellipsoid, the value of the ratio of its longest axis to its shortest axis is also a critical index to characterize its geometric, topological, and physical behaviors. Our results on an ellipsoid are extensions or generalizations of mathematicians' results on a sphere.

Methods and research findings from the point of view on an ellipsoid in this paper can provide a clue to the future research on a convex hyper-surface. (Received September 14, 2015)

1116-53-980 **Thanuja Paragoda*** (thanuja.paragoda@ttu.edu), Texas Tech University, Department of Mathematics and Statistics, Broadway and Boston, Lubbock, TX 79409, and **Giorgio Bornia**, **Bhagya Athukorallage** and **Magdalena Toda**. *Willmore-type energies and Willmore-type surfaces in space forms.* Preliminary report.

The current report studies Willmore-type energies and Willmore-type immersions in space forms. First, we introduce the notion of deformed Willmore energy for a space form. Next, we discuss the corresponding Euler-Lagrange equation for the deformed energy. This approach provides a natural justification to Willmore's definition of the appropriate Willmore-type energy in a space form. We deduce the Euler-Lagrange equation of the deformed Willmore energy in a space form, in a unified way, using an extrinsic Laplace-Beltrami operator (which depends on both the surface metric, and the ambient space form). We consider both the case of closed surfaces and the one of surfaces with boundary, for which we gave and discussed the necessary boundary value conditions, which the previous literature failed to do. Thus, we show that our work provides a bridge between prior works in the field, as well as a novel approach. (Received September 15, 2015)

1116-53-1006 **Paul T Allen*** (ptallen@lclark.edu), **James Isenberg**, **John M. Lee** and **Iva Stavrov Allen**. *Elliptic problems and weakly asymptotically hyperbolic manifolds.*

We present recent work concerning elliptic problems on weakly asymptotically hyperbolic manifolds. We present a definition of weakly asymptotically hyperbolic manifolds that is motivated by regularity results for elliptic problems. Following a discussion of the definition, we present Fredholm results for elliptic operators in the weakly asymptotically hyperbolic setting. We conclude with a discussion of applications in differential geometry and mathematical relativity. (Received September 16, 2015)

1116-53-1105 **Edward William Burkard*** (eburkard@nd.edu), 255 Hurley, University of Notre Dame, Notre Dame, IN 46556. *Non-triviality of the Fundamental Group of Symplectic Embeddings of 2 Ellipsoids.* Preliminary report.

In this talk, we will construct a symplecitc embedding of a pair of ellipsoids $E(a,b)\sqcup E(a,b)$ (one of which is parametrized) into a 4-ball $B^4(R)$ and give conditions on when this loop is contractible. This result is expected to have consequences for the fundamental group of symplectic embeddings of one ellipse into another. Here we think of $E(a,b)=\left\{(z_1,z_2)\in\mathbb{C}^2 \,\middle|\, \frac{\pi|z_1|^2}{a}+\frac{\pi|z_2|^2}{b}=1\right\}$ and $B^4(R)=E(R,R)$. (Received September 17, 2015)

1116-53-1133 **Boris Hanin*** (bhanin@mit.edu) and **Yaiza Canzani** (canzani@math.harvard.edu). *Universal Scaling Asymptotics for Spectral Projector of the Laplacian and Applications to Random Waves.*

Let (M^n,g) be a closed Riemannian manifold of dimension $n\geq 2$. The main result I will present is a new C^∞ off-diagonal remainder estimate in the pointwise Weyl law on (M,g) near a non-self focal point. (A point $x\in M$ is non self-focal if the set of geodesic loops through x has measure 0). A consequence is that the kernel of the spectral projector of the Laplacian $\Pi_{[\lambda,\lambda+1]}$ onto functions with frequencies lying in $[\lambda,\lambda+1]$ has a universal scaling limit around any non self-focal point. This implies that local statistics of monochromatic random waves are universal near a non self-focal point. This is joint work with Y. Canzani. (Received September 17, 2015)

1116-53-1134 **Jeffrey L Jauregui*** (jaureguj@union.edu). *Lower semicontinuity of the ADM mass.*

In general relativity a number of problems involve taking a limit (in some topology) of a sequence of asymptotically flat manifolds of nonnegative scalar curvature. It is of both geometric and physical interest to determine how the ADM (total) mass of such spaces behaves when passing to the limit. After giving several examples, I will discuss the main results on proving that the mass cannot increase in the limit, first for C^2 convergence and then, in joint work with Dan Lee, for merely C^0 convergence. (Received September 17, 2015)

1116-53-1376 **Sharif Ibrahim*** (jmm2016@sharifibrahim.com), **Bala Krishnamoorthy** and **Kevin R. Vixie**. *Flat norm decomposition of integral currents.*

The flat norm provides an important distance in the space of generalized surfaces (integral currents) by decomposing d-dimensional integral currents into d-dimensional pieces and (boundaries of) $(d+1)$-dimensional pieces in an optimal way. When these optimal pieces are also integral currents, the decomposition is easier to work with theoretically and has a clear physical meaning in applications. This is not always possible: some integral 1-currents in 4-dimensional space, for example, have no integral optimal decompositions. Integral decompositions are known to exist for codimension 1 integral currents with empty boundaries. For the case of 1-currents, we remove this boundary requirement with appeal to a discretized problem and triangulation mesh quality results. For higher dimensions, we present a framework which (assuming a reasonable triangulation conjecture) implies the result and comment on possible approaches to resolve it. (Received September 19, 2015)

1116-53-1490 **David A Herron*** (david.herron@uc.edu), Department of Mathematics, University of Cincinnati, Cincinnati, OH 45221. *Universal Convexity of Balls for QuasiHyperbolic Type Metrics.* Preliminary report.

We examine certain classes of conformal metrics on regions in the sphere and characterize the open sets which are geodesically convex in any containing domain. (Received September 20, 2015)

1116-53-1636 **Andrew A Cooper*** (andrew.cooper@math.ncsu.edu), Box 8205, North Carolina State University, Raleigh, NC 27695. *Lagrangian mean curvature flow, the Maslov class, and special lagrangians.*

Mean curvature flow, the downward gradient flow for the area functional, preserves the Lagrangian condition if the ambient manifold is Kähler-Einstein. Thomas-Yau, Joyce, and others have conjectured that mean curvature flow should find Lagrangian minimizers; however the development of singularities interferes with this approach. We will discuss recent progress in using the Maslov class of the evolving submanifold to understand the development of singularities. (Received September 20, 2015)

1116-53-1735 **Andrew Osten Hoffman*** (hoffmaao@stolaf.edu), 1500 St. Olaf Ave., Northfield, MN 99362, Northfield, MN 55057, and **Joe Benson**. *Invariants under the Poincare transformation and their corresponding evolution equations.* Preliminary report.

Although the partial differential equations that exhibit soliton behavior and their solutions have been well studied in the past decades, the underlying reasons why the known soliton equations are unique has remained unclear. Especially curious, is the ability to generate these partial differential equations from invariant curve evolutions under various lie group actions. The purpose of this study is to first identify differential invariants of curves under the Poincare group action and then analyze the evolution of these invariants under invariant curve flows in two-, three-, and four-dimensional Minkowski space. We construct differential invariants using the equivariant method of moving frames and the induced invariant variational bicomplex. We then study the corresponding curvature evolution equations of Poincare group actions on Minkowski space and link the systems to integrable soliton dynamics. We found that the differential invariants and evolution equations are very similar to the two-dimensional and three-dimensional Euclidean cases and that both have corresponding recursion operators. (Received September 21, 2015)

1116-53-1823 **Martha P. Dussan*** (dussan@ime.usp.br) and **Martin Magid**. *Solutions of Björling Problem for timelike surfaces and the homogeneous wave equation.*

We solve the Björling Problem for timelike surfaces in the Minkowski space $\mathbb{R}^3_1$ and $\mathbb{R}^4_1$ by obtaining a split-complex representation formula for those surfaces. Our approach includes the construction of split-holomorphic extensions, in a natural way, using the point of view of solutions to the homogeneous wave equation. Then we establish Schwarz reflection to obtain split-complex Björling representations in symmetric domains of the split-complex plane. (Received September 21, 2015)

1116-53-1961 **Jonathan Epstein*** (jonathan.m.epstein.gr@dartmouth.edu), Mathematics Department, 27. N. Main St., Hanover, NH 03755. *Topological Entropy of Left-Invariant Magnetic Flows on 2-Step Nilmanifolds.* Preliminary report.

We consider magnetic flows on 2-step nilmanifolds $M = \Gamma\backslash G$, where the Riemannian metric g and the magnetic field σ are left-invariant. Our first result is that when σ represents a rational cohomology class and its restriction to $\mathfrak{g} = T_eG$ vanishes on the derived algebra, then the associated magnetic flow has zero topological entropy. In particular, this is the case when σ represents a rational cohomology class and is exact. Our second result is the construction of a magnetic field on a 2-step nilmanifold that has positive topological entropy for arbitrarily high energy levels. (Received September 22, 2015)

1116-53-2047 **James Dibble*** (jr-dibble@wiu.edu). *Totally geodesic maps into manifolds with no focal points.*

A classical result of Eells–Sampson is that the set of harmonic maps in each homotopy class of maps between compact Riemannian manifolds, where the domain has non-negative Ricci curvature and the target non-positive sectional curvature, is non-empty and equal to the set of totally geodesic maps in that class. Hartman further proved that this set is path-connected. It will be shown that these results generalize to energy-minimizing maps into targets with no focal points. These are manifolds whose universal covers satisfy a simple synthetic condition: Each point and maximal geodesic are connected by a unique geodesic that intersects the latter perpendicularly. By contrast with previous approaches, the proof uses neither a geometric flow nor the Bochner identity for harmonic maps. (Received September 21, 2015)

1116-53-2052 **C. Robin Graham*** (robin@math.washington.edu) and **Nicholas Reichert**. *Higher-dimensional Willmore energies via minimal submanifold asymptotics.* Preliminary report.

This talk will describe a derivation of a conformally invariant energy for an even-dimensional submanifold of a Riemannian manifold generalizing the Willmore energy of a surface. The energy and its associated Euler-Lagrange equation both arise naturally upon considering the asymptotics of minimal submanifolds in asymptotically Poincaré-Einstein spaces associated to the background conformal manifold, in the spirit of the AdS/CFT correspondence. (Received September 21, 2015)

1116-53-2085 **Corey Shanbrom*** (corey.shanbrom@csus.edu) and **Richard Montgomery** (rmont@ucsc.edu). *Where does Kepler's third law hold?*

A theorem of Gromov asserts that the only homogeneous Riemannian manifolds admitting dilations are Euclidean spaces. We explain the surprising relationship between this theorem and Kepler's third law of planetary motion. Kepler's first two laws are known to hold in spherical and hyperbolic geometries, while the third law fails. Gromov tells us why, and where to look for geometries which may admit a version of the third law. We introduce the Kepler problem on the Heisenberg group, the simplest Carnot group, and state the Kepler-Heisenberg third law. Time permitting, we explore other interesting properties of this system, including the existence of periodic orbits and the near integrability of the dynamics. (Received September 22, 2015)

1116-53-2120 **James Dibble*** (jr-dibble@wiu.edu). *The convexity radius of a Riemannian manifold.*

An elementary result in Riemannian geometry is that the convexity radius and injectivity radius of a compact manifold M satisfy $r(M) \leq \frac{1}{2}\mathrm{inj}(M)$. Somewhat surprisingly, there are no examples in the literature where this inequality is strict. It will be shown in this talk that the ratio $\frac{r(M)}{\mathrm{inj}(M)}$ may be made arbitrarily small within the class of compact Riemannian manifolds of any fixed dimension at least two. This is proved using Gulliver's method of constructing manifolds with focal points but no conjugate points. The approach is suggested by a new characterization of the convexity radius, which resembles a classical result of Klingenberg about the injectivity radius. (Received September 21, 2015)

1116-53-2191 **Elizabeth Stanhope*** (stanhope@lclark.edu). *On the spectral geometry of orbifolds.* Preliminary report.

I will present recent results on the spectral geometry of compact Riemannian orbifolds. (Received September 22, 2015)

1116-53-2237 **Nicola Gigli*** (ngigli@sissa.it), via Bonomea 265, 34135 Trieste, Italy. *Nonsmooth differential geometry.*

In this talk I will discuss in which sense general metric measure spaces possess a first order differential structure and how on spaces with Ricci curvature bounded from below a second order one emerges. In this latter framework, the notions of Hessian, covariant/exterior derivative and Ricci curvature are all well defined. (Received September 22, 2015)

1116-53-2330 **Donato R. Cianci*** (dcianci@math.dartmouth.edu). *On hearing the length spectrum of lens spaces.* Preliminary report.

The spectrum of the Laplace-Beltrami operator on a compact Riemannian manifold is known to encode geometric data. For instance, the dimension and volume of the manifold can be recovered from the Laplace spectrum. The length spectrum of a compact Riemannian manifold is the list of the lengths of closed geodesics, i.e., the lengths of the periodic orbits of the geodesic flow. Motivated by the quantum correspondence principle, we have the following question: Is the length spectrum of a Riemannian manifold determined by the spectrum of the Laplacian? The answer is known to be affirmative for generic metrics. However, the answer is not known for manifolds of constant positive curvature. In this talk we will show that for homogeneous lens spaces and lens spaces with small fundamental group the length spectrum can be recovered from the Laplace spectrum. (Received September 22, 2015)

1116-53-2459 **Jonathan Holland*** (jehsma@rit.edu), School of Mathematical Sciences, 2330 Thomas Gosnell Hall, 85 Lomb Memorial Drive, Rochester, NY 14623. *Null geodesics and the universal Teichmüller space.* Preliminary report.

This talk will present some new results on null geodesics in a four-dimensional space-time. The main theorem is that it is possible to associate to a null geodesic in space-time a path in the universal Teichmüller space. This is proved using Penrose limits: there is a unique pp-wave space-time that osculates to the infinitesimal neighborhood of any null geodesic. Finally, the five-dimensional space of null geodesics $\mathcal{N}$ is examined using local twistor transport. There is a natural contact structure on $\mathcal{N}$: the contact distribution around a given null geodesic is the set of null geodesics that are infinitesimally abreast. The Lagrangian subspaces of the contact distribution correspond to the solutions of the Sachs equations, which govern the null geodesic deviation in space-time. The space of these Lagrangian subspaces is a three-dimensional conformal anti-de Sitter space, with metric $\delta\rho^2 - \delta\sigma\delta\overline{\sigma}$ in the Sachs parameters ρ and σ. The original null geodesic naturally embeds into a timelike curve in anti-de Sitter space, with its natural projective structure. (Received September 22, 2015)

1116-53-2582 **Sahana Vasudevan*** (svasudevan@college.harvard.edu). *Classifying Monotone Lagrangian Tori in $S^2 \times S^2$ up to Hamiltonian Isotopy.*

It was shown by Ivrii that any two Lagrangian tori in $S^2 \times S^2$ are Lagrangian isotopic. We consider the question of Hamiltonian isotopy for monotone Lagrangian tori. It is known that there are at least two Hamiltonian isotopy classes (corresponding to the Clifford torus and the Chekanov torus). This question can be reformulated in terms of the Hofer geometry of equatorial curves on S^2, and in this formulation we prove some results related to the classification problem. (Received September 22, 2015)

1116-53-2683 **Daniel A Cristofaro-Gardiner*** (gardiner@math.harvard.edu), 1 Oxford St., Cambridge, MA 02140. *Embedded contact homology cobordism maps and holomorphic curves.*

Embedded contact homology (ECH) is a kind of Floer homology for contact three-manifolds. It is possible to construct cobordism maps on ECH by using Seiberg-Witten theory. For various reasons, however, it would be desirable to have a direct definition of these maps in terms of holomorphic curves. I will explain some of the challenges to doing this, and give examples of specific cobordisms that are interesting to study. (Received September 22, 2015)

1116-53-2733 **George A. J. Sparling*** (gnilraps@gmail.com). *On the structure of the null geodesics of space-time.*

Null geodesics in space-time are the trajectories along which information about the past history of the universe is brought to us, the observers. In the last three years the author and Jonathan Holland have used an osculation method to produce a general cosmological theory, suitable to describe the beginning of the universe. Now we have applied similar techniques to the null geodesics that can connect us to the big bang. I will describe what we know about the space of null geodesics and what we hope to learn in the future. The overall philosophy is somewhat contrary to the prevailing view of space-time as a given tapestry: for us space-time is continually under development. (Received September 22, 2015)

1116-53-2964 **Arthur E. Fischer*** (aef@ucsc.edu), Department of Mathematics, University of California, Santa Cruz, CA 95064. *New Results in Conformal Ricci Flow and the Conformally Reduced Einstein Evolution Equations.*

We discuss new results in *conformal Ricci flow*, which is a variation of the Ricci flow equations that modifies the *volume constraint* of those equations to a *scalar curvature constraint*. The resulting equations are named the *conformal Ricci flow equations* because of the role that conformal geometry plays in constraining the scalar curvature. These new equations are

$$\begin{aligned} \frac{\partial g}{\partial t} + 2\big(\mathrm{Ric}(g) + \tfrac{1}{n} g\big) &= -pg \\ R(g) &= -1 \end{aligned}$$

for a dynamically evolving metric g and a non-dynamical scalar field p, known as the *conformal pressure*. The conformal Ricci flow equations are analogous to the Navier-Stokes equations

$$\begin{aligned} \frac{\partial v}{\partial t} + \nabla_v v + \nu \Delta v &= -\mathrm{grad}\ p \\ \mathrm{div}\ v &= 0 \end{aligned}$$

Just as the real physical pressure in fluid mechanics serves to maintain the incompressibility constraint of the fluid, the conformal pressure serves as a Lagrange multiplier to conformally deform the metric flow so as to maintain the scalar curvature constraint. The conformal Ricci flow equations can be thought of as Navier-Stokes style equations for the metric and also as a parabolic model for the *conformally reduced Einstein evolution equations.* (Received September 23, 2015)

1116-53-2995 **Abdullah Khan*** (2khanabdullah@gmail.com), University of North Texas at Dallas, Dallas, Texas 75241. *A taste of dual billiards.*

We discuss the dynamics of dual (outer) billiard system with finitely many singularities. First, we focus our attention to regular polygons, and study the singularity structure created by the dual billiards's path around the polygon. And then, we will expand our scope further toward irregular polygons and curvilinear shapes. We use Java programming and C programming to map our figures and analyze our visualization. (Received August 12, 2015)

54 ► General topology

1116-54-337 **Jocelyn R Bell*** (bell.jocelyn@gmail.com). *Topological games.*

Topological games can be used to concisely and naturally describe subtle topological properties. After a brief historical tour, we introduce a new infinite topological game that is played in generalized metric spaces. The existence of a winning strategy for our game in a space implies certain topological covering and separation properties hold in that space. We also discuss some further applications and results. (Received August 26, 2015)

1116-54-851 **Kenan Ince*** (kenan@rice.edu), Kenan Ince, MS-136, Box 1892, Houston, TX 77251-1892. *The untwisting number of a knot.*

The unknotting number of a knot is the minimum number of crossings one must change to turn that knot into the unknot. The algebraic unknotting number is the minimum number of crossing changes needed to transform a knot into an Alexander polynomial-one knot. We work with a generalization of unknotting number due to Mathieu-Domergue, which we call the untwisting number. The untwisting number is the minimum number (over all diagrams of a knot) of full twists on even numbers of strands of a knot, with half of the strands oriented in each direction, necessary to transform that knot into the unknot. We show that the algebraic untwisting number is equal to the algebraic unknotting number. However, we also exhibit several families of knots for which the difference between the unknotting and untwisting numbers is arbitrarily large, even when we only allow twists on a fixed number of strands or fewer. (Received September 14, 2015)

1116-54-1048 **W. Kulpa** and **A. Szymanski*** (andrzej.szymanski@sru.edu), Department of Mathematics, Slippery Rock University, Slippery Rock, PA 16057, and **M. Turzanski** and **D. Zagrodny**. *L^*-operators and fixed-point theorems.* Preliminary report.

An L*-operator on a topological space X is a function Λ satisfying the following condition: If A is a finite subset of X and $\{U_x : x \in A\}$ is an open cover of X, then there exists $\varnothing \neq B \subseteq A$ such that $\Lambda(B) \cap \bigcap\{U_x : x \in B\} \neq \varnothing$. The convex hull operator restricted to any convex subset of a topological vector space is an L*-operator. The family of all sets closed under an L*-operator is a convexity structure that generalizes L-structures due to Ben-El-Mechaiekh, et. al., and, independently, Park, 1998. Several types of fixed point theorems (e.g., Schauder-Tychonoff, Kakutani) and equilibrium type theorems (e.g., Nash, ESS) hold true for spaces endowed with continuous L*-operators. We are going to review some of the older results and report on the most recent progress. (Received September 17, 2015)

1116-54-1056 **Lori Alvin*** (lalvin@bradley.edu), **Drew Ash** and **Nic Ormes**. *Topological Speedups of Odometers and Substitutions.*

Let (X,T) and (Y,f) be minimal Cantor systems. We say that (Y,f) is a *speedup* of (X,T) if (Y,f) is topologically conjugate to (X,S), where S is a minimal homeomorphism of X defined by

$$S(x) = T^{p(x)}(x),$$

with $p : X \to \mathbb{Z}^+$. We study two families of dynamical systems, namely odometers and substitutions, and investigate the effects of a speedup on the original system. (Received September 16, 2015)

1116-54-2007 **Steven R Beres*** (sberes@zagmail.gonzaga.edu). *An Introduction to Klein Links and Their Relation to Torus Links.*

Klein links form a classification of links which may be embedded across the surface of a Klein bottle. That is, a Klein link is a set of interlocking mathematical knots which may be drawn across the surface of a Klein bottle without intersection. This particular classification of links has not yet been well studied by the mathematical community. Initially, our interest in these links stemmed from the relation between Klein knots and torus knots. It is a fairly well-known fact that all Klein knots are torus knots. The initial goal of our research had been to explore the nature of this relationship through the use of elementary methods. These investigations led us to extend our inquiries to Klein links. After studying these links for some time, we discovered that unlike Klein knots it is not the case that all Klein links are torus links. In this presentation, we will briefly discuss the major results of our research on these links. The techniques that we used in our study of these links (such as linking number) were purposefully elementary, so this presentation does not require any background in topology or knot theory. Topics will range from basic construction of the links on the Klein bottle to specific sub-classifications of Klein links which are not torus links. (Received September 21, 2015)

1116-54-2445 **Kyle Istvan*** (kistva1@math.lsu.edu), **Khaled Qazaqzeh** and **Ayman Abouzaid**. *The Kauffman Polynomial of Periodic Links.*

A periodic link has a diagram that is invariant under a finite-order rotation in the plane. I will define a necessary condition for a link to be p-periodic. It takes the form of a congruence between a specialization of the 2-variable Kauffman polynomial of a link and that of the link's mirror image. The result is derived using a state sum formula for the 2-variable polynomial, and can be used to verify (for example) Traczyk's result that the knot 10_{101} is not 7-periodic. (Received September 22, 2015)

1116-54-2558 **Kyle Leland Chapman***, 2509 Oak Crest Dr., Santa Barbara, CA 93105. *An ergodic algorithm for generating random knots of a prescribed thickness.*

Molecular chains and other physical knots have properties which can be influenced by their inherent thickness. The effects of this thickness are poorly understood. A major step forward for understanding the effects of thickness is to be able to randomly generate thick knots and use that as a point of comparison for experimental data. This talk will focus on describing the first algorithm which generates random knots with a prescribed thickness, which is also only the second which has been rigorously shown to be ergodic. We will also briefly highlight the struggle that other knot generation algorithms have had with ergodicity. (Received September 22, 2015)

1116-54-2642 **Eleni Panagiotou*** (panagiotou@math.ucsb.edu), South Hall, Room 6523, Department of Mathematics, Santa Barbara, CA 93106-3080, and **Ken Millett**. *Quantifying entanglement for collections of chains in periodic boundary conditions models.*

Periodic Boundary Conditions (PBC) are often used for the simulation of complex physical systems of open and closed curve models, such as polymer melts or vortex fields. In such dense systems the conformational freedom and motion of a chain is significantly affected by entanglement with other chains which generates obstacles of topological origin to its movement. In this talk we will discuss methods by which one may quantify and extract entanglement information from a physical system using tools from knot theory. We use the Gauss linking number and the periodic linking number to measure the entanglement of a collection of oriented curves in a system employing PBC. (Received September 22, 2015)

1116-54-2722 **Alissa S. Crans*** (acrans@lmu.edu). *Unital Shelves.* Preliminary report.

A shelf is a generalization of a rack whose single axiom,

$$(a * b) * c = (a * c) * (b * c)$$

algebraically encodes the Third Reidmeister move. A unital shelf has the additional structure of an element "1" that satisfies:

$$a * 1 = a \qquad \text{and} \quad 1 * a = a$$

It turns out that the shelf operation for unital shelves is associative! We will explore properties of unital shelves and their homology in this preliminary work with Mukherjee and Przytycki. (Received September 22, 2015)

55 ► Algebraic topology

1116-55-54 **David White*** (david.white@denison.edu), P.O. Box 810, Department of Mathematics, Granville, OH 43023, and **Javier Gutierrez**. *Encoding Equivariant Commutativity via Operads.*

The importance of equivariant commutative ring spectra (and of multiplicative norms in particular) has been conclusively demonstrated by the Kervaire Invariant One Theorem of Hill, Hopkins, and Ravenel. In this talk we will study these norms via certain equivariant operads, which we construct as cofibrant replacements in appropriate model structures on the category of G-operads. This approach allows us to characterize the homotopy type of the spaces of these operads as universal spaces for families of subgroups, simultaneously constructing the N-infinity operads of Blumberg-Hill, introducing more general multiplicative structures with some (but not all) multiplicative norms, extending existing work on norms to the setting of compact Lie groups, and passing model structures to categories of algebras over these operads. (Received June 27, 2015)

1116-55-109 **Michael Robinson***, 4400 Massachusetts Ave NW, Washington, DC 20016. *Sheaf-based communication network invariants.*

Communication networks are constrained by the capacity of their associated channels. Network performance degrades when channel capacity is reached in portions of the network. Capacity depends on many different parameters, not all of which are easy to measure or model. For instance, network protocols and traffic conditions can have a significant effect on network capacity. Since protocols are localized to individual nodes or links in a network, the mathematics of sheaves can be used to represent both capacity constraints and network protocols. This talk will connect the theory of sheaves to high-fidelity simulated models of networks, and demonstrate the effectiveness of sheaf-based algorithms under realistic network conditions. (Received July 27, 2015)

1116-55-123 **Jose Perea***, Department of Mathematics, Michigan State University, 619 Red Cedar Road, East Lansing, MI 48824. *The shape of data.*

Topology, and particularly algebraic topology, has been used for decades to study the shape of mathematical objects – from surfaces to categories and spaces of functions.

Recently some of these same ideas have been adapted to the study of data. I will show in this talk how one can use algebraic topology to probe the shape of data, and provide some examples of applications to computer vision and biology. (Received August 02, 2015)

1116-55-176 **Noureen Khan*** (noureen.khan@unt.edu), 7400 University Hills Blvd., Dallas, TX 75007. *Virtual Rational Tangles and Conway's Theorem.*

We introduce virtual rational tangles and their characteristics that form basis for the classification of virtual knots and links. We use elementary combinatorial argument to generalize rational tangles and Conway's theorem for virtual rational tangles. We prove that any two virtual rational tangles are equivalent if and only if their tangle numbers are equal. (Received August 11, 2015)

1116-55-252 **Jon M Corson** and **Veny Liu*** (vliu@crimson.ua.edu), 608 Jack Warner Parkway NE, Apt. F3, Tuscaloosa, AL 35404. *Free Inverse Semigroupoid and Their Inverse Subsemigroups.*

Semigroupoids are generalizations of semigroups and of small categories. However, the quotient of a semigroupoid in general is not a semigroupoid and the homomorphisms of semigroupoids can also behave badly. We define such congruence and homomorphism to form the first isomorphism theorem for semigroupoid homomorphisms for this special type. Hence, we can investigate inverse semigroupoid which is a semigroupoid in which each element has a unique inverse. Using Stalling's folding and Munn tree, this will lead us to free inverse semigroupoids and their inverse subsemigroup. (Received August 18, 2015)

1116-55-280 **Jang Hyun Jo** (jhjo@sogang.ac.kr) and **Jong Bum Lee*** (jlee@sogang.ac.kr), Sogang University, Seoul, 04107, South Korea. *Nielsen fixed point theory on infra-solvmanifolds of* Sol.

In Nielsen fixed point theory for maps f on closed manifolds M, there are three important homotopy invariants $L(f), N(f)$ and $R(f)$ which are called the Lefschetz, Nielsen and Reidemeister numbers of f, respectively. It is well known that if $L(f) \neq 0$ then any map homotopic to f has a fixed point, and $N(f) \leq \min\{\#\mathrm{Fix}(g) \mid g \simeq f\}$ with equality when $\dim M \geq 3$. Hence $N(f)$ gives better information concerning the existence of fixed points than $L(f)$. However, the computation of $N(f)$ is in general much more difficult than that of $L(f)$ or $R(f)$.

Utilizing the averaging formulas for the Lefschetz, Nielsen and Reidemeister numbers of maps on infra-solvmanifolds of type (R), we compute $L(f), N(f)$ and $R(f)$ of maps f on infra-solvmanifolds of the 3-dimensional solvable Lie group Sol. (Received August 21, 2015)

1116-55-305 **Elizabeth Munch*** (emunch@albany.edu) and **Bei Wang** (beiwang@sci.utah.edu). *Reeb Space Approximation with Guarantees.*

The Reeb space, which generalizes the notion of a Reeb graph, is one of the few tools in topological data analysis and visualization suitable for the study of multivariate scientific datasets. First introduced by Edelsbrunner et al., the Reeb space of a multivariate mapping $f : \mathbb{X} \to \mathbb{R}^r$ parameterizes the set of components of preimages of points in $\mathbb{R}^r$. Intuitively, it summarizes the data by compressing the components of the level sets of f and captures the relationship among the multiple real-valued functions within subsets of the domain. Two approximations of the Reeb space have been given, the Joint Contour Net (JCN) by Carr and Duke, and the mapper construction given by Singh et al. While it is often assumed that these constructions converge to the Reeb space, to the knowledge of the authors, no formal statement or proof to that effect has been previously given.

In this talk, we give formal results proving the convergence between the Reeb space and its discrete approximations, JCN and mapper, in terms of the interleaving distance. At a fixed resolution of the discretization, this distance allows us to quantify the approximation quality and leads to guarantees for existing Reeb space approximations. (Received August 24, 2015)

1116-55-379 **Alexander Mednykh*** (smedn@mail.ru), Sobolev Institute of Mathematics, pr. Koptyga, 4, Novosibirsk, 630090, Russia. *Branched coverings and harmonic automorphisms of graphs.* Preliminary report.

We give a short survey of old and new results about branched coverings of graphs. This notion was introduced independently by T. D. Parsons, T. Pisanski, P. Jackson (1980), H. Urakawa (2000), B. Baker, S. Norine (2009) and others. The branched covering of graphs are also known as harmonic maps or vertically holomorphic maps of graphs. The main idea of the present talk to is create a parallel between classical results on branched covering of Riemann surfaces and those for graphs. We introduce the notion of harmonic action on a graph and discuss the Hurwitz type theorems for the groups acting harmonically. These results can be regarded as discrete analogues of the well known theorems by Hurwitz and Accola–Maclachlan. They, respectively, give sharp upper and lower bounds for the order of an automorphism group acting on a Riemann surface.

We present discrete versions of theorems by Wiman (1895), Oikawa (1956) and Arakawa (2000), which sharpen the Hurwitz' upper bound for various classes of groups acting on a Riemann surface of given genus.

Then we define a hyperelliptic graph as the two fold branched covering of a tree. A few discrete versions of the well-known results on hyperelliptic Riemann surface will be given. (Received August 28, 2015)

1116-55-437 **Leyda M. Almodovar Velazquez*** (leyda-almodovar@uiowa.edu) and **Isabel K. Darcy** (isabel-darcy@uiowa.edu). *Could topology provide insight into brain diseases?* Preliminary report.

While it is known that certain brain diseases are genetic, scientists have not been able to pinpoint the exact cause of several diseases. Advances in functional imaging allow us to collect brain images while subjects perform a given task. But, how are brains related to mathematics? Topologists can study the brain networks structures of healthy subjects and subjects predisposed to a brain disease in order to identify different brain behavior among the subjects. We can apply cutting edge tools from topological data analysis (TDA), an area where algebraic topology, statistics and computational geometry intersect, in order to analyze data. Specifically, the idea behind TDA is to describe the"shape" of the data by representing them as a geometrical object, describing the relationship between data points, thus possibly providing new information that could not be obtained via statistical methods alone. (Received September 01, 2015)

1116-55-525 **Peter N Wong*** (pwong@bates.edu), 3 Andrews Road, Hathorn Hall, Lewiston, ME 04240. *Fixed point theory of geometric 3-manifolds.* Preliminary report.

In topological fixed point theory, the Nielsen number $N(f)$ of a self map $f : M \to M$ is equal to the minimal number of fixed points among all maps homotopic to f provided M is a compact manifold of dimension at least 3. In this talk, we consider the computation of $N(f)$ when M is a *geometric* 3-manifold, i.e., M is endowed with one of the eight geometries according to Perelmann-Thurston geometrization theorem. In particular, we focus on the cases when M admits Euclidean, spherical, $S^2 \times \mathbb{R}$, Nil, or Sol geometry. (Received September 05, 2015)

1116-55-555 **Frederic Chazal*** (frederic.chazal@inria.fr), INRIA Saclay - Ile-de-France, Alan Turing Bldg, Campus Ecole Polytechnique, 1 rue Honoré d'Estienne d'Orves, 91120 Palaiseau, France. *Subsampling methods for persistent homology.*

Computational topology has recently seen an important development toward data analysis, giving birth to Topological Data Analysis. Persistent homology appears as a fundamental tool in this field. It is usually computed from filtrations built on top of data sets sampled from some unknown (metric) space, providing "topological signatures" revealing the structure of the underlying space. When the size of the sample is large, direct computation of persistent homology often suffers two issues. First, it becomes prohibitive due to the combinatorial size of the considered filtrations and, second, it appears to be very sensitive to noise and outliers.

In this talk we will present a method to overcome these issues by computing persistent diagrams from several subsamples and combining them in order to efficiently infer robust and relevant topological information from data. (Received September 07, 2015)

1116-55-950 **Michael Lesnick*** (lesnick@gmail.com) and **Matthew L. Wright** (wright5@stolaf.edu). *Interactive Visualization of 2-D Persistent Homology.*

In topological data analysis, we often study data by associating to the data a filtered topological space, whose structure we can then examine using persistent homology. However, in many settings, a single filtered space is not a rich enough invariant to encode the interesting structure of our data. This motivates the study of multidimensional persistence, which associates to the data a topological space simultaneously equipped with two or more filtrations. The homological invariants of these "multifiltered spaces," while much richer than their 1-D counterparts, are also far more complicated. As such, adapting the usual 1-D persistent homology methodology for data analysis to the multi-D setting requires some some new ideas.

In this talk, I'll introduce multi-D persistent homology and discuss joint work with Matthew Wright on the development of a tool for the interactive visualization of 2-D persistent homology. (Received September 15, 2015)

1116-55-1110 **Sophie Raynor***, s.raynor@abdn.ac.uk. *Formal Perspectives on Hierarchical Networks.*

In applications ranging from neuroscience, to business, to ecology, and many more, there is an increasing need to understand hierarchical structures of complex networks. My work aims to develop a rigorous mathematical formalism that captures the structure and function of complex networks at multiple spatio-temporal scales in one single model. This formalism should enable us to use information from one scale to understand structure at another, and, eventually, to make predictions about behaviour of the system at all scales.

I will present three different perspectives of networks carrying a hierarchical structure (clustering at multiple levels) and explain how each viewpoint plays a different role in our understanding of this structure. If there is time, I will discuss how we can start to understand (non-deterministic) processes on such networks. (Received September 17, 2015)

1116-55-1165 **Lori Beth Ziegelmeier*** (lziegel1@macalester.edu), 1600 Grand Avenue, Saint Paul, MN 55104. *Persistence Images: An Alternative Persistent Homology Representation.*

Many datasets can be viewed as a noisy sampling of an underlying topological space. Topological data analysis aims to understand and exploit this underlying structure for the purpose of knowledge discovery. A fundamental tool of the discipline is persistent homology, which captures underlying data-driven, scale-dependent homological information. A representation in a persistence diagram concisely summarizes this information. By giving the space of persistence diagrams a metric structure, a class of effective machine learning techniques can be applied. We modify the persistence diagram to a persistence image in a manner that allows the use of a wider set of distance measures and extends the list of tools from machine learning which can be utilized. It is shown that several machine learning techniques, applied to persistence images for classification tasks, yield high accuracy rates on multiple data sets. Furthermore, these same machine learning techniques fare better when applied to persistence images than when applied to persistence diagrams. We discuss sensitivity of the classification accuracy to the parameters associated to the approach. An application of persistence image based classification to a data set arising from dynamical systems is presented to further illustrate. (Received September 17, 2015)

1116-55-1268 **Vidit Nanda***, Department of Mathematics, 209 South 33rd Street, Philadelphia, PA 19104. *Reconstructing manifolds and functions from random samples.*

We survey the work of Niyogi, Smale and Weinberger which provides explicit bounds on the number of uniform random samples required to reconstruct the homotopy type of an underlying compact Riemannian manifold with high confidence. We also describe an alaogous result for Lipschitz functions between such manifolds: one can recover the action on homotopy of such a function using sampled points on the domain, the codomain, and values of the function restricted to the sampled domain points. (Received September 18, 2015)

1116-55-1277 **Michael S Willis*** (msw3ka@virginia.edu), 141 Cabell Dr, Kerchof Hall, PO Box 400137, Charlottesville, VA 22904-4137. *Stabilization of the Khovanov Homotopy Type of Torus Links.*

The structure of the Khovanov homology of torus links $T(n,m)$ has been extensively studied; in particular, Marko Stošić showed in 2005 that the homology groups stabilize as $m \to \infty$. In 2013, Robert Lipshitz and Sucharit Sarkar constructed the Khovanov homotopy type $\chi(L)$ for a knot or link L, a spectrum whose reduced cohomology gives the Khovanov homology of L. In this talk I will discuss the analogue of stability for the Khovanov homotopy type of torus links as $m \to \infty$. (Received September 18, 2015)

1116-55-1344 **Martina Scolamiero*** (martina.scolamiero@epfl.ch), EPFL SV BMI UPHESS MA B3 495, 1015 Lausanne, Switzerland. *Combinatorial invariants for directed graphs with applications to neuroscience.*

Directed graphs offer a simple but efficient formalism to model relational information between agents. For example, in neuroscience, they are used to study structural and functional connectivity between neurons or brain regions.

In this talk I will review some well known topological invariants and introduce new ones which allow to identify patterns and densely connected regions in a directed graph. Robust connections between pairs of vertices will be ensured by the so called highways, and local cohesiveness within a graph measured by the clustering polynomial.

I will then present applications of such invariants to study brain connectivity at the micro-scale. The focus will be on understanding the neural spiking activity generated by different stimuli on the Blue Brain model: a simulation of the neocortical columns of a fourteen days old rat built within the Blue Brain Project.

Joint work with: Pawel Dlotko, Kathryn Hess, Ran Levi, Eilif Muller, Henry Markram, Max Nolte, Michael Reimann. (Received September 18, 2015)

1116-55-1398 **Matthew Hogancamp*** (mhoganca@indiana.edu) and **Benjamin Elias**. *Diagonalization of the full twist.* Preliminary report.

I will discuss recent work with Ben Elias in which we diagonalize the action of the full-twist braid on the category of Soergel bimodules. The “eigenprojections” yield categorified Young symmetrizers, which can be used to give a construction of an arbitrarily colored triply-graded link homology theory, and are also important in the categorical representation theory of Hecke algebras. I will mention a conjecture of Gorsky-Rasmussen relating our construction to the flag Hilbert scheme. The categorified Young symmetrizers are also related to stable homology of torus links, which was recently investigated by myself and Michael Abel. (Received September 19, 2015)

1116-55-1409 **Brian P Foley*** (bfoley17@wooster.edu), 1506 Arthur Dr., Wooster, OH 44691, and **Michael A Bush**. *Using a Set of Monotonically Reducing Moves to Solve the Unknotting Problem.* Preliminary report.

The three basic Reidemeister Moves have been proven to be the only moves necessary to demonstrate knot equivalence. We propose a set of four generalized moves which demonstrate the equivalence of one knot projection to another projection with an equal or lesser number of crossings. We prove this using a similar strategy to the original Reidemeister proof. Applied inductively, we assert that these four moves are able to monotonically reduce a knot to its minimal crossing projection. The algorithm which applies these moves should thus solve the Unknotting Problem. We also discuss the feasibility and current progress of our computer program written to apply these moves in polynomial time. (Received September 19, 2015)

1116-55-1714 **Christin Bibby*** (cbibby2@uwo.ca) and **Justin Hilburn**. *Quadratic-linear duality and rational homotopy theory of chordal arrangements.*

To any graph and smooth algebraic curve C one may associate a “hypercurve” arrangement and one can study the rational homotopy theory of the complement X. In the rational case ($C = \mathbb{C}$), there is considerable literature on the rational homotopy theory of X, and the trigonometric case ($C = \mathbb{C}^{\times}$) is similar in flavor. The case of when C is a smooth projective curve of positive genus is more complicated due to the lack of formality of the complement. When the graph is chordal, we use quadratic-linear duality to compute the Malcev Lie algebra and the minimal model of X, and we prove that X is rationally $K(\pi, 1)$. (Received September 21, 2015)

1116-55-1721 **Paul M. Alsing**, **Howard A. Blair**, **Matthew Corne*** (cornem@uwstout.edu), **Gordon Jones**, **Warner A. Miller**, **Konstantin Mischaikow** and **Vidit Nanda**. *Topological Signatures of Singularities in Ricci Flow.*

We apply the methods of persistent homology to investigate singularity formation in a selection of geometries evolved numerically by Ricci flow. To implement persistent homology, we construct a triangular mesh for a sample of points. The scalar curvature along the edges of the triangulation, computed as an average of scalar curvatures at the endpoints of the edges, serves as a filtration parameter at each time step. We analyze the characterization of geometric criticality obtained from the application of persistent homology to a two–dimensional rotational solid that collapses and three–dimensional dumbbells that manifest neckpinch singularities under Ricci flow. Finally, we discuss the interpretation and implication of these results and future applications. (Received September 21, 2015)

1116-55-1754 **Greg Bell*** (gcbell@uncg.edu), Department of Mathematics and Statistics, 144 Petty Building, 317 College Ave, Greensboro, NC 27412, and **Austin Lawson**, **Joshua Martin**, **James Rudzinski** and **Clifford Smyth**. *Multiscale persistence.* Preliminary report.

Let X be a finite point set $X = \{x_1, \ldots, x_n\}$ in a metric space and $R = \{r_1, \ldots, r_n\}$ be real numbers such that for each i, $r_i \in (0, 1]$. For a real parameter t we consider the Rips complex built from the nerve of the collection $\{B(x_i; t \cdot r_i)\}$. We study the corresponding persistence module on these complexes. We prove a Vietoris-Rips lemma, a stability theorem, and show how this fits into the framework of generalized persistence. (Received September 21, 2015)

1116-55-1758 **Justin Michael Curry*** (curry@math.duke.edu). *Recent results on constructible Reeb spaces and the interleaving distance.* Preliminary report.

I will describe recent results connecting constructible cosheaves, Reeb spaces, and MacPherson's entrance path category. These structures are foundational for discussing results on the interleaving distance—a fascinating new metric that allows us to define distance between sheaves. (Received September 21, 2015)

1116-55-1859 **Jason Lucas*** (lucas11@purdue.edu), 150 N. University Street, West Lafayette, IN 47907-2067. *Decorated Feynman Categories.*

The combinatorial structure of graphs provides a basic tool in describing and studying structures and relations. For instance, graphs can be used to capture interactions between individuals in a network, bonds between atoms in a molecule, or the behavior of subatomic particles.

Graphs are also useful in illustrating algebraic structures by encoding generators, relations, and operations. Also, thickening a graph gives rise to a surface —a common procedure— and is thus a part of many areas of geometry. Often one graph alone does not suffice to capture the entire structure and a whole class together with decorations, relations, and operations is needed.

Feynman categories provide the natural context and rules for an analysis of these ideas. As such they generalize operads, a known tool in algebraic topology, but are more flexible and basic. Moving from the broad framework to more particular cases, one can start decorating the Feynman categories to model specific situations. In this talk we examine the idea of a Feynman category decorated by extra data, which in technical terms is given by a functor. This enables us to capture several known constructions, such as cyclic or up-to-homotopy algebras or string topology operations, and produce new natural concepts. (Received September 21, 2015)

1116-55-1970 **Safia Chettih*** (safia@uoregon.edu). *Topology of Configurations on Trees.*

The homology and cohomology groups of configurations of n unordered points are known on a number of simple graphs, but elude a general combinatorial description. By considering instead a discretized model for configuration spaces of graphs, we can apply a discretized version of Morse theory that simplifies calculations of homotopy type. I will describe how recent results may be extended to ordered configurations and give explicit presentations for homology and cohomology classes as well as pairings for ordered and unordered configurations of two and three points on trees, and talk about the geometric and combinatorial structures interrelating configurations on graphs. (Received September 21, 2015)

1116-55-2099 **Matthew G Wheeler*** (maw148@pitt.edu), Department of Mathematics, University of Pittsburgh, 301 Thackeray Hall, Pittsburgh, PA 15260. *Rational structures and their Differential Refinements.* Preliminary report.

In geometry, topology and physics, there is a collection of geometric structures that arise out of the Whitehead tower over BO, which can be ascribed to vector bundles. These include structures such as Spin, String, and Fivebrane. The notion of rational structures will be introduced, which provides a coarser type of structure. These are useful in relating higher geometric structures with an induced Spin structure, allowing us to use techniques such as Chern-Weil and Chern-Simons forms to make the differential geometric qualities of these structures more accessible. (Received September 21, 2015)

1116-55-2262 **Gregory Henselman*** (grh@seas.upenn.edu). *A Morse-theoretic algorithm to compute persistent homology, with generators.*

We introduce two Morse-theoretic methods for memory-efficient computation of persistent homology on a filtered clique complex. The first utilizes a notion of 'ghost' simplex to remove top-dimensional cells dynamically during construction of the input space; the second appeals to an algebraic interpretation of the Morse boundary operator to recover, in a memory-efficient fashion, barcode representatives in the unreduced complex via row operations. Experiments with random, geometric, and empirical data suggest that, for complexes with large cliques, the reduction approach may decrease the number of cells stored in memory by several orders of magnitude, while the memory requirement of storing generators remains approximately linear in the rank of the top-dimensional boundary operator. (Received September 22, 2015)

1116-55-2421 **Courtney M Thatcher*** (cthatcher@pugetsound.edu). *Free Group Actions on Products of Spheres.*

The spherical space form problem, the classification of all groups that act freely on S^n, was first stated by Hopf in 1925, and Madsen, Thomas, and Wall provided the following strong result: a finite group G can act freely on a sphere if and only if for every p, every subgroup of order p^2 and order $2p$ is cyclic. Much work has been done related to this result and various extensions of the question, and its study provided motivation for early algebraic K-theory and surgery theory.

One direction that continues to be open and of interest is the classification of what groups can act on a product of spheres and how they act. A group G that acts on $S^n \times S^n$ cannot contain A_4 or $\mathbb{Z}/p \times \mathbb{Z}/p \times \mathbb{Z}/p$, $p > 3$ prime, as a subgroup, but it is not known whether $\mathbb{Z}/p \times \mathbb{Z}/p \rtimes SL_2(\mathbb{F}_2)$ can act on $S^n \times S^n$, for example. In this talk we will present how the subgroups, $\mathbb{Z}/p$ and $\mathbb{Z}/p \times \mathbb{Z}/p$, can act on $S^n \times S^n$. In particular, all of the $\mathbb{Z}/p$ actions are linear and determined by the first k-invariant, but cohomology calculations show further restrictions in the $\mathbb{Z}/p \times \mathbb{Z}/p$ case. (Received September 22, 2015)

1116-55-2452 **Chi-Kwong Fok*** (ckfok@ntu.edu.tw), 2F of Astronomy-Mathematics Building, No. 1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan, and **Jeffrey Carlson**. *Equivariant formality and K-theory of compact homogeneous spaces.* Preliminary report.

Let G be a compact connected Lie group and K its connected Lie subgroup. In this talk we will first introduce equivariant formality in K-theory, which is shown to be equivalent to equivariant formality in equivariant cohomology. We will then consider the problem of determining if G/K, with K acting on it by left translation, is equivariantly formal. Using K-theory, we will sketch a more uniform proof of the recent result that G/K is equivariantly formal if it is a generalized symmetric space. We will also give some sufficient conditions for G/K to be equivariantly formal which can be verified using Macaulay2 and SAGE. (Received September 22, 2015)

1116-55-2934 **Yifei Zhu*** (zyf@math.northwestern.edu). *Modular equations for Lubin-Tate formal groups at chromatic level 2.*

We give an integral lift of the Kronecker congruence for moduli of finite subgroups of elliptic curves. This leads to a uniform presentation for the power operation structure on Morava E-theories of height 2. (Received September 23, 2015)

57 ► Manifolds and cell complexes

1116-57-235 **Seiichi Kamada*** (skamada@sci.osaka-cu.ac.jp), Department of Mathmatics, Osaka City University, Sumiyoshi, Osaka, 558-8585, Japan. *Tensor products of quandles and classification of 1-handles.*

We introduce the notion of the tensor product of quandles. As an application, we use it for classifying 1-handles attached to surface-knots. 1-handles are naturally understood via the tensor product of knot quandles, or knot symmetric quandles. Especially, for a case of surface-links, it seems simpler than presentation in terms of groups. (Received August 16, 2015)

1116-57-256 **J. Pakianathan*** (jonpak@math.rochester.edu), **M. Herman** and **E. Yalcin**. *An elementary construction of tessellated Riemann surfaces using finite groups.*

In this talk, I will discuss an elementary construction that came up in joint work of M. Herman, E. Yalcin and myself that takes as input a finite nonabelian group G, and outputs in a functorial way, a finite collection of compact, connected, orientable surfaces equipped with a regular or dual quasi regular closed cell structure/pattern/graph embedding. For example when applied to the symmetric group on 6 letters, it results in 4477 tessellated surfaces of 27 distinct genus and a variety of tessellation patterns in each genus.The group G also acts by conjugation on this construction inducing faithful actions of sub quotients of G on these surfaces that form an index at most two subgroup of the orientated automorphism group of the cell structure/graph embedding. Various examples of this process including those that achieve actions giving the strong symmetric genus of a surface will be discussed as time permits. (Received August 18, 2015)

1116-57-493 **Heather A Dye*** (heatheranndye@gmail.com). *Red black Khovanov Homology for virtual knots.* Preliminary report.

This is a preliminary talk on red-black Khovanov homology for virtual knots. (Received September 04, 2015)

1116-57-522 **Robert Lipshitz** and **Ciprian Manolescu*** (cm@math.ucla.edu), UCLA Dept. of Mathematics, 520 Portola Plaza, Los Angeles, CA 90095-1555. *Constructing Floer homotopy using polyfolds.* Preliminary report.

I will describe the problem of constructing a Floer stable homotopy type as a refinement of Lagrangian Floer homology. A scheme for doing so was proposed by Cohen, Jones and Segal, but there are analytical details to be overcome even in the case of exact Lagrangians in an exact symplectic manifold. One needs to put a structure of smooth manifolds with corners on the moduli spaces of holomorphic disks, and then to equip them with compatible stable framings. (This also involves a topological obstruction, the polarization class.) I will outline how this problem can be approached using polyfold theory. (Received September 05, 2015)

1116-57-616 **Tian Yang*** (yangtian@math.stanford.edu), Building 380, Stanford, CA 94305. *On type-preserving representations of the four-punctured sphere group.*

We give counterexamples to a conjecture of Bowditch that if a non-elementary type-preserving representation $\rho : \pi_1(\Sigma_{g,n}) \to PSL(2;\mathbb{R})$ of a punctured surface group sends every non-peripheral simple closed curve to a hyperbolic element, then ρ must be Fuchsian. The counterexamples come from relative Euler class ±1 representations of the four-punctured sphere group. As a related result, we show that the mapping class group action on each non-extremal component of the character space of type-preserving representations of the four-punctured sphere group is ergodic. The main tool we use is Penner's lengths coordinates of the decorated character spaces defined by Kashaev. (Received September 09, 2015)

1116-57-665 **Oliver Dasbach** and **Adam Lowrance*** (adlowrance@vassar.edu). *Signature and alternating tangle decompositions.* Preliminary report.

Alternating links play an important role in knot theory and 3-manifold geometry and topology. Link invariants are often easier to compute and take on special forms for alternating links. The alternating tangle decomposition of a link diagram is a decomposition of the diagram into its maximally alternating regions. In this talk, we discuss the relationship between the signature of a link and its alternating tangle decomposition. (Received September 10, 2015)

1116-57-677 **Allison H Moore*** (allison.h.moore@rice.edu), MS-136, Box 1892, Houston, TX , and **Tye Lidman**, 1 Einstein Drive, Princeton, NJ 08540. *The cosmetic crossing conjecture and symmetric unions.*

The cosmetic crossing conjecture asserts that the only crossing changes which preserve the isotopy class of a knot are nugatory. Previously, the knots known to satisfy this conjecture included two-bridge and fibered knots. We will show that knots with branched double covers that are L-spaces also satisfy the cosmetic crossing conjecture, provided the first singular homology of the branched double cover decomposes into summands of square-free order. We will also demonstrate how a symmetric union, a classical construction of Kinoshita-Terasaka, can be used to generate an infinite family of knots satisfying this conjecture. Part of this work is joint with Lidman. (Received September 10, 2015)

1116-57-680 **Francis Bonahon*** (fbonahon@math.usc.edu). *Representations of the Kauffman bracket skein algebra of a surface.* Preliminary report.

The Kauffman bracket skein algebra of a surface is closely related to the Jones polynomial invariant of knots. It is generated by pictures of knots on the surface, modulo 3–dimensional isotopy and the Kauffman skein relations. We will discuss various results on the existence and uniqueness of irreducible representations of this algebra, with emphasis on the case when the underlying parameter q is a root of unity. (Received September 10, 2015)

1116-57-684 **Tim D Cochran** and **Arunima Ray*** (aruray@brandeis.edu), Brandeis University, MS 050, 415 South St, Waltham, MA 02453. *Shake slice and shake concordant knots.*

Consider the set of knots in the 3–sphere. There are a number of 4–dimensional equivalence relations on knots, which have interesting implications towards the study of 4–manifolds. The most well-studied of these is the relation called concordance, under which knots form an abelian group; knots concordant to the trivial knot are said to be slice. We study a generalization of concordance, called shake concordance; in this realm, the analogue for slice knots are called shake slice knots. Any slice knot is shake slice, but the converse is unknown. We construct infinite families of knots that are pairwise shake concordant but not concordant. We also give a complete characterization of shake concordant and shake slice knots in terms of concordance, which allows us to construct new infinite families of possible r–shake slice knots that are not slice. (Received September 10, 2015)

1116-57-693 **Daniel S. Silver*** (silver@southalabama.edu), Department of Mathematics and Statistics, ILB, University of South Alabama, Mobile, AL 36688, and **Susan G. Williams**. *Periodic Graphs, Spanning Trees and Mahler Measure.*

Motivated by techniques of knot theory and algebraic dynamical systems, we prove several results about graphs G with free Z^d-action by automorphisms and finite quotient. For any such graph, a *Laplacian polynomial* $\Delta(G)$ in d variables is defined. Its logarithmic Mahler measure $m(\Delta(G))$ is a growth rate of spanning trees. When G is a lattice graph, this rate determines the so-called *thermodynamic limit* of G, usually computed by analytic methods rather than the algebraic ones used here.

We prove that $m(\Delta(G))$ is minimized by the standard d-dimensional grid graph G_d. We prove also that $m(\Delta(G_d))$ is asymptotic to $\log 2d$ as d goes to infinity. (Received September 10, 2015)

1116-57-697 **Thomas E Mark**, University of Virginia, and **Bulent Tosun*** (bt5t@virginia.edu), University of Virginia. *Naturality of Heegaard Floer invariants under positive rational contact surgery.*

We consider the problem of tightness of a contact structure obtained by contact surgery along a Legendrian knot in the three-sphere, with positive rational surgery coefficient. We prove that in this situation the Heegaard Floer contact invariant of three sphere is mapped by a surgery cobordism to the contact invariant of the result of contact surgery. We also characterize the spin^c structure on the cobordism that induces the relevant map. We will describe this result and outline the applications to positive rational contact surgeries, which generalize previous results of Golla and Lisca-Stipsicz. Our proof involves a construction called reducible open book surgery. (Received September 10, 2015)

1116-57-814 **Peter Albers** (peter.albers@wwu.de), **Benjamin Filippenko*** (river@berkeley.edu), **Joel Fish** (joel.fish@umb.edu) and **Katrin Wehrheim** (wehrheim@berkeley.edu). *Arnold conjecture via SFT polyfolds.*

In joint work with Peter Albers, Joel Fish, and Katrin Wehrheim, we study the Piunikhin-Salamon-Schwarz-map from Morse homology to Floer homology. It is classically defined for semi-positive symplectic manifolds by counting pseudoholomorphic curves. We extend these definitions to morphisms $PSS : HM \to HF$ and $SSP : HF \to HM$ for general closed symplectic manifolds using a polyfold description of the moduli spaces and abstract transversality results. The polyfolds are built as fiber products of the symplectic field theory polyfolds and compactified Morse moduli spaces. Cobordism and grading arguments then prove that the composition of SSP with PSS is an isomorphism on Morse homology with Novikov coefficients. While there is no such cobordism for the reversed composition, the previous suffices to reprove the Arnold conjecture, bounding the number of Hamiltonian orbits below by the total rank of homology, which was previously proven by virtual moduli cycle techniques. Moreover, we outline further refined polyfold techniques which will prove that PSS is indeed an isomorphism with inverse SSP. (Received September 13, 2015)

1116-57-832 **Michał Adamaszek**, **Henry Adams*** (adams@math.colostate.edu) and **Samadwara Reddy**. *Vietoris–Rips complexes of circles and ellipses.*

Given a metric space X and a distance threshold $r > 0$, the Vietoris–Rips simplicial complex has as its simplices the finite subsets of X of diameter less than r. If X is a Riemannian manifold and r is sufficiently small then the Vietoris–Rips complex is homotopy equivalent to the original manifold, but little is known about Vietoris-Rips complexes for larger values of r even though they are used in applications of persistent homology. We show that as r increases, the Vietoris–Rips complex of the circle obtains the homotopy types of the circle, the 3-sphere, the 5-sphere, the 7-sphere, . . . , until finally it is contractible. Paradoxically, we show that the Vietoris–Rips complex of an arbitrarily dense subset of the ellipse need not be homotopy equivalent to the Vietoris-Rips complex of the entire ellipse. (Received September 14, 2015)

1116-57-836 **Michael Hutchings*** (hutching@math.berkeley.edu). *From SFT to ECH.* Preliminary report.

We discuss what would be required to extract the foundations of embedded contact homology from the holomorphic curve counts in symplectic field theory, assuming that the latter have been constructed (for example using polyfolds) and shown to satisfy the expected properties. (Received September 14, 2015)

1116-57-873 **Elizabeth Denne***, Washington & Lee University, Lexington, VA 24450. *Folded knots in the plane.* Preliminary report.

Knots and links are modeled as folded ribbons lying in the plane, origami style. The ribbonlength of a knot is the the length of a knot divided by the width of the ribbon around it. The ribbonlength problem seeks to minimize the ribbonlength for a knot or link type. In this talk we'll discuss the construction of folded ribbon knots, and give examples of folded ribbon knots and their ribbonlength. It turns out there are several good candidates for the notion of equivalent folded ribbon knots, which complicates the ribbonlength problem. I'm hoping the origami community might be able to give some insight into this problem, and perhaps provide computational ideas for minimizing ribbonlength. This is joint work with undergraduate students from Smith College and Washington & Lee University. (Received September 14, 2015)

1116-57-875 **Susan G Williams***, swilliam@southalabama.edu, and **Daniel S. Silver**. *Frieze and wallpaper graphs and their medial links.*

The medial link construction associates to any finite plane graph G an alternating link $\mathcal{L}$ for which G is the Tait graph. It is well known that the number of components of $\mathcal{L}$ is the nullity of the mod-2 Laplacian matrix of the graph.

We give analogous results for *frieze graphs* and *wallpaper graphs*, plane graphs admitting a free action of $\mathbb{Z}$ or $\mathbb{Z}^2$ with finite quotient graph. The medial link construction gives a (generalized) link that may have infinitely many components, not necessarily closed. We associate to G a finitely generated module $C(G)$ over the ring of Laurent polynomials in one or two variables with mod-2 coefficients, presented by a Laplacian matrix that is easily obtained from the graph data. We determine the orbit structure of the components of the link under the free action from the sequence of elementary divisors of $C(G)$. (Received September 14, 2015)

1116-57-889 **Christine Ruey Shan Lee*** (clee@math.utexas.edu). *Link homologies from Bar-Natan skein modules.*

Generally speaking, skein modules are free modules of links or surfaces quotiented by certain skein relations. The talk will discuss constructions of link homologies from Bar-Natan skein modules as defined by Frohman and Asaeda, which are quotients of free modules of isotopy classes of marked surfaces in a 3-manifold. The examples include a diagramless link homology by McDougall which is a direct sum of copies of Khovanov homology. (Received September 14, 2015)

1116-57-896 **Mark Hughes*** (hughes@mathematics.byu.edu). *Braided cobordisms and the braid rank of a knot.*

We describe a new technique to recast geometric problems involving the 4-ball genus of a link in terms of algebraic properties of a braid representative. These techniques make use of braided cobordisms, and require the study of certain shortest word problems in the braid group described by Rudolph. This leads to a new algebraic invariant of the knot. We will present an upper bound to the solution of this shortest word problem. (Received September 14, 2015)

1116-57-931 **Effie Kalfagianni*** (kalfagia@math.msu.edu), Department of Mathematics, Michigan State University, 619 Red Cedar Road, East Lansing, MI 48824, and **Ahn T. Tran** (att140830@utdallas.edu), Department of Mathematical Sciences, The University of Texas at Dallas, 800 West Campbell Road, FO 35, Richardson, TX 75080-3021. *Topology in the degree of the Colored Jones Polynomial.*

I plan to discuss conjectures and results relating the degree(s) of the colored Jones knot polynomial(s) to the topology of essential surfaces in knot complements. (Received September 15, 2015)

1116-57-1007 **Naoko Kamada*** (kamada@nsc.nagoya-cu.ac.jp), 1 Yamanohata, Mizuho-cho, Mizuho-ku, Nagoya, Aich 467-8501, Japan. *Normal virtual link diagrams and double covers of twisted link diagrams.*

Twisted link diagrams are virtual link diagrams possibly with some bars on their arcs. We discuss a virtual link diagram associated with a twisted link diagram which is called a double cover. We introduce a method of converting a virtual link diagram to a normal virtual link diagram by use of a double cover of a twisted link diagram. (Received September 16, 2015)

1116-57-1008 **Hugh Morton** and **Peter Samuelson*** (peter-samuelson@uiowa.edu). *The Homfly skein and elliptic Hall algebras.*

The Homflypt skein algebra of the torus is the vector space of (framed) links in the torus modulo the Homflypt skein relations. Stacking links makes this an algebra, and we describe a natural set of generators and relations.

The Hall algebra of a category has isomorphism classes of objects as elements and a product determined by extensions. The elliptic Hall algebra $E_{q,t}$ is the Hall algebra of the category of coherent sheaves over an elliptic curve in finite characteristic. A presentation of $E_{q,t}$ was given by Burban and Schiffmann, and we use this to show the skein algebra is isomorphic to $E_{q,q}$. (Received September 16, 2015)

1116-57-1016 **Louis H Kauffman*** (kauffman@uic.edu), Math UIC, 851 South Morgan Street, Chicago, IL 60607-7045. *Rotational Virtual Links and Quantum Link Invariants.* Preliminary report.
Rotational virtual links are virtual links where the detour move is restricted to regular homotopy in the plane or on the 2-sphere. We prove that all classical quantum link invariants extend to rotational virtual links and we give numerous examples of specific invariants of rotational virtuals. We use rotational virtuals to study the limits of detection by quantum link invariants, giving examples of rotational virtual links that appear to be non-trivial but are not detected by quantum link invariants. (Received September 16, 2015)

1116-57-1041 **M Kate Kearney*** (kearney@gonzaga.edu). *Stable Concordance Genus of Knots.*
The concordance genus of a knot is the least three–genus of a knot concordant to the knot. The concordance genus is bounded below by the four–genus (or slice genus), and bounded above by the three–genus. This makes the concordance genus a valuable tool to describe the difference between these invariants. In simple cases the concordance genus is not difficult to calculate, since there are a variety of algebraic tools that give bounds for the concordance genus. Unfortunately, as the crossing number increases, it becomes increasingly difficult to find concordances. The stable concordance genus, which we will discuss in this talk, describes the behavior of the concordance genus of a given knot under connect sum. We will briefly define the invariant, give some examples of calculations, and discuss applications to the study of concordance. In particular, we will observe a realization result for the stable concordance genus in relation to the stable four—genus. (Received September 16, 2015)

1116-57-1092 **Thomas C. Hull*** (thull@wne.edu), Western New England University, Springfield, MA 01119. *On folding compact manifolds without boundary.*
The mathematics of origami has seen a surge of interest over the past decade, in part due to a simultaneous surge in applications of origami in physics and engineering. Yet in 1976 a British mathematician named Stewart Robertson, motivated by paper folding, performed an extensive study of piecewise-isometric mappings between manifolds of arbitrary dimension. In doing so he discovered some mathematical properties of origami a full decade before they were rediscovered by others. In this talk we will survey Robertson's results and use them to answer the question of whether the canonical local results of 2-dimensional origami, namely Maekawa's and Kawasaki's Theorems, hold in higher dimensions. (Received September 16, 2015)

1116-57-1106 **Anh T Tran*** (att140830@utdallas.edu), The University of Texas at Dallas, Richardson, TX 75080. *The topology of the Jones polynomial.*
I will discuss old and new conjectures about the topology of the Jones polynomial. These include the volume conjecture, the AJ conjecture, the slope conjecture, and the strong slope conjecture. (Received September 17, 2015)

1116-57-1143 **David Auckly***, dav@math.ksu.edu, and **Hee Jung Kim**, **Paul Melvin** and **Daniel Ruberman**. *From Tangles to Equivariant Hyperbolic Corks.* Preliminary report.
It is possible to pass from certain tangles to interesting cobordisms of 3-manifolds. Under the right conditions on the tangle, this will allow one to construct equivariant corks with hyperbolic boundary. The original definition of a cork is a smooth, contractible 4-manifold together with an involution on the boundary that extends as a homeomorphism, but does not extend as a diffeomorphism. Any two simply-connected, homeomorphic, smooth 4-manifolds are related by a cork twist – remove the cork and re-glue via the involution. There are a number of explicit examples of this known. We generalize these examples to allow other groups to act on the boundary changing the diffeomorphism type. (Received September 17, 2015)

1116-57-1155 **Moshe Cohen*** (mcohen@tx.technion.ac.il). *Invariants of random knots using Chebyshev billiard table diagrams.* Preliminary report.
Koseleff and Pecker proved that every knot can be described by a curve parametrized by Chebyshev polynomials. I use these curves to introduce a model for random knot diagrams developed with Krishnan. I relate the number of crossings of these diagrams to the crossing numbers of the knots with Even-Zohar. Using these results, I study various aspects of the Alexander polynomials of random 2-bridge knots, with applications to genus and detecting fiberedness. (Received September 17, 2015)

1116-57-1156 **Nicolas Petit*** (nicolas.petit.gr@dartmouth.edu), Dept of Mathematics, Hanover, NH 03755. *Finite-type invariants of framed virtual knots.*
We will talk about finite-type invariants of framed virtual knots, of the Goussarov-Polyak-Viro kind as well as of the Vassiliev kind. We will talk about the definition of framed Goussarov-Polyak-Viro invariants and talk about a universal order one Vassiliev invariant for framed virtual knots. (Received September 17, 2015)

1116-57-1229 **Kanako Oshiro*** (oshirok@sophia.ac.jp). *Twisted quandles and matrix invariants for oriented links.*

In this talk, we introduce a twisted quandles and a matrix invariant for oriented links associated with a quandle representation. The matrix invariant is related to a twisted quandle operation and gives a generalization of twisted Alexander matrices. This study is a joint work with Atsushi Ishii (University of Tsukuba). (Received September 18, 2015)

1116-57-1260 **Michael A Abel*** (maabel@math.duke.edu) and **Matt Hogancamp**. *Stable homology of torus links via categorified one-column Young symmetrizers.*

We construct complexes of Soergel bimodules which categorify the Young idempotents corresponding to one-column partitions. A beautiful recent conjecture of Gorsky and Rasmussen relates the Hochschild homology of categorified Young idempotents with the flag Hilbert scheme. We prove this conjecture for the one-column case and its twisted variants. We also show that this homology is also a certain limit of Khovanov-Rozansky homologies of (n,nm+k) torus links. (Received September 18, 2015)

1116-57-1314 **Matthew L. Sikkink Johnson***, sikki035@umn.edu, and **Julian R. Skotheim**, **Helen Wong** and **Crystal Lai**. *A Finite Generating Set for Muller's Arc Algebra, Part 2.*

G. Muller recently defined an arc algebra generalizing the Kauffman bracket skein algebra for surfaces with marked points on its boundary. In particular, it allows framed arcs that go from marked point to marked point. We provide an explicit, finite set of generators. (Received September 18, 2015)

1116-57-1315 **Julian R Skotheim*** (julian.skotheim@gmail.com), **Matt Sikkink Johnson**, **Crystal Lai** and **Helen Wong**. *A Finite Generating Set For Muller's Arc Algebra - Part 1.*

G. Muller recently defined an arc algebra generalizing the Kauffman bracket skein algebra for surfaces with marked points on its boundary. In particular, it allows framed arcs that go from marked point to marked point. We provide an explicit, finite set of generators. (Received September 18, 2015)

1116-57-1358 **Charles D Frohman** and **Joanna Kania-Bartoszynska*** (jkaniaba@nsf.gov). *Structure of the Kauffman bracket skein algebra of a surface.*

The Kauffman bracket skein algebra of an orientable surface is formed by taking linear combinations of isotopy classes of links in the cylinder over that surface, and dividing by the Kauffman bracket relations. Multiplication comes from stacking one link on top of another. We will discuss the structure of this algebra for closed surfaces and for surfaces with boundary. (Received September 18, 2015)

1116-57-1369 **Jennifer Hom** and **Tye Lidman*** (tlid@math.ias.edu). *Positive-definite symplectic four-manifolds.*

We will use Heegaard Floer homology to prove that certain simply-connected four-manifolds with positive-definite intersection forms cannot admit symplectic structures. (Received September 19, 2015)

1116-57-1380 **Elaina K Aceves*** (ekaceves@mail.fresnostate.edu). *A Study of Bouquet Pseudograph Diagrams.* Preliminary report.

Spatial graph theory is a subfield of knot theory that focuses on the embeddings of graphs in three-dimensional space. When we observe a (spatial) graph diagram in the plane and two arcs of the diagram overlap, we have a crossing. We can distinguish between which strand lies over or under the other when we construct the crossing in the diagram. If we have no information at the crossing, we denote this as a precrossing. Pseudograph diagrams are graph diagrams that contain precrossings. The trivializing number (and knotting number, respectively) of a pseudograph diagram is the number of precrossings that need to be changed to a crossing to represent a trivial graph (and a nontrivial graph, respectively) regardless of how the remaining precrossings are resolved. This talk will focus on the trivializing and knotting number for bouquet pseudograph diagrams based on the number of precrossings and the placement of the precrossings in the pseudograph diagram. (Received September 19, 2015)

1116-57-1383 **Kanako Oshiro** (oshirok@sophia.ac.jp), Sophia University, **Ayaka Shimizu*** (shimizu@nat.gunma-ct.ac.jp), Department of Mathematics, Gunma National College of Technology, 580 Toriba-cho, Maebashi-shi, Gunma 371-8530, Japan, and **Yoshiro Yaguchi** (yaguchi-y@nat.gunma-ct.ac.jp), Gunma National College of Technology. *On a coloring function and the necessity of Reidemeister move of type II.*

In this talk we consider the up-down coloring of a knot diagram which is a kind of generalized warping degree labeling. We define a coloring function over up-down colored knot diagrams which is preserved under Reidemeister moves except at type II. By using the function, we show that for any virtual knot diagram D, there is a diagram D' representing the same virtual knot such that any sequence of generalized Reidemeister moves between D and D' must contain a Riedemeister move of type II. (Received September 19, 2015)

1116-57-1399 **Nathan Druivenga*** (nathan-druivenga@uiowa.edu), The University of Iowa, 14 MacLean Hall, Iowa City, IA 52242, and **Charles Frohman** and **Sanjay Kumar**. *Tangle Functors at Roots of Unity.*

We prove that there is a tangle functor underlying certain semicyclic representations of $U_q sl_2$ when $q = e^{i\pi/N}$ where N is odd. Specifically, when $U_q sl_2$ is presented in the standard way with generators E, F and K these representations have $E^N = a$, where a is a nonzero scalar, $F^N = 0$ and $K^N = 1$.

After proving the existence of the tangle functor we compare the answer to the colored Jones polynomial of level $N-1$ at $q = e^{i2\pi/N}$, for the figure eight knot. (Received September 19, 2015)

1116-57-1406 **Christopher R. Cornwell*** (cornwell@cirget.ca), 1225 Rue du Sussex, Montreal, Quebec H3H 2A2, Canada. *Understanding character varieties via contact homology.*

I will discuss a relationship between a version of knot contact homology and the $SL_2\mathbb{C}$ character variety of the two-fold branched cover over a knot. Trace-free $SL_2\mathbb{C}$ characters for a knot complement, and whether or not they correspond to a metabelian representation, play an important role. The relationship produces an effective tool for understanding SU(2) representations of relevance to Kronheimer and Mrowka's singular instanton knot homology. In addition, it provides a method to find double branched covers with left-orderable fundamental group, which is of interest to a conjecture of Boyer, Rolfsen, and Wiest. (Received September 19, 2015)

1116-57-1429 **W. Edwin Clark** and **Masahico Saito*** (saito@usf.edu). *Sequences of quandle extensions and cocycle knot invariants.*

Quandle 2-cocycles define invariants of classical and virtual knots, and extensions of quandles. We show that the quandle 2-cocycle invariant is trivial for classical knots when the corresponding extension satisfies certain algebraic condition. Specific examples are presented from the list of quandles. In particular, quandle cocycle invariants can be used to detect non-classicality of some virtual knots. (Received September 19, 2015)

1116-57-1454 **Adam Giambrone*** (adam.giambrone@uconn.edu). *σ-Adequate Link Diagrams and the Tutte Polynomial.* Preliminary report.

A well-known bijection between checkerboard-colored link diagrams and edge-signed planar graphs has led to a number of connections between link polynomials and graph polynomials. As an example, Thistlethwaite extracted a "boundary term polynomial" from the unnormalized Kauffman polynomial and expressed this polynomial as a product of Tutte polynomials. From this result, Thistlethwaite proved that a link diagram is A-adequate if and only if its boundary term polynomial is nonvanishing. In this talk, we will discuss an extension of this result to σ-adequate link diagrams. We will also show how a relatively recent expansion of the Tutte polynomial can be used to prove that every link diagram is σ-adequate. (Received September 19, 2015)

1116-57-1456 **Kelsey Renee Friesen*** (kelseyfriesen@mail.fresnostate.edu). *An Invariant for Virtual Singular Links.*

A singular link is an immersion of a disjoint union of circles into three-dimensional space that admits only finitely many singularities that are all transverse double points. A singular link diagram is a projection of a singular link into a plane, and contains two types of crossings, namely classical crossings and singular crossings.

Virtual knot theory, introduced by Lou Kauffman in 1996, can be regarded as a "projection" of classical knot theory in thickened surfaces. We take one step further by studying virtual singular links, which can be thought as immersions of disjoint unions of circles into thickened surfaces. Much as in the case of the classical and virtual knot theory, when studying virtual singular links we seek for ways to tell them apart. An invariant for a virtual singular link is a quantity associated to it, which is independent on the link diagram.

In this research, we employ a certain model for the sl(n) polynomial of classical links and extend it to a polynomial invariant for virtual singular links, which is defined as a state-sum formula. After this extension, we investigate how the polynomial behaves with respect to mirror images, disjoint unions, and compositions of virtual singular links. (Received September 19, 2015)

1116-57-1528 **Radmila Sazdanovic*** (rsazdanovic@math.ncsu.edu), Department of Mathematics NCSU, SAS Hall 2311 Stinson drive, PO Box 8095, RALEIGH, NC 27695. *Homology of generalized configuration spaces.* Preliminary report.

The configuration space of n distinct points in a manifold is a well-studied object with lots of applications. Eastwood and Huggett relate homology of so-called graph configuration spaces to the chromatic polynomial of graphs. In this talk we will describe generalization of this approach from graph to simplicial complexes. (Received September 20, 2015)

1116-57-1562 **Carmen L Caprau*** (ccaprau@csufresno.edu), Department of Mathematics, California State University, Fresno, 5245 North Backer Avenue, M/S PB 108, Fresno, CA 93740. *On the sl(n) homology theory.* Preliminary report.

This talk will focus on recent progress on providing a purely combinatorial foam construction of an integral sl(n) link homology for n >3, which corresponds (to some degree) to a Frobenius extension of rank n. Oriented 4-valent planar graphs and dotted foams (singular cobordisms between 4-valent planar graphs) modulo a set of local relations play a central role in our construction.

Several years ago, the author was able to partially construct the desired homology theory and proved that it is invariant under the Reidemeister moves of type I and II. In this talk we will discuss some modifications/additions to our construction that are needed in order to obtain a homology theory which is invariant under the Reidemeister move of type III, as well. (Received September 20, 2015)

1116-57-1606 **Thomas Stephens*** (tstephe3@gmu.edu), 4400 University Drive, MS: 3F2, Exploratory Hall, room 4400, Fairfax, VA 22030. *Rigorous validation of isolating blocks for flows and their Conley indices.*

Isolating blocks are particular compact and connected subsets in the phase space of a dynamical system generated by an ordinary differential equation. Points in the boundary of an isolating block which are carried out of the block by the differential equation in forward time belong to the so-called exit set. Conley index theory recognizes that the isolated invariant set, defined as the maximal invariant subset of the flow contained within the interior of a block, is topologically related to the block and its exit set, and that this information is robust under perturbation. In this talk we present a new method for rigorously verifying isolating blocks and their exit sets. Our method makes use of a recently developed adaptive algorithm for rigorously determining the topology of nodal sets (sublevel and superlevel sets) of smooth functions, which combines an adaptive subdivision technique with interval arithmetic. This procedure has been used to rigorously compute the homological Conley index of several isolated invariant sets, and in turn has provided computer assisted proofs of the existence of heteroclinic orbits in several nontrivial examples. (Received September 20, 2015)

1116-57-1622 **John Burke*** (jburke@ric.edu). *Operads and the space of string links.*

In this talk, we will discuss operads which encode the connected sum operation on the set of knots and the operation of infection on the set of string links. In addition, we will demonstrate how these operads aid in improving our understanding of the structure of the homotopy groups of the space of knots and the space of string links. (Received September 20, 2015)

1116-57-1746 **Patricia Cahn*** (pcahn@mpim-bonn.mpg.de), **Herman Gluck** and **Haggai Nuchi**. *Deformation and Extension of Fibrations of Spheres by Great Circles.*

In 1983, Gluck and Warner proved that the space of all oriented great circle fibrations of the 3-sphere S^3 deformation retracts to the subspace of Hopf fibrations, and so has the homotopy type of a pair of disjoint two-spheres. Since that time, no generalization of this result to higher dimensions has been found, so we instead show that in a certain infinitesimal sense, the space of oriented great circle fibrations of the (2n+1)-sphere S^{2n+1} deformation retracts to the subspace of Hopf fibrations. The tools developed to prove this result also show that every germ of a fibration of S^{2n+1} by great circles extends to such a fibration of all of S^{2n+1}, a result previously only known for S^3. (Received September 21, 2015)

1116-57-1809 **Jessica Purcell** and **Alexander Zupan*** (zupan@unl.edu). *Hyperbolic volume and higher genus bridge numbers.* Preliminary report.

By a theorem of Jorgensen and Thurston, the Heegaard genus of a closed hyperbolic 3-manifold gives a linear lower bound on its volume. For knots in the 3-sphere, the classical bridge number is analogous to the Heegaard genus, and so it is natural to ask whether there is any relationship between the bridge number and volume of a hyperbolic knot. We show that genus g bridge numbers and hyperbolic volumes are independent by producing sequences of knots with bounded volume and arbitrarily large genus g bridge numbers, and vice versa. (Received September 21, 2015)

1116-57-1831 **Christian R Millichap*** (cmillich@linfield.edu) and **William Worden**. *Can two hyperbolic 2-bridge link complements be commensurable?*

Two manifolds are commensurable if they share a common finite sheeted cover. In this talk, we show that the only commensurable hyperbolic 2-bridge link complements are the figure-eight knot complement and the 6_2^2 link complement. To prove this fact, we first show that any non-arithmetic hyperbolic 2-bridge link complement admits no hidden symmetries. As a corollary, we obtain a characterization of 3-manifolds with non-trivial JSJ-decomposition and rank two fundamental groups. This work requires a careful analysis of the tilings of $\mathbb{R}^2$ that come from lifting the canonical triangulations of the cusps of hyperbolic 2-bridge link complements. (Received September 21, 2015)

1116-57-1883 **J. Scott Carter*** (carter@southalalabama.edu), Department of Mathematics and Statistics, ILB 325, Mobile, AL 36688. *Foams and homology.* Preliminary report.

An n-dimensional foam is modeled on the space that is a deformation retraction of an $(n+1)$ dimensional simplex that has had its vertices removed. These n-foams potentially can be knotted in $(n+2)$-dimensional spaces. In such knottings, we can co-orient the sheets, and write down a presentation for the fundamental group. It depends upon relations at junctions and relations at crossings. The group leads us to consider an algebraic structure that has a homology theory. Homology cycles correspond to knottings up to a cobordism-like relation. The homology simultaneously generalizes group and quandle homology. (Received September 21, 2015)

1116-57-1885 **Nicholas J Owad*** (nowad2@math.unl.edu), University of Nebraska–Lincoln, Department of Mathematics, 203 Avery Hall PO BOX 880130, Lincoln, NE 68588-0130. *Gaps in bridge spectra.* Preliminary report.

The bridge spectrum is a generalization of the bridge number of a knot to higher genus Heegaard decompositions. It is necessarily a decreasing sequence, and it has been proven that certain knots obtain a stair-step bridge spectrum, which decreases by one with each step. We will cover recent progress in computing the bridge spectra of Montesinos knots and cabled knots and discuss the occurrence of gaps in the bridge spectra. (Received September 21, 2015)

1116-57-1931 **Katherine Vance*** (kvance@rice.edu). *Tau invariants for balanced spatial graphs and applications to link cobordisms.*

In 2003, Ozsvath and Szabo defined the concordance invariant τ for knots in oriented 3-manifolds as part of the Heegaard Floer homology package. In 2011, Sarkar gave a combinatorial definition of τ for knots in S^3 and a combinatorial proof that τ gives a lower bound for the slice genus of a knot. Recently, Harvey and O'Donnol defined a relatively bigraded combinatorial Heegaard Floer homology theory for transverse spatial graphs in S^3, extending HFK for knots. We define a $\mathbb{Z}$-filtered chain complex for balanced spatial graphs whose associated graded chain complex has homology determined by Harvey and O'Donnol's graph Floer homology. We use this to show that there is a well-defined τ invariant for balanced spatial graphs generalizing the τ knot concordance invariant. In particular, this defines a τ invariant for links in S^3. Using techniques similar to those of Sarkar, we show that our τ invariant is an obstruction to a link being slice. (Received September 21, 2015)

1116-57-1939 **Aldo Cruz-Cota***, aldo.h.cruz.cota@gmail.com. *The Topological Complexity of a Surface.*

Let p be a branched covering of a Riemann surface to the Riemann sphere $\mathbb{P}^1$, with branching set $B \subset \mathbb{P}^1$. We define the *complexity* of p as infinity, if $\mathbb{P}^1 \setminus B$ does not admit a hyperbolic structure, or the product of its degree and the hyperbolic area of $\mathbb{P}^1 \setminus B$, otherwise. The *topological complexity* of a surface S is defined as the infimum of the set of all complexities of branched coverings $M \to \mathbb{P}^1$, where M is a Riemann surface homeomorphic to S. We prove that if S is a connected, closed, orientable surface of genus $g > 0$, then the topological complexity of S is a linear function of its genus. (Received September 21, 2015)

1116-57-1958 **Kristen Hendricks***, hendricks@math.ucla.edu, and **Ciprian Manolescu**. *Involutive Heegaard Floer homology.*

In joint work with C. Manolescu, we use the conjugation symmetry on the Heegaard Floer complexes to define a three-manifold invariant called involutive Heegaard Floer homology, which is meant to correspond to Z-4-equivariant Seiberg-Witten Floer homology. From this we obtain two new invariants of homology cobordism, explicitly computable for surgeries on L-space knots and quasi-alternating knots, and two new concordance invariants of knots, one of which (unlike other invariants arising from Heegaard Floer homology) detects non-sliceness of the figure-eight knot. (Received September 21, 2015)

1116-57-2171 **Sumiko Horiuchi** (horiuchi@lab.twcu.ac.jp), **Yoshiyuki Ohyama** (ohyama@lab.twcu.ac.jp) and **Migiwa Sakurai*** (migiwa@ge.ibaraki-ct.ac.jp), 866 Nakane, Hitachinaka, Ibaraki 312-8508, Japan. *Examples of virtual knots with vanishing n-writhes.*

Satoh and Taniguchi define a numerical invariant called an n-writhe. This invariant induces a lot of virtual knot invariants such as an index polynomial, an odd writhe polynomial and an affine index polynomial. In this talk, we show that there exists infinitely many virtual knots whose n-writhes are all zero. (Received September 22, 2015)

1116-57-2314 **Kenneth C Millett*** (millett@math.ucsb.edu), Department of Mathematics, UCSB, Santa Barbara, CA 93106. *Local spatial entanglement of protein structures.* Preliminary report.

Although knotting and slipknotting have been identified within several classes of proteins, to date none of the topoisomerases have been found to contain knotted structure. They do, however, visually exhibit important structural features that may correlate with functional features. In this work, we employ a new method to identify and exhibit regions of local chiral entanglement thereby providing a new means to compare structure within these families and with those proteins that exhibit local knotting features. Our objective is to shine new light on facets of the mechanism by which topoisomerases act in relationship with their altering DNA topology. We will review the local linking structure of knotted and slipknotted proteins and describe the extension of this to unknotted proteins. (Received September 22, 2015)

1116-57-2440 **Cody W. Armond*** (carmond@southalabama.edu) and **Adam M. Lowrance** (adlowrance@vassar.edu). *Turaev Genus and Alternating Decompositions.*

We prove that the genus of the Turaev surface of a link diagram is determined by a graph whose vertices correspond to the boundary components of the maximal alternating regions of the link diagram. Furthermore, we use these graphs to classify link diagrams whose Turaev surface has genus one or two, and we prove that similar classification theorems exist for all genera. (Received September 22, 2015)

1116-57-2462 **Rolland Trapp*** (rtrapp@csusb.edu), 5500 University Pkwy, San Bernardino, CA 92407, and **John Harnois**. *Tangle surgeries and hyperbolic augmented links.* Preliminary report.

Given two consecutive crossing circles in a fully augmented link, we define four tangle surgeries that replace them with tangles that result in generalized fully augmented links. Two of the surgeries are shown to preserve volume, while the others increase it by twice the volume of a regular ideal octahedron. It is then shown that any octahedral fully augmented link can be obtained from the Borromean rings by a sequence of these surgeries. Finally, the surgeries are generalized to describe the geometry of generalized fully augmented links that contain certain nested thrice-punctured spheres. (Received September 22, 2015)

1116-57-2593 **Katherine Paullin*** (katherine.paullin@uky.edu), **David Letscher** (letscher@slu.edu) and **Erin Wolf Chambers** (echambe5@slu.edu). *Spinning Almost Normal Surfaces.* Preliminary report.

It is known that we can put any incompressible surface into normal form and extending those techniques, we can put strongly irreducible surfaces into almost normal form. We will discuss a combinatorial approach to generalize Walsh's spinning techniques to include strongly irreducible surfaces. (Received September 22, 2015)

1116-57-2725 **Nathan A Smith*** (nsmith@uttyler.edu). *Nearrings of endomorphisms of group objects in the category of quandles.* Preliminary report.

Quandles are an algebraic structure whose axioms correspond to the three Reidemeister moves on a knot diagram. If Q is a group object in the category of quandles then under suitable operations its endomorphisms form a group, a quandle, and a nearring (a ring-like structure in which only one of the distributive laws hold), and homomorphisms from another quandle R into Q form a module-like structure with an action of this nearring. We study properties of this nearring and its modules. (Received September 22, 2015)

1116-57-2809 **Neil R Hoffman*** (nhoffman@ms.unimelb.edu.au), **Nathan M Dunfield** and **Joan E Licata**. *Asymmetric knots with two cyclic surgeries.*

The cyclic fillings of a hyperbolic manifold are of considerable interest. John Berge constructed a list of knots in S^3 that admit a non-trivial cyclic filling and the Berge conjecture states that this list is complete. A consequence of the Berge Conjecture is that all such knot complements admit an order two symmetry. While the natural generalization of the Berge Conjecture still provides a list of hyperbolic manifolds with two cyclic fillings, we show such a list is incomplete. Finally, this provides examples of L-spaces which are not the double branched covers of knots in S^3. (Received September 22, 2015)

1116-57-2880 **Krzysztof K. Putyra** and **Alexander N. Shumakovitch*** (shurik@gwu.edu), Monroe Hall, 2115 G St. NW, room 240, Department of Mathematics, The George Washington University, Washington, DC 20052. *Homological operations on different versions of Khovanov homology.* Preliminary report.

There are several homological operations that can be defined between even and odd Khovanov homology theories using the unified even/odd Khovanov homology theory developed by Putyra. This construction works for both reduced and unreduced versions of the Khovanov homology. We discuss these homological operations, compare different versions of them, and show how they can give rise to new knot invariants with interesting properties. (Received September 22, 2015)

1116-57-2963 **Rosemary K Guzman*** (rguzma1@illinois.edu), Mathematics Department, 1409 W Green St, Urbana, IL 61801. *Special subgroups of hyperbolic 3-manifold groups.*

lower bounds on the vol M, ≥ 3.44. In the context of hyperbolic geometry, this volume bound tells more than the volume of M alone, since an implication of Mostow Rigidity is that the volume of a hyperbolic manifold is a topological invariant. In this talk, I will explain how implications of previous work along with a special rank-2 subgroup Ξ of the fundamental group of M gotten from the 5-free Theorem (G.) noted, reveal information about M by examining new bounds (gotten by topological data) on the displacement of points in Ξ. (Received September 23, 2015)

1116-57-2971 **Rosemary K Guzman*** (rguzma1@illinois.edu), Mathematics Department, 1409 W Green St, Urbana, IL 61801. *Extending the* $\log(2k-1)$*-Theorem.*

In this talk, I discuss current work that expands the scope of the $\log(2k-1)$-Theorem of Anderson, Canary, Culler and Shalen. This was a seminal result in that it articulated a relationship between a set of k freely-generating isometries of hyperbolic 3-space and how they interacted with points in hyperbolic 3-space; namely, under certain conditions, at least one of the given isometries must move a point P by a distance $\geq \log(2k-1)$. The result lay the foundation for future novel geometric-topological results. Here I discuss an expansion of the theorem, wherein we consider sets of length-n words contained in a rank-2 free group Ξ on 2 letters (one can consider ≥ 2 letters via the same methods), and present a generalized version that restricts how these isometries displace points in hyperbolic 3-space. This has application to classifying certain hyperbolic 3-manifolds in that the volume of the resulting manifold M gotten by quotient of hyperbolic 3-space with Ξ, is expected to have a bounded volume which is improved from known volume bounds. (Received September 23, 2015)

58 ► Global analysis, analysis on manifolds

1116-58-154 **Guillaume Roy-Fortin*** (gui@math.northwestern.edu), 2033 Sheridan Rd, Evanston, IL 60208, Canada. *Growth and nodal sets of Laplace eigenfunctions on manifolds.*

We will discuss a recent result that exhibits a relation between the average local growth of a Laplace eigenfunction on a smooth, compact, boundaryless Riemannian surface and the global size of its nodal set. More precisely, we provide a lower and an upper bound for the Hausdorff measure of the nodal set in terms of the expected value of the growth exponents of an eigenfunction on disks of radius comparable to the wavelength. Combined with Yau's conjecture, the result implies that the average local growth of an eigenfunction on such disks is bounded by constants in the semi-classical limit. We also will discuss results that link the size of the nodal set to the growth of solutions of planar Schrodinger equations with small potential. (Received August 08, 2015)

1116-58-472 **Scott Zimmerman*** (srz5@pitt.edu), Department of Mathematics, University of Pittsburgh, 301 Thackeray Hall, Pittsburgh, PA 15260. *The Whitney Extension Theorem for* C^1*, horizontal curves in* $\mathbb{H}^n$*.*

For a real valued function defined on a compact set $K \subset \mathbb{R}^m$, the classical Whitney Extension Theorem from 1934 gives necessary and sufficient conditions for the existence of a C^k extension to $\mathbb{R}^m$. In this talk, we will see a version of the Whitney Extension Theorem in the case of C^1, horizontal extensions for mappings defined on compact subsets of $\mathbb{R}$ taking values in the Heisenberg Group $\mathbb{H}^n$. (Received September 03, 2015)

1116-58-789 **Andres Larrain-Hubach*** (andreslh83@gmail.com), 617 N Santa Rita Ave, Office 315, Tucson, AZ 85721. *Instantons on Taub-NUT Spaces.*

The Yang-Mills Equations is a system of partial differential equations used in physics to study weak and strong nuclear interactions. In mathematics, these equations allowed Atiyah, Donaldson, Witten and others to discover fascinating topological and geometrical properties of low-dimensional manifolds. After giving basic definitions and explaining the general set-up, I will describe some recent joint work with Sergey Cherkis and Mark Stern concerning properties of solutions of Yang-Mills equations over an important class of four-manifolds called Taub-NUT spaces. (Received September 13, 2015)

1116-58-864 **Gabriel Rivière*** (gabriel.riviere@math.univ-lille1.fr), Laboratoire Paul Painlevé, UFR de mathématiques, Université Lille 1, 59655 Villeneuve d'Ascq, France. *Conormal cycles of random nodal sets.*

I will discuss asymptotic properties of Gaussian random superposition of Laplace eigenfunctions on a compact Riemannian manifold without boundary. More precisely, I will describe the behaviour of the conormal cycle attached to the corresponding nodal sets. When the dimension is odd, I will show that the expectation of the associated current of integration converges to the pullback of the Riemannian volume. When the dimension is even, I will obtain an upper bound of lower order.
This is a joint work with Nguyen Viet Dang (Université Lyon 1) (Received September 14, 2015)

1116-58-892 **Steve Zelditch***, Northwestern University, Evanston, IL 60208. *Chaotic billiards and vibrations of drums.*

There are two ways to 'play' on a drum, which we allow to be shaped in any way, for instance as a standard circular drum-head, or as a stadium-shaped drum-head. First, one may play billiards on it, shooting a ball in a straight line that bounces off the sides by the law of equal angles. For a circular drum-head the billiard trajectories are completely predictable, but for the stadium-shaped drum they are chaotic and unpredictable. Second, the drum-head may vibrate in one if its normal modes. To visualize these modes,one sprinkles sand on the drum and watches the sand accumulate on the nodal set, where the drum is not vibrating (Chladni). My talk is concerned with the question, how are billiard trajectories related to nodal lines? What do the nodal lines look like as the frequency of vibration tends to infinity? In particular, what happens if the billiards are 'chaotic'. (Received September 14, 2015)

1116-58-953 **David Bate***, Dept. of Mathematics, University of Chicago, 5734 S. University Avenue, Chicago, IL 60637. *The geometry of Radon Nikodym Lipschitz differentiability spaces.*

We give a purely geometric characterisation of those metric measure spaces that satisfy the differentiability theory of Cheeger for Lipschitz maps into Banach spaces with the Radon-Nikodym property. We will then see that this is also equivalent to satisfying an asymptotic non-homogeneous Poincaré inequality. This is joint work with Sean Li. (Received September 15, 2015)

1116-58-1026 **Michael Gekhtman***, mgekhtma@nd.edu. *Inverse Moment Problem for Non-Abelian Coxeter Double Bruhat Cells.*

We introduce a family of non-Abelian nonlinear lattices that generalize Coxeter-Toda lattices in GL(n) and show that matrix Weyl functions can be used to encode the Hamiltonian structure of these lattices, to establish their complete integrability and to explicitly solve them via the matrix generalization of the inverse moment problem. (Received September 16, 2015)

1116-58-1103 **Xiaolong Han***, Department of Mathematics, Australian National University, Canberra, ACT 2601, Australia. *Small scale quantum ergodicity in negatively curved manifolds.*

Quantum ergodicity is the study of how the ergodicity (or chaos, i.e. with exponential instability) of a classical Hamiltonian system is reflected in its corresponding quantum system. For example, what implication does ergodicity (or chaos) of the geodesic flow on a compact Riemannian manifold have on the Laplacian eigenfunctions? The quantum ergodic theorem states that, if the geodesic flow is ergodic, then a full density subsequence of eigenfunctions tend equidistributed asymptotically in any fixed region. In negatively curved manifolds, the geodesic flows display stronger chaotic properties than ergodicity. It has further implication on its quantum system. Using the property of exponential decay of correlation, we prove that the asymptotic equidistribution can be improved to regions of small scales (e.g. balls logarithmically shrinking to points). (Received September 17, 2015)

1116-58-1254 **Fabrice Baudoin*** (fbaudoin@purdue.edu), 150 N. University street, West Lafayette, IN 47906. *Stochastic analysis on sub-Riemannian manifolds.*

We develop a Malliavin calculus on the horizontal path space over a foliated Riemannian manifold. This calculus is used to prove logarithmic Sobolev inequalities under curvature conditions and concentration inequalities for the horizontal Brownian motion of the foliation. (Received September 18, 2015)

1116-58-1408 **Eduardo González***, Mathematics Department, 100 Morrissey Blvd., Boston, MA 02125, and **Hiroshi Iritani**. *A conjectural formula for counting discs via degeneration.*

Let M be a symplectic manifold equipped with a Hamiltonian circle action and let L be an invariant Lagrangian submanifold of M. We will discuss the problem of counting holomorphic disc sections of the trivial M-bundle over a disc with boundary in L through degeneration. We obtain a conjectural relationship between the potential function of L and the Seidel element associated to the circle action. This relation should follow from the underlying geometry of the moduli structure of the spaces of disc sections involved in this problem. (Received September 19, 2015)

1116-58-1628 **Emily B. Dryden*** (`ed012@bucknell.edu`), **Diana Macedo** and **Rosa Sena-Dias**. *Can you hear the metric on a sphere?*

Asking whether you can "hear" a geometric attribute of a surface is an informal way of asking about the relationship between the attribute and the vibration frequencies of the surface. In the simple setting of metrics on a S^2 that are invariant with respect to a natural circle action, we examine situations in which the metric can be determined by the vibration frequencies plus information coming from the action. This is joint work with Diana Macedo and Rosa Sena-Dias. (Received September 20, 2015)

1116-58-1707 **Antônio Sá Barreto** and **Yiran Wang*** (`yrwang.math@gmail.com`). *The Scattering Relation on Asymptotically Hyperbolic Manifolds.*

The scattering relation plays an important role in (inverse) scattering theory. For non-trapping asymptotically hyperbolic manifolds (AHM) which are natural generalizations of the hyperbolic manifolds, we analyze the global behavior of Lagrangian submanifolds associated to the geodesic flows. We define the scattering relation and obtain the asymptotics of the distance function. We also generalize the analysis to conformal compact manifolds, where the curvature is not asymptotically constant at infinity. (Received September 21, 2015)

1116-58-1882 **Phillip Andreae*** (`pandreae@math.duke.edu`). *Analytic torsion: generalized metric invariance.*

We study the Ray-Singer analytic torsion T associated to a flat vector bundle with hermitian metric h over an odd-dimensional compact manifold with Riemannian metric g. In the acyclic case (and, with the appropriate interpretation, more generally), T is known to be independent of the metrics h and g, i.e., T is a topological invariant. We frame the metric independence of T in terms of a certain closed one-form on the space of metrics, and we prove that furthermore T is independent of the metric on the exterior bundle, which may be chosen independently of g. (Received September 21, 2015)

1116-58-2446 **Sofya Chepushtanova*** (`sofya.chepushtanova@wilkes.edu`), Department of Math and CS, Wilkes University, 84 West South Street, Wilkes-Barre, PA 18766. *Persistent Homology on Grassmann manifolds for Analysis of Hyperspectral Movies.*

We present a geometric framework for characterizing information in hyperspectral movies, i.e., sequences of hyperspectral data cubes evolving in time. Time frames in such a movie are mapped to a sequence of abstract points on the real Grassmann manifold $G(k, n)$, a manifold that parameterizes the k-dimensional subspaces of $\mathbb{R}^n$. The Grassmannian framework affords data compression while retaining pertinent data structure. This structure, associated with the evolution of the frames of a hyperspectral movie, can be revealed by persistent homology, a relatively new multiscale method from topological data analysis. The proposed approach is applied to the detection of chemical signals in the Long-Wavelength Infrared data set. (Received September 22, 2015)

1116-58-2645 **Derdei Bichara*** (`dbichara@asu.edu`), Engineering Center A, P.O. Box 873901, Tempe, AZ 85287-3901, and **Carlos Castillo-Chavez** (`ccchavez@asu.edu`), Engineering Center A, P.O. Box 873901, Tempe, AZ 85287-3901. *Vector-borne diseases model with residence time - a Lagrangian perspective.*

Modeling vector-borne interactions have often been based on well-mixed models that make it difficult to address effectively the role of host mobility on vector borne disease dynamics. Here, we consider a Lagrangian framework where hosts' dispersal is modeled via the proportion of time that individuals, residents, spend in different environments. We consider a general SIS framework to account for the host dynamics and an SI framework to account for the vector dynamics. The transmission terms take a modified frequency-dependent incidence that accounts for the effective density of infected hosts within each patch at any time generated by the residence time matrix $\mathbb{P} = (p_{ij})_{\substack{1\leq i\leq n,\\ 1\leq j\leq m}}$, where the p_{ij} denotes the proportion of time the host of group i spends in environment j. We compute the basic reproduction number $\mathcal{R}_0^2(\mathbb{P}, m, n)$ for the general host-vector mode. We derive conditions under which either the disease free equilibrium or a unique endemic equilibrium is globally asymptotically stable (GAS). The approach include both when hosts' structure is the same as vectors's structure. (Received September 22, 2015)

1116-58-2981 **Hart F. Smith***, University of Washington, Seattle, WA 98195. *The trace of the heat kernel and regularity of potentials.*

We establish a sharp relation between the Sobolev regularity of a potential and the existence of finite order expansions in time for the trace of the heat kernel of the associated Schrodinger operator. (Received September 30, 2015)

1116-58-2984 **Christopher Sogge*** (csogge@jhu.edu), Johns Hopkins University, Baltimore, MD. *Problems related to the concentration of eigenfunctions.*

We discuss estimates and problems related to the concentration of eigenfunctions. (Received September 30, 2015)

1116-58-2985 **Gunther Uhlmann*** (gunther@math.washington.edu), University of Washington, Seattle, WA. *Seeing Through Space Time.*

We will consider some inverse problems arising in general relativity. This is joint work with Y. Kurylev and M. Lassas. (Received September 30, 2015)

1116-58-2986 **Steve Zelditch*** (zelditch@math.northwestern.edu), Northwestern University, Evanston, IL 60208. *Logarithmic growth of nodal domains in negative curvature.*

We use recent results of X. Han and H. Hezari-G. Riviere and Christiant-Toth-Zelditch to improve a result joint with J. Jung, showing that the number of nodal domains grows logarithmically with the eigenvalue. (Received September 30, 2015)

60 ► Probability theory and stochastic processes

1116-60-157 **Hongwei Mei*** (ev0554@wayne.edu), 940 W. Forest Ave, Apt 5, Detroit, MI 48201, and **Fuke Wu** and **George Yin**. *Stochastic Functional Differential Equations with Infinite Delay.*

This work is devoted to stochastic functional differential equations (SFDEs) with infinite delay. First, existence and uniqueness of the solutions of such equations are examined. Because the solutions of the delay equations are not Markov, a viable alternative for studying further asymptotic properties is to use solution maps or segment processes. By examining solution maps, this work investigates the Markov properties as well as the strong Markov properties. Also obtained are adaptivity and continuity, mean-square boundedness, and convergence of solution maps from differential initial data. This paper then examines the ergodicity of underlying processes and establishes existence of the invariant measure for SFDEs with infinite delay under suitable conditions. (Received August 09, 2015)

1116-60-247 **Maxim Bichuch*** (mbichuch@jhu.edu) and **Ronnie Sircar** (sircar@princeton.edu). *Optimal Investment with Transaction Costs and Stochastic Volatility.*

Two major financial market complexities are transaction costs and uncertain volatility, and we analyze their joint impact on the problem of portfolio optimization. When volatility is constant, the transaction costs optimal investment problem has a long history, especially in the use of asymptotic approximations when the cost is small. Under stochastic volatility, but with no transaction costs, the Merton problem under general utility functions can also be analyzed with asymptotic methods. Here, we look at the final time optimal investment and consumption problem, when both complexities are present, using separation of time scales approximations. We find the first term in the asymptotic expansion in the time scale parameter, of the optimal value function, consumption, and of the optimal strategy, for fixed small transaction costs. We give a proof of accuracy in the case of fast mean-reverting stochastic volatility. Additionally, we derive the long-term growth rate. (Received August 18, 2015)

1116-60-331 **Indranil SenGupta***, Department of Mathematics, North Dakota State University, NDSU Dept # 2750, Minard Hall 408E12, Fargo, ND 58108-6050, and **Semere Habtemicael**. *Pricing covariance swaps in Lévy driven market.*

The objective of this presentation is to study the arbitrage free pricing of the covariance swap for Barndorff-Nielsen and Shephard type Levy process driven financial markets. One of the major challenges in arbitrage free pricing of swap is to obtain an accurate pricing expression which can be used with good computational accuracy.

In this presentation we demonstrate closed form expressions for the pricing of covariance swap. (Received August 25, 2015)

1116-60-401 **José Enrique Figueroa-López** and **Ruoting Gong*** (rgong2@iit.edu), Room 116-B, Engineering 1 Building, 10 West 32nd Street, Chicago, IL 60616, and **Christian Houdré**. *Small-Time Asymptotics for At-The-Money Option Prices Under Exponential Lévy Models.*

The short-time asymptotic behavior of option prices for a variety of models with jumps has received much attention in recent years. In the present work, a novel high-order approximation for ATM option prices is derived for a large class of exponential Lévy models with or without Brownian component. The results hereafter shed new light on the connection between both the volatility of the continuous component and the jump parameters and the behavior of ATM option prices near expiration. The asymptotic behavior of the corresponding Black-Scholes implied volatilities is also addressed. Our approach is sufficiently general to cover a wide class of Lévy processes which satisfy the latter property and whose Lévy densities can be closely approximated by a stable density near the origin. (Received August 30, 2015)

1116-60-442 **John C. Wierman*** (wierman@jhu.edu), Dept. of Applied Mathematics & Statistics, 100 Whitehead Hall, Johns Hopkins University, Baltimore, MD 21218. *A lower bound for the difference between the bond percolation thresholds of the cubic and face-centered cubic lattices.* Preliminary report.

The exact percolation threshold is not known for any three-dimensional lattice bond percolation threshold, and rigorous bounds are quite poor. It has been long been known that since the cubic lattice is a subgraph of the face-centered cubic lattice, there is a strict inequality between their percolation thresholds: $p_c(\text{ cubic }) > p_c(\text{ face-centered cubic })$. However, there has been no positive lower bound on the size of the difference. Using the substitution method, we show that $p_c(\text{ cubic }) - p_c(\text{ face-centered cubic }) > 0.064$. For comparison, simulation estimates indicate that the difference is approximately 0.124. (Received September 01, 2015)

1116-60-528 **Ami Radunskaya*** (aer04747@pomona.edu), Math Dept., Pomona College, 610 N. College Ave., Claremont, CA 91711. *Chaos and Noise: the implications of stochasticity in growth laws.*

Many biological and physiological processes involve self-regulating mechanisms that prevent too much growth while ensuring against extinction. The rate of growth is often random ("noisy"), possibly affected by fluctuations in the environment. Some questions that we'd like to answer are: what happens to the system in the long term? Does the system have a well-defined average? How does this long-term average compare to the long-term behavior of the deterministic (not random) system? What can we say about the distribution of "survival times", i.e. the distribution of times until the system reaches a particular value?

In this talk we answer these questions for a family of maps on the unit interval that model self-limiting growth. We then look at more complicated systems and make several conjectures. (Received September 05, 2015)

1116-60-565 **Fan Ny Shum*** (fan.shum@uconn.edu). *Stabilization by Noise of a $\mathbb{C}^2$-valued Coupled System.*

David Herzog and Jonathan Mattingly took a system of ODEs in the form of a complex-valued polynomial and added an isotropic Brownian term to stabilize the system. In particular, they showed that this perturbed system has ergodic properties; that is, it has nonexplosive solutions and a unique invariant measure. The next natural step is to look at ODEs in higher dimensions, for instance, the complex-valued ODE

$$\begin{cases} \dot{z}_t = -\nu z_t + \alpha z_t w_t \\ \dot{w}_t = -\nu w_t + \beta z_t w_t \quad \text{ where } \nu \in \mathbb{R}^+, \alpha, \beta \in \mathbb{R}. \\ z_0, w_0 \in \mathbb{C}, \end{cases}$$

Similar to the polynomial system, this higher-dimensional ODE has solutions that blow up in finite time. Using a transformation of coordinates, we show how this system with an additive Brownian term is ergodic. (Received September 07, 2015)

1116-60-600 **Andrey Sarantsev*** (ansa1989@gmail.com), South Hall 5607A, Santa Barbara, CA 93106, and **Ioannis Karatzas** (ik@math.columbia.edu), Room 509, MC 4406, 2990 Broadway, New York, NY 10027. *Market Models with Splits and Mergers.*

Consider a model of a stock market: Each stock is represented by a positive stochastic process, jointly governed by a system of SDEs. We introduce splits and mergers in this model, so that the quantity of stocks is not constant. Under certain conditions, we show this model does not allow arbitrage. (Received September 08, 2015)

1116-60-617 **Jun Kigami*** (kigami@i.kyoto-u.ac.jp), Graduate School of Informatics, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto, Kyoto 6068501, Japan. *Time change of Brownian motion: Poincare inequality, heat kernel estimate and protodistance.*

In this talk, time change of the Brownian motion of the 2-dim. square is considered. Time change corresponds to the introduction of inhomogeneity of medium. As a consequence, after time change the process has the same paths as the Brownian motion but it can have different speed at each point. Recently, time change with respect to random measures such as Liouville measure, or Liouville quantum gravity has been of much interest in relation with associated random geometry We will define a class of measures called measures with weak exponential decay, which includes Liouville measure, and show the existence of associated time changed process which posesses a jointly continuous heat kernel. To give an estimate of heat kernel, we will introduce the notion of "protodistance", which is a candidate of proper substitute of intrinsic metric. (Received September 09, 2015)

1116-60-647 **F Alberto Grunbaum*** (grunbaum@math.berkeley.edu), Math Dept, UC Berkeley, Berkeley, CA 94720. *Urn models and the Darboux process.*

Abstract

We look at classical urn models with a nice physical interpretation and ask what happens when they are subject to certain variants of the Darboux process which has played in important role in building complex systems from simpler ones. (Received September 09, 2015)

1116-60-698 **Heng Yang** (brazy.yang@gmail.com), 365 5th ave, New York, NY 10016, **Olympia Hadjiliadis*** (olympia.hadjiliadis@gmail.com), 695 Park ave, New York, NY 10065, and **Michael Ludkovski** (ludkovski@pstat.ucsb.edu), Santa Barbara, CA 93106. *Quickest detection in the Wiener disorder problem with post-change drift uncertainty.*

We consider the problem of quickest detection of an abrupt change when there is uncertainty about the post-change distribution. In particular, we examine this problem in the continuous-time Wiener model where the drift of observations changes from zero to a random drift with a prescribed discrete distribution. We set up the problem as a stochastic optimization in which the objective is to minimize a measure of detection delay subject to a constraint on frequency of false alarms. We design a novel composite stopping rule and prove that it is asymptotically optimal of third order under a weighted Lorden criterion for detection delay. We also analyze the conditional identification error for the post-change drift asymptotically. Our composite rules are based on CUSUM stopping times, as well as their reaction periods, namely the times between the last reset of the CUSUM statistic process and the CUSUM alarm. The established results shed new light on the performance of CUSUM strategies under model uncertainty and offer new asymptotic optimality results in this framework. (Received September 10, 2015)

1116-60-758 **Song Yao*** (songyao@pitt.edu). *Robust Dynkin games.*

We analyze a robust version of the Dynkin game over a set P of mutually singular probabilities. We first prove that conservative player's lower and upper value coincide (Let us denote the value by V). Such a result connects the robust Dynkin game with second-order doubly reflected backward stochastic differential equations. Also, we show that the value process V is a submartingale under an appropriately defined nonlinear expectations up to the first time τ_* when V meets the lower payoff process. If the probability set P is weakly compact, one can even find an optimal triple (P_*, τ_*, γ_*) for the value V_0. This is a joint work with Erhan Bayraktar. (Received September 11, 2015)

1116-60-839 **Daniel Conus** and **Mackenzie Wildman*** (mackenzie.wildman@gmail.com). *A Gaussian Markov alternative to fractional Brownian motion for pricing financial derivatives.*

Replacing Black-Scholes' driving process, Brownian motion, with fractional Brownian motion allows for incorporation of a past dependency of stock prices but faces a few major downfalls, including the occurrence of arbitrage when implemented in the financial market. I will discuss the development, testing, and implementation of a simplified alternative to using fractional Brownian motion for pricing derivatives. By relaxing the assumption of past independence of Brownian motion but retaining the Markovian property, we are developing a competing model that retains the mathematical simplicity of the standard Black-Scholes model but also has the improved accuracy of allowing for past dependence. This is achieved by replacing Black-Scholes' underlying process, Brownian motion, with the Dobrić-Ojeda process. (Received September 14, 2015)

1116-60-927 **Sergio Albeverio**, **Barbara Rüdiger** and **Padmanabhan Sundar*** (sundar@math.lsu.edu), Department of Mathematics, Louisiana State University, Baton Rouge, LA 70803. *The Enskog Process.*

The existence of a weak solution to a McKean-Vlasov type stochastic differential system corresponding to the Enskog equation of the kinetic theory of gases is established under natural conditions. The distribution of any solution to the system at each fixed time is shown to be unique. The existence of a probability density for the time-marginals of the velocity is verified in the case where the initial condition is Gaussian, and is shown to be the density of an invariant measure. (Received September 15, 2015)

1116-60-993 **Jianfeng Zhang*** (jianfenz@usc.edu). *Dynamic Approaches for Some Time Inconsistent Problems.*

There are typically two strategies for time inconsistent problems: strategy of precommitment and strategy of consistent planning, which induce different value functions. The latter is a game approach where the player plays with infinitely many future selves, and most papers in continuous time models follow this approach. However, in situation where frequent "reneogotiation" is not allowed, the strategy of precommitment is more appropriate and it is the subject of this work. We shall discuss the source of time inconsistency and propose a few possible dynamic approaches for the problem. (Received September 15, 2015)

1116-60-1058 **Zachary P Kilpatrick*** (zpkilpat@math.uh.edu), Department of Mathematics, University of Houston, Houston, TX 77204, **Kresimir Josic**, Department of Mathematics, University of Houston, Houston, TX 77204, and **Alan Veliz-Cuba**, Department of Mathematics, University of Dayton, Dayton, OH 45469. *Stochastic models of evidence accumulation in changing environments.*

Organisms and ecological groups accumulate evidence to make decisions. Classic experiments and theoretical studies have explored this process when the correct choice is fixed during each trial. However, we live in a constantly changing world. What effect does such impermanence have on classical results about decision making? To address this question we use sequential analysis to derive a tractable model of evidence accumulation when the correct option changes in time. Our analysis shows that ideal observers discount prior evidence at a rate determined by the volatility of the environment, and the dynamics of evidence accumulation is governed by the information gained over an average environmental epoch. A plausible neural implementation of an optimal observer in a changing environment shows that, in contrast to previous models, neural populations representing alternate choices are coupled through excitation. Our work builds a bridge between statistical decision making in volatile environments and stochastic nonlinear dynamics. (Received September 17, 2015)

1116-60-1073 **Dan Hrozencik*** (dhro@att.net), Chicago State University, Department of Mathematics HWH 332, 9501 S. King Dr., Chicago, IL 60423. *When Genes Fail: Modeling Stochasticity in Gene Regulatory Networks.*

In gene regulatory networks (GRNs), the expression of genes is subject to not only the input from other genes but also possible internal and/or external noise. Thus it is possible for genes in seemingly identical environmental conditions to behave differently. For this reason we are interested in studying variability in GRNs. In this talk the authors demonstrate a method for determining the variability in the probabilistic state space by estimating the activation and degradation propensities for the genes in the network as well as their distributions, and using this information to create an accurate simulation of the network, which is then used to calculate the previously unknown variations in the probabilistic state space. (Received September 16, 2015)

1116-60-1148 **Ennio Fedrizzi**, **Wladimir Neves** and **Christian Olivera*** (colivera@ime.unicamp.br), Rua Sérgio Buarque de Holanda, 651, Cidade Universitária "Zeferino Vaz" ., CEP 13083-859, Campinas, SP , Brazil. *On a class of stochastic transport equations for L2loc vector fields.*

We study in this talk the existence and uniqueness of solutions to a class of stochastic transport equations with irregular coefficients. Asking only boundedness of the divergence of the coefficients (a classical condition in both the deterministic and stochastic setting),we can lower the integrability regularity required in known results on the coefficients themselves and on the initial condition, andstill prove uniqueness of solutions. (Received September 17, 2015)

1116-60-1173 **Nguyet T. Nguyen*** (ntnguyen01@ysu.edu), Department of Mathematics & Statistics, One University Plaza, Youngstown, OH 44555, and **Dung A. Nguyen** (dung@ndr.com), 600 Bird Bay Drive West, Venice, FL 34285. *Regime Switching Model for Economic Crisis and Stock Selection.*

In this talk, we will use regime switching model (or hidden Markov model) to predict economic crisis (or recession regime) using some macro economics variables such as Inflation (CPI), Economics Growth (GDP), Stock Market Index (S&P500) and Market Volatility (VIX). We also analyze the performances of all of the S&P 500 stocks during economic regimes to make a monthly stock selection for our investment portfolio. Our numerical results showed that our portfolio had higher returns and lower risk compared to the benchmark index S&P 500. (Received September 17, 2015)

1116-60-1190 **Peter T. Otto*** (potto@willamette.edu), Salem, OR 97301. *The aggregate path coupling method for mixing times of Markov chains.*

The classical path coupling method to bound the mixing times of Markov chains is a powerful probabilistic tool that reduces the problem to bounding the mean coupling distance between all pairs of neighboring configurations. Aggregate path coupling is an extension of the path coupling method that applies large deviation bounds and aggregation of the mean coupling distance in order to make bounding only certain pairs of neighboring configurations sufficient to bound the mixing time of the Markov chain. (Received September 17, 2015)

1116-60-1238 **Woosok Moon*** (wm275@cam.ac.uk), 346 Glenalmond Ave., Cambridge, CB2 8DT, United Kingdom, and **John S Wettlaufer** (john.wettlaufer@yale.edu), 210 Whitney Ave., New Haven, CT 06511. *A stochastic perturbation theory for non-autonomous systems.*

We develop a perturbation theory for a class of first order nonlinear non-autonomous stochastic ordinary differential equations that arise in climate physics. The perturbative procedure produces moments in terms of integral delay equations, whose order by order decay is characterized in a Floquet-like sense. Both additive and multiplicative sources of noise are discussed and the question of how the nature of the noise influences the results is addressed. The generality of the analysis is demonstrated by developing it both for a Brownian particle moving in a periodically forced quartic potential, which acts as a simple model of stochastic resonance, as well as for our more complex climate physics model. The validity of the approach is shown by comparison with numerical solutions. The particular climate dynamics problem upon which we focus involves a low-order model for the evolution of Arctic sea ice under the influence of increasing greenhouse gas forcing ΔF_0. The deterministic model, developed by Eisenman and Wettlaufer[**?**,]]EW09 exhibits several transitions as ΔF_0 increases and the stochastic analysis is used to understand the manner in which noise influences these transitions and the stability of the system. (Received September 18, 2015)

1116-60-1426 **Steven E Shreve*** (shreve@andrew.cmu.edu), Department of Mathematical Sciences, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213-3890. *Markov Projection of a Stochastic Process.*

Dupire has shown how to construct a local volatility model that matches given option prices. More generally, if one has an underlying stochastic process on which derivative securities are written, it is desirable to construct a low-dimensional Markov process that generates the same derivative security prices. In this talk, we show how to begin with a general multi-dimensional underlying process whose drift and diffusion are themselves stochastic processes, and then construct a solution of a low-dimensional stochastic differential equation whose distribution at each fixed time agrees with the distribution of the original underlying stochastic process. Indeed, we can do this is such a way that functions of the paths of the two processes, such as running maximum or running average, also have the same distribution at each fixed time. This can be done without assuming non-vanishing volatility or continuity of coefficients, although in this general setting, the low-dimensional stochastic differential equation may have spurious solutions. (Received September 19, 2015)

1116-60-1440 **Yao Li*** (yaoli@math.umass.edu), 710 N. Pleasant Street, Department of Math & Stats, Amherst, MA 01003, and **Lai-Sang Young**, 253 Mercer Street, New York, NY 10003. *Asymptotic dynamics of some microscopic heat conduction models.*

In this talk I will present our recent results on the asymptotic dynamics for a class of stochastic microscopic heat conduction models. In these models, particles undergo both diffusion and energy exchange with their "local environments". Those stochastic models are derived from mechanical chain models (Eckmann & Young 2006) by randomizing certain chaotic quantities. We proved various rigorous results including the existence and uniqueness of nonequilibrium steady-states (NESS), the exponential convergence towards NESS, and the existence of local thermodynamic equilibrium (LTE). (Received September 19, 2015)

1116-60-1467 **S.M. Mousavi*** (mostafa.mousavi22@gmail.com), Cubicle S, South Hall, UCSB, Santa Barbara, CA 93106, and **J-P Fouque**. *Mean field games in interbank models.*

We study in the setting of mean-field games the model of interbank borrowing and lending proposed by Carmona et al (2014) while taking into account that any lending (or borrowing) needs to be returned after some specific time. In this model, log monetary reserves of banks are described by a system of stochastic differential equations with delays, coupled through their drifts. The game feature of the model comes from the fact that each bank is trying to optimize its rate of lending/borrowing to the central bank to minimize the associated quadratic cost whose rate is determined by the regulator. Therefore, each bank has incentive to start borrowing when its log monetary reserve is less than some critical value, which in here is the average log monetary reserve, and vice versa. Given that the log monetary reserve process is no longer Markovian, in order to solve the corresponding optimization problem, its process is recasted as an abstract stochastic differential equation on a Hilbert space. (Received September 20, 2015)

1116-60-1513 **Erhan Bayraktar** and **Alexander Munk*** (amunk@umich.edu). *An α-Stable Limit Theorem Under Sublinear Expectation.*

For $\alpha \in (1, 2)$, we present a generalized central limit theorem for α-stable random variables under sublinear expectation. The foundation of our proof is an interior regularity estimate for partial integro-differential equations (PIDEs). A classical generalized central limit theorem is recovered as a special case, provided a mild but natural additional condition holds. Our approach contrasts with previous arguments for the result in the linear setting which have typically relied upon tools that are nonexistent in the sublinear framework, e.g., characteristic functions. (Received September 20, 2015)

1116-60-1541 **Ivo Mihaylov*** (ivo.mihaylov06@imperial.ac.uk), Huxley Building, 180 Queens Gate, South Kensington, London, SW7 2AZ, United Kingdom. *A class of approximate Greek weights: high-order schemes and extrapolation techniques.*

This paper defines a class of approximate option sensitivity (Greek) weights and provides high-order approximations and justification for extrapolation techniques. Under certain regularity assumptions on the value function of the pricing partial partial differential equation, Greek approximations are proved for a fully implementable Monte Carlo framework using weak Taylor discretisation schemes. The variance and bias are studied for the Delta and Gamma for such discrete-time approximations. (Received September 20, 2015)

1116-60-1587 **Joe P. Chen*** (joe.p.chen@uconn.edu), Department of Mathematics, University of Connecticut, Storrs, CT 06269, and **Alexander Teplyaev** (teplyaev@math.uconn.edu), Department of Mathematics, University of Connecticut, Storrs, CT 06269. *Current large deviations in the boundary-driven symmetric simple exclusion process on the Sierpinski gasket.*

We study the symmetric simple exclusion process on the Sierpinski gasket (SG) driven by the action of particle reservoirs attached to boundary vertices of SG.

We establish three hydrodynamic limit theorems for the empirical current: the law of large numbers, the large deviations principle, and the large deviations principle for the mean current on a long-time interval. On $\mathbb{Z}^d$ these results were established assuming translational invariance and Gaussian space-time diffusive estimates. But on SG neither assumption is valid, and it is unclear how to make sense of the resulting reaction-diffusion PDE.

In this work we overcome all the aforementioned obstacles. First, we prove the "moving particle lemma" on weighted graphs using the "octopus inequality" of Caputo, Liggett, and Richthammer in their seminal proof of Aldous' spectral gap conjecture. This enables us to prove a local version of the two-blocks estimate on SG, thereby answering a question posed by Jara. Second, we actively use the theory of differential 1-forms on SG developed by the second author and collaborators, which allows us to characterize the speed of convergence of discrete 1-forms on SG, and prove uniqueness of solutions to the resulting reaction-diffusion PDE. (Received September 20, 2015)

1116-60-1589 **Elizabeth Skubak Wolf*** (ewolf@saintmarys.edu). *Computing Sensitivities in Discrete Stochastic Reaction Networks with Delay.* Preliminary report.

Continuous time Markov chains have recently become widely used in biochemistry as models for intracellular mechanisms such as the transcription and translation of DNA or genetic switching. These models are also applicable in many other fields, such as ecology or epidemiology. For many of these applications, one may wish to incorporate delay into the model; for example, several recent studies have shown that the time it takes for DNA transcription to be completed once initiated is not negligible in the dynamics of the network.

In this talk I will describe an efficient method to solve for the expectations of desired quantities in these models and their sensitivities to model parameters. (Received September 20, 2015)

1116-60-1597 **John K. McSweeney*** (mcsweene@rose-hulman.edu). *Single-Seed Cascades on Clustered Networks.*

We consider a dynamic network (graph) cascade process developed by Duncan Watts – nodes (vertices) enter an 'active' state if and only if a specified proportion of their neighbors do. We analyze this process on a class of random networks which have a specified amount of clustering, and are thus not locally tree-like. We adapt existing tree-based methods to formulate an appropriate two-type branching process to describe the spread of a cascade started with a single active node, and obtain a fixed-point equation to implicitly express the extinction probability of such a cascade. In so doing, we also establish a compact criterion for certain extinction of the cascade. (Received September 20, 2015)

1116-60-1611 **Richard H Hammack** (rhammack@vcu.edu), Virginia Commonwealth University, Department of Mathematics, Richmond, VA 23284, and **Gregory Douglas Smith*** (greg@wm.edu), Department of Applied Science, The College of William & Mary, Williamsburg, VA 23187. *Cycle bases of reduced powers of graphs.* Preliminary report.

Given a graph G and a positive integer k, the *reduced kth power of G*, denoted $G^{(k)}$, is the configuration space in which k indistinguishable tokens are placed on the vertices of G, so that any vertex can hold up to k tokens. Two configurations are adjacent if one can be transformed to the other by moving a single token along an edge to an adjacent vertex. The reduced power $G^{(k)}$ is the transition graph of the master Markov chain for k identical and indistinguishable stochastic automata with transition graph G. This talk will give an overview of propositions related to the structural properties of reduced graph powers and, most significantly, present a construction of minimum cycle bases of $G^{(k)}$. The minimum cycle basis construction yields conditions that ensure against violations of microscopic reversibility in biophysical applications, such as Markov chain models of the stochastic gating of coupled ion channels. (Received September 20, 2015)

1116-60-1616 **Brian Rider** and **Patrick Thomas Waters***, 310 N 12th St Apt #310, Philadelphia, PA 19107. *Universality of operator limits at the Laguerre hard edge.* Preliminary report.

Random differential operator limits for the tridiagonal random matrix beta ensembles were conjectured by Edelman and Sutton. Rider and collaborators have given rigorous proofs for the stochastic Airy operator limit at the Hermite soft edge ($V(x) = x^2$) and stochastic Bessel limit at the Laguerre hard edge ($V(x) = x$). Furthermore they proved that the stochastic Airy operator is universal ($V(x)$=convex polynomial). We will attempt to prove a universality theorem for the stochastic Bessel operator. Joint work with Brian Rider. (Received September 20, 2015)

1116-60-1675 **Tomoyuki Ichiba*** (ichiba@pstat.ucsb.edu). *Rank-based markets with model uncertainty.*

In this talk we shall enhance Knightian uncertainty to a class of rank-based equity market models where drift and diffusion coefficients are piece-wise constants in each polyhedral domain. We study stochastic differential equations with constraints on the coefficients in terms of supermartingale problems, and then discuss long-term performance of Markovian portfolio rules under the models with uncertainty. (Received September 21, 2015)

1116-60-1696 **Michael A. Högele*** (ma.hoegele@uniandes.edu.co), Universidad de los Andes, Departamento de Matematicas, KR 1 No 18 A-10, BL H., Botota, D.C. , Colombia, and **Arnaud Debussche** and **Peter Imkeller**. *The dynamics of reaction-diffusion equations with heavy-tailed Lévy noise.*

In this talk we address the random dynamics of stochastic reaction-diffusion equations subject to small heavy-tailed Lévy noise. In particular we explain the associated first exit problem of the stochastic equation from the domain of attraction of a stable fixed point of the deterministic system in the limit of small noise intensity. After a short introduction to Lévy processes in a Hilbert space we shall state the main results and lay out the strategy of the proof. If time permits we will have a look at the associated metastability result. This is joint work with A. Debussche and P. Imkeller. (Received September 21, 2015)

1116-60-1700 **Louigi Addario-Berry*** (louigi.addario@mcgill.ca), Montreal, Quebec H3A2K6, Canada. *Most trees are short and fat.*

Let T be any Galton-Watson tree. Write vol(T) for the volume of T (the number of nodes), ht(T) for the height of T (the greatest distance of any node from the root) and wid(T) for the width of T (the greatest number of nodes at any level). We study the relation between vol(T), ht(T) and wid(T).

In the case when the offspring distribution $p = (p_i, i \geq 0)$ has mean one and finite variance, both ht(T) and wid(T) are typically of order $\mathrm{vol(T)}^{1/2}$, and have sub-Gaussian upper tails on this scale (A-B, Devroye and Janson, 2013). Heuristically, as the tail of the offspring distribution becomes heavier, the tree T becomes "shorter and bushier". We prove a collection of theorems which can be viewed as justifying this heuristic. In particular, we show that the random variable ht(T)/wid(T) always has sub-exponential tails, and the random variable ht(T)/vol}(T)$^{1/2}$ always has sub-Gaussian tails.
(Received September 21, 2015)

1116-60-1757 **Cameron Bruggeman*** (bruggeman@math.columbia.edu). *Dynamics of Large, Rank Based Models.*

We consider a model of n companies whose capitalizations evolve according to dynamics depending only on the companies rank in the market (so big companies behave differently than small ones). In the limit as n gets large, it is shown that the overall distribution of capital converges to a deterministic constant, and that the dynamics of a single firm can be written down explicitly, and studied independently of the rest of the market. (Received September 21, 2015)

1116-60-1832 **Timothy Chumley*** (tchumley@iastate.edu), **Scott Cook** and **Renato Feres**. *Random billiards and a thermally active Brownian particle.*

In this talk we present a model for the motion of a rigid body, whose boundary has a constant, non-uniform temperature distribution, as it interacts with a countable collection of point particles. The interaction mechanism is described by a Markov process which depends on the rigid-body-to-point-particle mass ratio as well as the temperature profile of the rigid body. Our main result is a diffusion approximation for the random process that describes the velocity of the rigid body. In particular, we make explicit the dependence of the coefficients of the approximating Ito process on certain microscopic features of the system such as mass ratio, temperature profile, and the parameters of the Poisson random measure that characterize the collection of point particles. Part of the aforementioned work is geometric in nature, dealing with the motion and collisions of rigid bodies in arbitrary dimensions, which requires the study of processes on Lie groups. If time permits, we describe a differential geometric elaboration of the model which arises by introducing mechanical constraints, holonomic and non-holonomic, on the motion of the rigid body. (Received September 21, 2015)

1116-60-1942 **Jean-Pierre Fouque** (fouque@pstat.ucsb.edu) and **Ruimeng Hu*** (hu@pstat.ucsb.edu). *Asymptotic Methods for Portfolio Optimization Problems with Stochastic Volatility.*

We revisit the portfolio optimization problems with slowly varying stochastic volatility, and using asymptotic methods with respect to volatility time scales. In the case of one factor and power utility, the problem is linearized and well-understood. However, the problem with general utility is still open. Here we address the case of general utility and prove asymptotically the optimality of the zeroth order strategy within a class of Markovian feedback control. (Received September 21, 2015)

1116-60-2017 **Hakima Bessaih*** (bessaih@uwyo.edu), 1000 E. University Avenue, Laramie, WY 82071. *Continuous Data Assimilation with Stochastically Noisy Data.*

We analyze the performance of a data-assimilation algorithm based on a linear feedback control when used with observational data that contains measurement errors. Our model problem consists of dynamics governed by the two-dimension incompressible Navier–Stokes equations, observational measurements given by finite volume elements or nodal points of the velocity field and measurement errors which are represented by stochastic noise. Under these assumptions, the data-assimilation algorithm consists of a system of stochastically forced Navier–Stokes equations. Our main result provides explicit conditions on the observation density (resolution) which guarantee explicit asymptotic bounds, as the time tends to infinity, on the error between the approximate solution and the actual solutions which is corresponding to these measurements, in terms of the variance of the noise in the measurements. (Received September 21, 2015)

1116-60-2051 **Jebessa B Mijena*** (jebessa.mijena@gcsu.edu), 2304 Sherry Cir. Apt. B7, Milledgeville, GA 31061. *Covariance structure of time-changed fractional Brownian motion.*

Fractional Brownian motion (fBm) is a centered self-similar Gaussian process with stationary increments, which depends on a parameter $H \in (0,1)$ called the Hurst index. Time - fractional order Fokker-Planck-Kolmogorov type equations driven by a time-changed fractional Brownian motion was given by Hahn, Kobayashi and Umarov. In modeling, the use of time-changed processes in often requires the knowledge of their second order properties such as covariance function. This paper provides the explicit expression for the covariance function for time-changed fractional Brownian motion and some examples are discussed, as well. (Received September 21, 2015)

1116-60-2138 **Don G Wilathgamuwa*** (don.wilathgamuwa@msubillings.edu), 1500 University Dr, Billings, MT 59101. *A comparison of stochastic differential equation models in population biology.* Preliminary report.

We discuss the existence and uniqueness results in stochastic differential equation models of the form $dX(t) = \mu(t, X(t), X(t-T))dt+\sigma(t, X(t), X(t-T))dB_t$, where B_t is either regular Brownian motion or fractional Brownian motion with Hurst parameter $H > 1/2$. Furthermore, we use analytical and numerical results to compare the models and their persistence times. (Received September 21, 2015)

1116-60-2326 **Ting Kam Leonard Wong*** (tkleonardwong@gmail.com). *Universal portfolios in stochastic portfolio theory.* Preliminary report.

Cover's universal portfolio is a wealth-weighted average of a family of portfolio strategies with the aim of achieving the growth rate of the best one. We study the distribution of wealth in the family from the point of view of stochastic portfolio theory. In particular, we consider the nonparametric family of functionally generated portfolios and study its universal portfolio, Glivenko-Cantelli property and large deviations. (Received September 22, 2015)

1116-60-2333 **Sean D. Lawley*** (lawley@math.utah.edu). *Randomly switching PDEs and SDEs.*

Motivated by diverse applications to biochemistry and physiology, we consider PDEs and SDEs with randomly switching boundary conditions. In this talk, I will describe the tools for analyzing these systems and highlight the surprising behavior that they can exhibit. Special attention will be given to establishing mathematical connections between these classes of stochastic processes. (Received September 22, 2015)

1116-60-2350 **John S. Wettlaufer*** (john.wettlaufer@yale.edu), Yale University, 210 Whitney Avenue, New Haven, CT 06520-8109. *Stochastic Perturbation Theory, Stochastic Dynamics and the Climatic Transitions of Arctic sea ice.*

We analyze the numerical and analytical solutions of a stochastic Arctic sea ice model over a wide range of external heat-fluxes, ΔF_0, which correspond to greenhouse gas forcing. The state variable describing the deterministic backbone of our model is the energy, $E(t)$, contained in the ice or the ocean and we choose the simplest form of multiplicative noise $\sigma E(t)\xi(t)$, where σ is the noise amplitude and $\xi(t)$ is the noise process. The case of constant additive noise we write as $\sigma\overline{E_S}\xi(t)$, in which $\overline{E_S}$ is the seasonally averaged value of the periodic deterministic steady-state solution $E_S(t)$, or the deterministic seasonal cycle. We then treat the case of seasonally-varying additive noise, $\sigma E_S(t)\xi(t)$, as well as two types of multiplicative noise that depend on the form of stochastic calculus (Itô or Stratonovich) used. The comparison of these four cases reveals the stochastic anatomy of the system over the entire range of the ΔF_0 from the perennial ice states to near the ice-free state. The analytical solutions derive from a perturbation theory developed for non autonomous systems and thereby allow a clear test of the numerical approach over a wide range of ΔF_0. (Received September 22, 2015)

1116-60-2393 **Jim Ferry*** (ferry@metsci.com), Metron, Inc., 1818 Library St., Suite 600, Reston, VA 20190. *Grounding Algorithms in Principled Mathematics: A Perspective from Industry.*

When mathematicians enter industry, how do they differ from engineers or computer scientists? This talk discusses algorithms, developed in more applied fields, that have subsequently been recast in more principled mathematical forms. We examine the problems of *data association* and *entity resolution*. For these problems efficient algorithms have been developed that select solutions from a combinatorially vast state space. With adequate testing and parameter selection, they perform well in practice. But algorithms cannot answer the natural question, "What is the posterior probability of the computed solution given the observed evidence?" We demonstrate the unreasonable effectiveness of providing these problems the rigorous, probabilistic basis necessary to answer this question. Among the benefits are (a) corrections to previously *ad hoc* formulas, (b) confidence estimates, and (c) the structural understanding necessary to generalize the algorithm. In particular, we show how the mathematically grounded approach allows us to generalize the data association problem from $\mathbb{R}^n$ to more general spaces. (Received September 22, 2015)

1116-60-2595 **Roger Lee*** (rogerlee@math.uchicago.edu) and **Ruming Wang**. *How Leverage Transforms a Volatility Skew: Asymptotics for Continuous and Jump Dynamics.*

To model leveraged investments such as leveraged ETFs, define the *β-leveraged product* on a positive semimartingale S to be the stochastic exponential of β times the stochastic logarithm of S.

In various asymptotic regimes, we relate rigorously the implied volatility surfaces of the β-leveraged product and the underlying S, via explicit shifting/scaling transformations. In particular, a family of regimes with *jump* risk admit a shift coefficient of $-3/2$, unlike the previously conjectured $+1/2$ shift. The $+1/2$, we prove, holds in a family of continuous stochastic volatility regimes at short expiry and at small volatility-of-volatility. (Received September 22, 2015)

1116-60-2698 **Alexander D Shkolnik*** (ads2@berkeley.edu) and **Kay Giesecke**. *A Simulation Measure Approach to Monte Carlo Methods in Credit Risk.*

Reduced-form models of name-by-name default timing are widely used to measure portfolio credit risk and to analyze securities exposed to a portfolio of names. Monte Carlo (MC) simulation is a common computational tool in such settings. We introduce a new change of measure perspective for MC simulation for default timing problems. The perspective provides the means of analyzing current methods and suggests a new MC algorithm which outperforms a widely used and standard technique. (Received September 22, 2015)

1116-60-2726 **David Eric Weisbart*** (dweisbart@gmail.com) and **Erik Bakken** (erikmaki@math.ntnu.no). *Discrete Time Random Walks and p-Adic Brownian Motion.*

The fundamental solutions to a large class of pseudo differential equations that generalize the formal analogy of the diffusion equation in the real setting to the p-adic setting give rise to p-adic Brownian motion. Although the pseudo differential equations appear only formally related to the diffusion equation, there are some striking similarities between real and p-adic Brownian motion. We show that a p-adic Brownian motion is a limit of a sequence of discrete time random walks on grids in $\mathbb{Q}_p$. These random walks are similar to the random walks that converge to Brownian motion in the real setting. (Received September 22, 2015)

1116-60-2729 **Eddy Kwessi*** (ekwessi@trinity.edu), 1 Trinity Place, San Antonio, TX 78212, and **Laila Assas**, **Brian Dennis** and **Saber Elaydi**. *Stochastic modified Beverton-Holt model with Allee effect II: the Cushing-Henson conjecture.*

We consider a single-species stochastic modified Beverton- Holt model with Allee effects caused by predator saturation. We prove that, under some conditions on the parameters, there ex- ists a Markov operator that is asymptotically stable. A stochas- tic version of the Cushing-Henson conjecture on attenuance and resonance is investigated. (Received September 22, 2015)

1116-60-2786 **William Ty Frazier*** (frazierw@goldmail.etsu.edu), 126 Hill Street, Gate City, VA 24251. *An Application of Symplectic Integration on an N-body, with evaluations of Hamiltonian Mechanics interpretations.*

Molecular Dynamics (MD) is the numerical simulation of a large system of interacting molecules, and one of the key components of an MD simulation is the numerical estimation of the solutions to a system of nonlinear differential equations. Such systems are very sensitive to discretization and round off error, and correspondingly, standard techniques such as Runge-Kutta methods can lead to poor results. However, MD systems are conservative, which means that we can use Hamiltonian mechanics and symplectic transformations (also known as canonical transformations) in analyzing and approximating solutions. This is standard in MD applications, leading to numerical techniques known as symplectic integrators, and often, these techniques are developed for well-understood Hamiltonian systems such as Hill's lunar equation. In this presentation, we explore how well symplectic techniques developed for well-understood systems (specifically, Hill's Lunar equation) address discretization errors in MD systems which fail for one or more reasons. (Received September 22, 2015)

1116-60-2887 **Alex Blocker** and **Xiao-Li Meng*** (meng@stat.harvard.edu), Department of Statistics, Science Center, 7th Floor, Harvard University, Cambridge, MA 02138. *The potential and perils of preprocessing: Building new foundations.*

Preprocessing forms an oft-neglected foundation for a wide range of statistical and scientific analyses. However, it is rife with subtleties and pitfalls. Decisions made in preprocessing constrain all later analyses and are typically irreversible. Hence, data analysis becomes a collaborative endeavor by all parties involved in data collection, preprocessing and curation, and downstream inference. Even if each party has done its best given the information and resources available to them, the final result may still fall short of the best possible in the traditional single-phase inference framework. The technologies driving "Big Data" explosion are subject to complex new forms of measurement error. Simultaneously, we are accumulating increasingly massive databases of scientific analyses. As a result, preprocessing has become more vital (and potentially more dangerous) than ever before. We propose a theoretical framework for the analysis of preprocessing under the banner of multiphase inference. We provide some initial theoretical foundations for this area, including distributed preprocessing, building upon previous work in multiple imputation. We motivate this foundation with two problems from biology and astrophysics, illustrating multiphase pitfalls and potential solutions. (Received September 22, 2015)

1116-60-2951 **dawit befekadu denu*** (dbd0005@auburn.edu), 351 east gleen avenue, apartment 11, auburn, AL 36830. *Stochastic Vector-Host Epidemic Model with direct transmission.*

In this talk I will discuss on the effect of introducing stochasticity into the deterministic vector-host epidemic model with direct transmission. First, I will discuss on the existence of a positive global solution and its stochastic boundedness. Then I will introduce a basic reproductive number Rs for the stochastic model and then investigate the dynamics of the stochastic epidemic model when Rs <1 and Rs >1. In particular, I will show that random effects may lead to extinction in the stochastic case while the deterministic model predicts persistence. Additionally, we provide conditions for the existence and uniqueness of the stationary distribution. Finally, numerical simulations are presented to illustrate some of the theoretical results. (Received September 23, 2015)

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1116-62-83 **Elvis Karanja Muchene*** (elviskaranja@gmail.com), Nairobi, Rift 20100. *Analysis of KCSE performance in Nakuru county: A generalized estimating equations approach.*

In the Kenyan education system, progression in tertiary education is dependent on a standardized national examination administered by the Kenya National Examinations Council(KNEC). The ministry of education guidelines stipulates that the pass mark for the university entry examination is C plus and above. Publicly available data on Kenya Certificate of Secondary Education(KCSE)performance in Kenya for the years 2006-2010 was analyzed.Differences between boys only, girls only, or mixed schools were assessed.A gee marginal model was applied using the SAS procedure PROC GENMOD.GEE goodness of fit statistics (QIC) was used to select best mean model and best working correlation structure for the study.A model with exchangeable correlation.Results indicated that there was a significant difference between the different school types in their candidates' probability of attaining the stipulated minimum university entry grade.boys' only schools had the highest probability,followed by girls' only schools and finally mixed schools.Contrasts indicated that boys in boys' only schools had a higher success rate than boys in mixed schools. Girls in girls' only schools had a higher success rate than girls in mixed schools while boys in mixed schools performed better than girls in mixed schools. (Received July 17, 2015)

1116-62-108 **Iliana De La Cruz**, **Taylor Spino**, **Melissa Stadt*** (stadtm@u.washington.edu) and **Catherine Sullivan**. *Detecting gene-gene interactions that underlie cancer using the R package algstat.* Preliminary report.

Interactions between single nucleotide polymorphisms (SNPs) and complex diseases have been an important topic throughout epidemiological studies. Previous genome-wide-association studies have mostly focused on gene variables at a single locus. In our project, we perform a focused candidate gene study to test the interaction of multiple SNPs with the risk of different types of cancer. Using the R package algstat, developed by Kahle, Garcia-Puente, and Yoshida, we developed an algorithm which can test for independence between several variables and the disease. We applied our methods to the study of gene-gene interaction on cancer data obtained from the European case-control study Gen-Air.

We were able to find strong evidence to reject independence of many triplet combinations of SNPs with the disease. These results are relevant to the general field of epidemiology due to the strong association found between the variables and the disease. Outside of the study of SNP-cancer association, this algorithm can be easily adjusted to perform general gene interaction studies using arbitrary log-linear statistical models.
(Received July 26, 2015)

1116-62-232 **Ranil Weerackoon*** (raniljw@yahoo.com) and **Michelle Hartono** (misschelle8@gmail.com). *Development of Clustering Algorithms for Ensemble Weather Forecasts.*

Large amounts of data are required to predict future atmospheric and weather conditions. Ensemble prediction techniques can be utilized to provide objective estimations by generating a range of weather predictions. Since ensemble forecasts contain data in 4-dimensional fields, we perform cluster analysis to group similar ensembles together while differentiating between different ensemble members. However, various cluster analyses produce different results and thus it can be difficult to ascertain which members are meant to be grouped together. We propose various techniques for measuring the robustness of the clustering methods by calculating the similarity that exists between the different cluster analyses to best determine how to cluster the ensembles. We also suggest ways for measuring the accuracy the ensembles maintain over time in order to ascertain the validity of a weather forecast and we conclude that better initial conditions regarding the atmosphere do not necessarily yield better predictions. (Received August 15, 2015)

1116-62-285 **Liyu Xia*** (xialiyu1995@gmail.com), 5050 S. Lake Shore Dr., Apt. S1604, Chicago, IL 60615, **Mary Marie Kemp** (marymariekemp@gmail.com), 362 Malden Turnpike, Saugerties, NY 12477, **Md Afzal Hossain**, 17049 cedarcroft Road, 3c, jamaica, NY 11432, and **Alexandra Mary Howes** (howesalexandra@gmail.com), 13 Warden Road, Minehead, Somerset TA24 5DS, United Kingdom. *Conversations: Customer Service through Twitter Platform.*

The study concentrated on the effectiveness of customer service between individuals and organizations on Twitter, through conversations built from 5M raw Tweets, where comparisons between industries were also drawn. We use feature extraction algorithms, such as super CWC/LCC, to identify keywords in the Tweet bodies of the first customer Tweets in conversations. We extract customer service related Tweets based on the keywords. And keyword analysis of the final Tweets in conversations enabled categorization of conversations into categories, including resolved and unresolved conversations. Differences in conversation features based on categories were explored, with particular emphasis on the Travel Industry. Logistic regression model was employed for identifying factors that influence the binary classification of resolved and unresolved conversations. Ultimately the results of this project should enable Twitter to develop features and capabilities to improve the way customer service issues are dealt with on Twitter. (Received August 21, 2015)

1116-62-497 **Paul B. Deignan*** (deignan@ada-vs.com), 3904 Shumard Oak Drive, Plano, TX. *Course Management of Engineering Statistics for Student Learning and Instructor Survival.*

Student evaluations are commonly used as management tools by administration to make inferences about instructor "success". In many colleges and universities, instructor success is equivalent to having high student evaluations. Instructor methods to drive high evaluations are well known, but inextricably at odds with student learning.

On the other hand, student evaluations are also used to infer instructor "failure". Since the assessment by administrators that an instructor has "failed" would be catastrophic, the space for the maximization of student learning is strictly bounded. Thus a criterion for optimization of course management might be the adoption of a strategy for maximizing student learning while avoiding even a temporary assessment of instructor "failure".

This presentation takes a systemic view of the problem and presents several tools and imperatives that have been demonstrated to be practical if an instructor is tempted to pursue the strategy of maximizing student learning while preserving his professional survival at the university. (Received September 04, 2015)

1116-62-850 **Davit Khachatryan*** (dkhachatryan@babson.edu), 247 Bowen st, Apt 8, Providence, RI 02906, and **Nathan Karst**. *Data Analytics for Non-STEM Majors (in the Age of Big Data).*

Initiatives promoting STEM majors among undergraduates are only one compelling way to close the gap between the quantitative acumen demanded by employers and the skills our students have at graduation. In this talk we present a complementary set of pedagogical approaches and course materials that we have developed and implemented in class to impart quantitative skills in the context of big data to both undergraduates and professional students in non-STEM fields. On the technical side these include techniques to make the delivery of statistical methods accessible to students with a variety of backgrounds, to involve students in pre-processing of data that are more complex (in terms of volume, variety, and/or velocity) compared to what appears in traditional textbook examples, and to familiarize students with statistical programming tools necessary for working with such data. Related to the non-technical skills, we will stress the importance of promoting a culture in class that encourages iteration through a "fail fast, fail cheap" framework, and requiring students to be comfortable with communicating the product of their analytical work not only in writing but also through effective verbal communication. (Received September 14, 2015)

1116-62-1121 **David J Marchette*** (dmarchette@gmail.com). *Spectral graph methods for inference on attributed graphs.* Preliminary report.

This talk investigates some spectral graph methodologies for fusing graph and covariate information. In particular, consider a graph G for which each vertex i has an associated attribute X_i. We wish to perform joint inference on G and X. Several methods utilizing spectral graph algorithms have been proposed, and we will describe these and illustrate them on several inference tasks. We will discuss some preliminary work on related methods, and

some attempts to place the different methodologies into a single framework. The algorithms discussed scale well to large sparse graphs, and we will illustrate them on graphs on the order of 10^6 vertices. (Received September 17, 2015)

1116-62-1307 **Mitra Lal Devkota*** (mdevkota@shawnee.edu), Department of Mathematical Sciences, 940 Second Street, Portsmouth, OH 45662, and **Gary D Hatfield** and **Rajesh Chintala**. *Spatial modeling of crop residue yield potential for the north central region of the USA.*

In this research work, Spatial Modeling Techniques applied to crop residue yield potential were discussed. In addition to the traditional regression method; various types of spatial regression techniques were used. Comparative studies of these modeling techniques were carried out using a real world data set and an artificially generated spatial data set. The results showed that the Geographically Weighted Regression model was more suitable for the purpose of incorporating the spatial autocorrelation of the regression residuals. .... (Received September 18, 2015)

1116-62-1317 **Xiao-Li Meng*** (meng@stat.harvard.edu). *Statistical Paradises and Paradoxes in Big Data.*

Statisticians are increasingly posed with thought-provoking and often paradoxical questions, challenging our qualifications for entering the statistical paradises created by Big Data. Questions addressed in this talk include 1) Which one should I trust: a 1% survey with 60% response rate or a self-reported administrative dataset covering 80% of the population? 2) With all the big data, is sampling or randomization still relevant? 3) Personalized treatments—that sounds heavenly, but where on earth did they find the right guinea pig for me? The proper responses are respectively 1) "It depends!," because we need *data-quality indexes*, not merely quantitative sizes, to determine; 2) "Absolutely!," and indeed Big Data has inspired methods such as *counterbalancing sampling* to combat inherent selection bias in big data; and 3) "They didn't!," but the question has led to a *multi-resolution framework* for studying statistical evidence for predicting individual outcomes. All proposals highlight the need, as we get deeper into this era of Big Data, to reaffirm some time-honored statistical themes (e.g., bias-variance trade-off), and to remodel some others (e.g., approximating individuals from proxy populations verses inferring populations from samples). (Received September 18, 2015)

1116-62-1356 **Sami Cheong*** (cheongs@uwm.edu), 3200 N Cramer st, Milwaukee, WI 53211. *Estimating parameters for the spatial Ornstein-Uhlenbeck process with missing observations.* Preliminary report.

The Ornstein-Uhlenbeck (OU) process can be used to model spatially dependent observations made on a lattice sampling grid, such as data from population epidemics, weather, and agriculture. When complete observations are available, the OU covariance structure has a tridiagonal inverse, which is computationally efficient. However, this is not necessary the case when some observations are missing. In this work, we study the covariance structure of the OU process under different types of missing observations, and construct approximated likelihood functions to estimate its parameters. Through simulation experiments, we compute and compare the estimated parameters obtained from different estimation schemes. Our goal is then to study the asymptotic properties of these estimators and compare them with the maximum likelihood estimator under complete observations. (Received September 18, 2015)

1116-62-1449 **Talithia D. Williams*** (twilliams@hmc.edu). *Show me the data: Using data-enhanced classroom experiences to engage student learning.*

Big data analytics is often used to describe the process of analyzing large data sets to discover previously unknown patterns and gain new insights. Mathematical experiences that incorporate real world data within fundamental pedagogy condition and solidify student understanding, while improving student retention of course material. Situations in which students collect and interpret their own data and those in which they explore online databases can easily be incorporated into both introductory and advanced mathematics and statistics courses. This talk will provide pedagogical approaches to incorporating big data analytics in the classroom. (Received September 19, 2015)

1116-62-1663 **Paul Raff*** (paraff@microsoft.com), 7921 146th Ave NE, Redmond, WA 98052. *Preparing Mathematicians for Big Data Careers: An Industry's Point of View.*

While the Big Data industry is growing rapidly, it is still in its early stages as it relates to a common understanding and identification of the complete skillset needed to be a top-notch data scientist in the industry. While being a mathematics major provides a great foundation for what's required to be a good data scientist, we discuss what else is necessary. These include the following:

- Increased Emphasis on Scientific Computing
- Connections to Industry
- Realistic Big Data Analysis Exercises
- Data Science, not Data Engineering
- A Nudge Towards Graduate School

Given that there is still a large amount of unfulfilled demand for data scientists in the industry, there is a great opportunity for math departments to better train those students that are aiming for Big Data careers. This talk will provide details from the perspective of a 20-person (and growing) team of data scientists that has been steadily hiring for the past several years. (Received September 21, 2015)

1116-62-1943 **Sara LaPlante*** (sara.cox.laplante@gmail.com), **Jessica Mao** (jmao@smith.edu) and **Madison Laethem** (mlaethem@smith.edu). *Predicting Arrest from NYPD Stop, Question and Frisk Data.* Preliminary report.

In 2014, the New York City Police Department recorded 46235 stops of pedestrians that comprise the Stop, Question and Frisk database. The Stop, Question and Frisk database contains 111 variables, such as race, age, gender, whether a stop was preceded by a radio call, and others. This research investigates whether a collection of variables from the database can predict whether a stop resulted in an arrest. Using a training set of the 2014 database, we develop a logistic regression model to determine which variables in the dataset best predict an arrest. Testing the model on the remaining cases determines how well this model fits the data. Such a model highlights the common characteristics that pedestrians arrested during 2014 share across the database. (Received September 22, 2015)

1116-62-2140 **Lily S. Khadjavi*** (lkhadjavi@lmu.edu) and **David Greenberg** (dg4@nyu.edu). *The Fourth Amendment, race, and policing in Los Angeles.*

Although racial profiling is not legal, Gallup polls indicate that most Americans believe it is a regular police practice, a perception so common that the practice of stopping a driver of color has been nicknamed by some as a DWB, or "Driving while black (or brown)." Data which was collected by the Los Angeles Police Department under a Consent Decree with the U.S. Department of Justice provide a prime opportunity to better understand police practice, well beyond counting who is stopped. For example, when a driver is pulled over, the stop may include a frisk or search but only if certain legal criteria are satisfied. Who is searched, under what basis? Are particular drivers asked to consent to a search, thereby waiving their Fourth Amendment rights? Who declines? This statistical analysis will not only illuminate racial and ethnic disparities in stops, frisks, searches, and outcomes, but in fact point to concrete policy recommendations. (Received September 22, 2015)

1116-62-2183 **Deborah Nolan*** (nolan@stat.berkeley.edu), Department of Statistics, 367 Evans Hall MC 3860, Berkeley, CA 94720-3860. *Statistical Thinking in a Data Science Course.*

The intuition and experience needed for sound statistics practice can be hard to learn, and a course that combines computing, statistics, and working with data offers an excellent learning environment in this regard. An integrated approach to data science creates opportunities to reinforce statistical thinking skills throughout the full data analysis cycle, from data acquisition and cleaning to data organization and analysis to communicating results. As a result, students gain the ability to express themselves through computations, actively engage in statistical problem solving, and keep abreast of new technologies as they evolve. This talk will describe approaches and provide examples for teaching data science in this integrated way. (Received September 22, 2015)

1116-62-2370 **Leslie New***, 14204 Salmon Creek Avenue, Vancouver, WA 98686, and **Trish Miller**, **Adam Duerr**, **Melissa Braham** and **Todd Katzner**. *Modelling Remote Sensing Data in Ecology.* Preliminary report.

The movement of animals is of interest to researchers in ecology. Remotely tracking animal movements is a frequent practice that has yielded a wealth of knowledge. The development and deployment of the required technology has also increased significantly over time. Initially, analyses of data collected via this technology had two primary focuses: 1) the estimation of error around location measurements and 2) the interpolation of potential movement pathways, since the time between measurements could be large given the speed at which an animal is capable of travelling. As technology has improved, both the error around location measurements and the time period between measurements have decreased for to the point where these sources of error are non-existent for some species. For example, deployment of remote sensing devices on golden eagles (Aquila chrysaetos) collected data at 30 sec intervals over the course of a day. This included not only location data, but also information on factors such as altitude, velocity, acceleration and environmental covariates. As a result, the research question shifts from where the birds were flying to their behavior and use of a landscape. This talk will discuss the potential of different statistical approaches to answer these ecological questions. (Received September 22, 2015)

1116-62-2468 **Patrick J Wolfe*** (p.wolfe@ucl.ac.uk). *Big Network Data.*

How do we draw sound and defensible data-analytic conclusions from networks? This question has recently risen to the forefront of mathematical statistics, and it represents a fundamental challenge for data science. In this talk I will describe new large-sample theory that helps us to view and interpret networks as statistical data objects, along with the transformation of this theory into new statistical methods to model and draw inferences from network data in the real world. The insights that result from connecting theory to practice also feed back into pure mathematics and theoretical computer science, prompting new questions at the interface of combinatorics, analysis, probability, and algorithms. (Received September 22, 2015)

1116-62-2510 **Katherine M. Kinnaird*** (kkinnair@macalester.edu), Macalester College, Department of Mathematics, Statistics, and, Computer Science, Saint Paul, MN 55105. *Structure-Based Comparisons for Sequential Data.* Preliminary report.

We present ***aligned hierarchies***, a low-dimensional representation for sequential data streams. The aligned hierarchies encode all hierarchical decompositions of repeated elements from a high-dimensional and noisy sequential data stream in one object. These aligned hierarchies can be embedded into a classification space with a natural notion of distance. We motivate our discussion through the lens of Music Information Retrieval (MIR), constructing aligned hierarchies by finding, encoding, and synthesizing all repeated structure present in a song. For a data set of digitized scores, we conducted experiments addressing the *fingerprint task*, a song comparison task in MIR, that achieved perfect precision-recall values and provide a proof of concept for the aligned hierarchies.

We also introduce *aligned sub-hierarchies* and *aligned sub-decompositions*. Both derived from the aligned hierarchies, these structure based representations for songs can be embedded into classification spaces and can address additional MIR tasks. We compare properties of the aligned hierarchies, aligned sub-hierarchies, and the aligned sub-decompositions. (Received September 23, 2015)

1116-62-2542 **C R Donovan*** (crd2@st-andrews.ac.uk), CREEM, The Observatory, Buchanan Gardens, St Andrews, KY169LZ, United Kingdom, and **M L Mackenzie**, **A Webb** and **N B Erichson**. *Modelling spatio-temporal animal distributions using high-definition video surveys.*

High-definition aerial surveying is becoming an increasingly popular means to survey animal populations, particularly in the context of Environmental Impact Assessments. The data gathered naturally avoids some of the biases found in other surveying methods, but still presents substantive modelling challenges, such as extremely large data volumes. We present here a) work on efficient object identification in video using randomised Dynamic Mode Decomposition and b) modelling approaches for density surface estimation using spatially adaptive smoothers, whilst accounting inferentially for temporal autocorrelation. (Received September 22, 2015)

1116-62-2646 **Regina Y Liu*** (rliu@stat.rutgers.edu). *Statistical Fusion Learning: Combining Inferences from Multiple Sources for More Powerful Findings.*

Inferences from multiple databases or studies can often be fused together to yield a more powerful overall inference than individual studies alone. Fusion learning refers to the development of such effective approaches to synergize learnings from different sources. Effective fusion learning is particularly important in this era of data explosion, with the trove of data nowadays collected routinely from diverse sources in all domains and at all time.

Using the tracking of aircraft landing performance as an illustrative example, we present a powerful fusion learning approach. Specifically, we apply the concepts of confidence distribution (CD) and data depth to develop a new nonparametric approach for combining inferences from multiple studies for a common hypothesis. We discuss several new approaches in fusion learning in the context of combining test results from independent studies or joint modeling of data from possibly heterogeneous sources. These approaches are completely data driven and have several desirable properties. Examples of simulation data and aircraft landing data are presented.

This is joint work with Minge Xie, Department of Statistics, Rutgers University. (Received September 22, 2015)

1116-62-2723 **Eric Ruggieri*** (eruggier@holycross.edu), 1 College Street, Worcester, MA 01610. *A Pruned Recursive Solution to the Multiple Change Point Problem.*

Long time series are often heterogeneous in nature. As such, the most appropriate model is one whose parameters are allowed to change through time. The exponential number of solutions to the multiple change point problem requires an efficient algorithm in order to be computationally feasible. Exact Bayesian solutions have at best quadratic complexity in the number of observations, which can still be too slow for very large data sets. Here, a pruned dynamic programming algorithm is introduced to fit a piecewise regression model to a data set with unknown break points. The algorithm removes unessential calculations, reducing the complexity of the most time consuming step of the algorithm from quadratic in the number of observations to quadratic in the average distance between change points. Analysis of two real data sets shows that this approximate algorithm produces a nearly identical representation of the joint posterior distribution on the locations of the change points, but with a significantly faster run time than its exact counterpart. (Received September 22, 2015)

1116-62-2731 **Michael E Ramsey*** (mer19@geneseo.edu) and **Jacob A Goldberg**. *Typical Meteorological Year versus Actual Meteorological Year Weather Data: How modern data collection improves previous methods.*

Typical Meteorological Year (TMY) data files are intended to be representative of actual weather by carefully piecing together historical weather data to create a "typical" year. These TMY files are employed by those working in the field of building technology and clean energy to gauge how much energy a building will use. This process is currently the standard for industry; however the use of actual weather data might produce more accurate predictions. Actual weather data is increasingly easy to come by, with many stations offering an abundance of data for free or for little cost.

We utilize TMY and Actual Meteorological Year (AMY) data along with the Department of Energy's EnergyPlus Model to estimate heating and cooling loads of a residential home in Rochester, NY. We perform statistical analysis to demonstrate that there are striking differences in the predicted energy consumption. In response to a request from our industry partner, Resource Refocus, LLC, we also give ideas for how a more detailed portfolio of energy use might look now that computational power is much larger than it was at the inception of energy modeling. (Received September 22, 2015)

1116-62-2814 **Shannon Stock*** (sstock@holycross.edu). *Two-Sample Tests for Latent Recurrent Events: Application to Multiple Sclerosis EDSS Scores.*

The Expanded Disability Status Scale (EDSS) is a widely used measure of neurologic impairment and disease progression in patients with multiple sclerosis. However, since patients may experience small exacerbations of their disease severity that eventually subside, there is uncertainty whether an observed increase in EDSS scores is due to an actual jump in the disease process. Therefore, analyses involving such data require modeling unobservable recurrent events. In this paper, we introduce a two-sample test that accommodates latent recurrent events by weighting changes in an observable outcome measurement by the probability one or more events occurred since the previous time of measurement. We obtain estimates of these probabilities using an Expectation-Maximization algorithm. The utility of this method is demonstrated using simulation studies and the analysis of a motivating data set involving a cohort of patients with recent-onset multiple sclerosis. (Received September 22, 2015)

1116-62-2842 **Chaoran Wei*** (cwei02@email.wm.edu), 1400 Middle Street, Williamsburg, VA 23185, and **Nadia Aly**, **Daniel McGibney** and **Daniel Vasiliu**. *Image Classification of Plankton Data Using Convolutional Neural Networks.*

Plankton are very important for the balance of the food cycle in our ecosystem. It's critical role make it necessary to monitor its population. Nevertheless, the traditional ways to monitor the population by detecting the plankton images taken by underwater camera with human eyes are both inefficient and error-prone. In this presentation, we present an effective machine learning algorithm to automate the process of monitoring the plankton population by classifying images of different plankton.

Our methodology adopts the typical deep learning pipeline. We use several image transformation techniques to artificially increase the amount of image data. Also, we use Restricted Boltzmann Machine to pre-train the original data. Next, Convolutional Neural Networks (CNN) is adopted to train the image data. Finally, we attempt several different ensemble learning schemes to combine different models and increase the predicting power with hyper-parameters chosen by cross-validation. By carefully extracting information with a variety of unsupervised deep learning algorithms and semi-supervised learning algorithms, we create a hybrid model with strong predictive power and significantly lower misclassification rate than popular algorithms such as random forest. (Received September 22, 2015)

65 ► Numerical analysis

1116-65-26 **Jie Shen** (shen7@purdue.edu) and **Yingwei Wang*** (wang838@purdue.edu), Department of Mathematics, Purdue University, West Lafayette, IN 47907, and **Jianlin Xia** (xiaj@math.purdue.edu). *Fast Structured Spectral Methods.*

Spectral methods have been used extensively in numerical approximation of partial differential equations due to their bigger accuracy when compared to Finite Differences (FD) and Finite Elements (FE) methods. However, FD and FE usually lead to a sparse linear system while spectral methods often suffer from the huge computational complexity caused by dense matrices. Fortunately, although the matrices arising from spectral methods are dense, they enjoy a hidden nice property, named *low-rank structure*, which means their off-diagonal blocks have small (and even bounded) numerical ranks for a given tolerance. This property could be exploited to dramatically reduce the computational cost and give birth to fast solvers with nearly optimal complexity and memory, thanks to the hierarchically semiseparable (HSS) representation for structured matrices.

The *Fast Structured Spectral Methods* presented here include fast structured Jacobi transforms, fast structured spectral Gelerkin methods for differential equations with variable coefficients and fast structured spectral collocation methods. (Received June 02, 2015)

1116-65-43 **Qin Sheng*** (qin_sheng@baylor.edu), Department of Mathematics, Baylor University, One Bear Place, Waco, TX 76798-7328. *The Legacy of ADI and LOD Methods and Their Applications for Solving Highly Oscillatory Wave Equations.* Preliminary report.

This talk concerns the numerical solution of partial differential equations. We are particularly interested in finite difference method based splitting methods. The ADI and LOD approaches are two of them with extraordinary features in structure simplicity, computational efficiency and flexibility in applications. They look similar, but are fundamentally different. Naturally, they lead to different ways of operations, and offer different strategies in computational realizations. This talk will provide an insight into the glorious history of these numerical methods, and discuss some of their latest reinforcements including applications for solving highly oscillatory wave equations. (Received June 17, 2015)

1116-65-58 **Necibe Tuncer** and **Trang Le*** (trang-le@utulsa.edu). *Structural Identifiability Issues of Epidemic Models.*

Structural identifiability in epidemic models is a crucial issue because unreliable estimates of parameters could result in inaccurate estimates of important epidemiological values such as the basic reproduction number. We performed structural identifiability analysis on various epidemic models using a differential algebra approach to investigate the characteristics of these models. It is necessary to note that a model which is structurally identifiable may not be practically so. Furthermore, we carried out practical identifiability analysis on these models using Monte Carlo simulations and sensitivity based analysis. (Received July 07, 2015)

1116-65-180 **Arezou Ghesmati*** (aghesmati@math.tamu.edu), 1201 Harvey Rd, Apt #80, College Station, TX 77840, **Bruno Turcksin** (turcksin@math.tamu.edu), Department of Mathematics, Mailstop 3368, Texas A&M University, Bloc. 507E, College Station, TX 77843-3368, and **Wolfgang Bangerth** (bangerth@math.tamu.edu), Department of Mathematics, Mailstop 3368, Texas A&M University, College Station, TX 77843-3368. *A Residual Based A Posteriori Error Estimation in hp-adaptive FEM for the Stokes Equations.*

In this research we derive a residual based a posteriori error estimation for the hp- Adaptive Finite Element Method (hp-AFEM) for the steady state Stokes problem which describe slow motion of an incompressible fluid. The error estimator is obtained by extending the idea of a posteriori error estimator for the classical h-version of AFEM. The reliability and also the efficiency of the introduced error estimator are established. Moreover, we have proved that our hp-adaptive FEM method is a contraction both in energy error and also in quasi-error. The numerical experiments show the performance of the introduced adaptive hp-FEM algorithm using the proposed a posteriori error estimator. (Received August 11, 2015)

1116-65-245 **Chunmei Wang*** (cwang462@math.gatech.edu), Skiles building, 686 Cherry St, NW, Atlanta, GA 30332. *A Locking-Free Weak Galerkin Finite Element Method for Elasticity Problems in the Primal Formulation.* Preliminary report.

We present an arbitrary order locking-free numerical scheme for linear elasticity on general polygonal/polyhedral partitions by using weak Galerkin (WG) finite element methods. Like other WG methods, the key idea for the linear elasticity is to introduce discrete weak strain and stress tensors which are defined and computed by solving inexpensive local problems on each element. Such local problems are derived from weak formulations of the corresponding differential operators through integration by parts. Locking-free error estimates of optimal order are derived in a discrete H^1-norm and the usual L^2-norm for the approximate displacement when the exact solution is smooth. Numerical results are presented to demonstrate the efficiency, accuracy, and the locking-free property of the weak Galerkin finite element method. (Received August 17, 2015)

1116-65-251 **J. B. Collins*** (jcollins@wtamu.edu), West Texas A&M University, WT Box 60787, Canyon, TX 79016, and **Don Estep** and **Simon Tavener**. *A posteriori error estimation for a cut cell method with uncertain interface location.*

We study a simple diffusive process in which the diffusivity is discontinuous across an interface interior to the domain. In many situations, the location of the interface is measured at a small number of locations and these measurements contain error. Thus the location of the interface and the solution itself are subject to uncertainty. A Monte Carlo approach is employed which requires solving a large number of sample problems, each with a different interface location. An efficient adjoint-based a posteriori technique is used to estimate the error in a quantity of interest for each sample problem. This error has a component due to the numerical approximation of the diffusive process and a component arising from the uncertainty in the interface location. A recognition of these separate sources of error is necessary in order to construct effective adaptivity strategies. (Received August 18, 2015)

1116-65-272 **Wen Wang*** (wen.wang@bellevuecollege.edu), 3000 Landerholm Cir, Bellevue, WA 98007, **Hong-Ming Yin** (hyin@wsu.edu), Department of Mathematics, Washington State University, Pullman, WA 99164, and **Wenhan Wang**, One Microsfot Way, Redmond, WA 98052. *Numerical Simulation for a Nonlinear American Option-Pricing Model.* Preliminary report.

In this talk I will discuss recent result about an American option-pricing model with a nonlinear volatility. Various numerical methods are presented. (Received August 19, 2015)

1116-65-321 **Md. Shafiqul Islam*** (mdshafiqul@du.ac.bd), Department of Applied Mathematics, AF Mujibur Rahman Ganit Bhavan, Ramna, Dhaka, 1000, Bangladesh. *Numerical solutions of higher order eigenvalue problems.*

The aim of this research article is to compute the eigenvalues of high order linear Sturm-Liouville problems (SLP) numerically by the well known Galerkin weighted residual method. In the approximated Galerkin method Bernstein polynomials are used as the trial functions. Imposing boundary conditions to the higher order eigenproblems is quite complicated which comprise of derivatives of order more than one. Since higher order problems without reducing the order of the equations and all kind of derivative boundary conditions are imposed directly in the weak form of the integrand, so a rigorous matrix formulation for eighth order SLP is developed. This formulation can be applied for any high even order (e.g., fourth, sixth, tenth, etc.) SLP. Details, the efficiency and the implementation of the proposed method, are thus described by considering fourth, sixth, eighth and tenth order linear SLP as numerical examples. The numerical results, investigated in this proposed method, are compared with those obtained, by other numerical and analytical techniques, available in the literature. Finally, the computational eigenvalues are found with a great accuracy. (Received August 25, 2015)

1116-65-330 **Hongtao Fan** and **Xinyun Zhu***, 5200 Arbor CT, Odessa, TX 79762. *A generalized relaxed positive-definite and skew-Hermitian splitting preconditioner for non-Hermitian saddle point problems.* Preliminary report.

For non-Hermitian saddle point problems with the non-Hermitian positive definite (1,1)-block, Zhang et al. (2014) presented a relaxed positive-definite and skew-Hermitian splitting (RPSS) preconditioner to accelerate the convergence rates of the Krylov subspace iteration methods such as GMRES. In this paper, the convergence property of the GRPSS iteration method is proved and a generalized RPSS (GRPSS) preconditioner is proposed. The GRPSS preconditioner is much closer to the coefficient matrix than the RPSS preconditioner in certain norm, which straightforwardly results in an GRPSS iteration method. We employ the GRPSS preconditioner to accelerate some Krylov subspace methods (like GMRES). The spectral distribution of the preconditioned matrix is described and an upper bound of the degree of the minimal polynomial of the preconditioned matrix is obtained. Finally, numerical experiments of a model Navier–Stokes equation are presented to illustrate the efficiency of the GRPSS preconditioner. (Received August 25, 2015)

1116-65-384 **Xu Zhang*** (xuzhang@purdue.edu). *Nonconforming Immersed Finite Element Methods for Interface Problems.*

Immersed finite element (IFE) methods are a class of finite element methods for solving interface problems whose solution mesh is not required to align with interface. Classic IFE functions are constructed from conforming

Lagrange finite elements. Conforming IFE methods are usually less accurate around the interface than the rest of simulation domain due to the discontinuity of approximation functions across element boundaries. Recently, we develop a class of new IFE functions based on nonconforming finite element functions on rectangular meshes. A different approach to impose the continuity greatly reduce the impact of the discontinuity across the elementary boundary; hence, the accuracy around interface is improved significantly. We will show some new and fundamental inequalities that lead to the optimal error estimates. Numerical Experiments will be presented to demonstrate features of new IFE methods. (Received August 29, 2015)

1116-65-481 **Andrei Bourchtein*** (bourchtein@gmail.com), Rua Gomes Carneiro 1, Campus Porto da UFPEL, Pelotas, 96010-610, Brazil, and **Ludmila Bourchtein**. *A time-splitting scheme for non-hydrostatic atmospheric models.*

The non-hydrostatic atmospheric models contain solutions originated by various physical sources such as the atmosphere compressibility, deformation effects, the gravity force, and also by the non-inertial forces related to the rotated reference frame. These phenomena have different characteristics of the propagation speed and energy contribution. The acoustic waves are the fastest and have negligible energy contribution, the inertial processes are the slowest and the most valuable in energy spectrum, and the gravity waves occupy the intermediate position.

In this study, we develop a semi-implicit time-splitting scheme for the non-hydrostatic atmospheric model. The acoustic and gravity waves are approximated implicitly, while slow inertial terms are treated explicitly. At each time step, the implicit part of approximation is reduced to three-dimensional elliptic equations solved by multigrid method. Stability analysis of the scheme shows that the time step is restricted only by the maximum velocity of advection. The performed numerical experiments show computational efficiency of the designed scheme and accuracy of the predicted atmospheric fields. (Received September 03, 2015)

1116-65-562 **Jerome Detemple**, **Matthew Lorig**, **Marcel Rindisbacher**, **Stephan Sturm** and **Liangliang Zhang*** (mathinheart@gmail.com), 533 Cambridge Street, Unit 110, Allston, MA 02134. *Analytical Expansion to Forward-Backward Stochastic Differential Equations.*

In this paper, we document a powerful converging asymptotic expansion method in solving a general non-linear uncoupled forward-backward stochastic differential equation (FBSDE). As numerical illustration, an exponential OU stochastic volatility option pricing model is considered to show the effectiveness and accuracy of the method. To the best of our knowledge, our scheme is among the very few methods in the literature that are converging. The complexity of the solution increases not exponentially but according to a power function with the increase in the dimensionality of the problem. (Received September 07, 2015)

1116-65-648 **Vira Babenko*** (vera.babenko@gmail.com), The University of Utah, Department of Mathematics, Rm 233 155 S 1400 E, Salt Lake City, UT 84112. *Optimization and Numerical Analysis of Set-Valued or Fuzzy-Valued functions - A Unified Approach and Applications.*

A wide variety of questions from social, economic, physical, and biological sciences can be formulated using functions with values that are fuzzy sets or sets in finite or infinite dimensional spaces. Set-valued and fuzzy-valued functions attract attention of many researchers and allow them to look at numerous problems from a new point of view and provide them with new tools, ideas and results. In this talk we consider a generalized concept of such functions, that of functions with values in L-spaces. This class of functions encompasses set-valued and fuzzy-valued functions as special cases which allows us to investigate them from a common point of view. We will discuss several problems of Approximation Theory, Optimization and Numerical Analysis for functions with values in L-spaces. In particular, we will present numerical methods for solving Fredholm and Volterra integral equations for such functions. (Received September 10, 2015)

1116-65-749 **Joseph Eichholz*** (eichholz@rose-hulman.edu). *A New Method for Solving the Obstacle Problem.*

The obstacle problem is a standard example of a variational inequality of the first kind. Variational inequalities naturally arise in a wide range of applications, for example, elastoplasticity, contact mechanics, heat control problems, and options pricing problems in finance. Due to the inequality in the formulation of the obstacle problem, the standard quadratic finite element method only achieves $\mathcal{O}(N^{-3/4+\epsilon})$ convergence, where N is the number of degrees of freedom and $\epsilon > 0$ arbitrary. We introduce a two-grid algorithm for solving the obstacle problem in which we solve the obstacle problem, capture the free boundary, refine the mesh, and solve the problem on a new mesh. We demonstrate that the method has has nearly optimal convergence order $\mathcal{O}(N^{-1+\epsilon})$. Numerical evidence is provided indicating superior performance to standard finite element methods. (Received September 11, 2015)

1116-65-785 **Kyle T Mandli*** (kyle.mandli@columbia.edu). *Developments and Applications of a Multilayer Shallow Water Model.* Preliminary report.

The multilayer shallow water equations have often been used to model stratified fluids, in particular the ocean. Unfortunately even for two-layers the system is a stiff set of PDEs owing to the disparate wave-speeds that are present. In most ocean modeling this is avoided by splitting the barotropic and baroclinic waves apart and solving them separately. This has the drawback that the wave-speeds are not captured correctly and can lead to substantial diffusive error in their solution. Instead of taking this approach we will examine a model that can handle a few layers but is fully coupled leading to more reliably accurate wave speeds and less diffusive error. Development of the numerical method and notable applications will be discussed along with existing challenges. (Received September 12, 2015)

1116-65-874 **Samet Y Kadioglu*** (samet.kadioglu@inl.gov), P.O. Box 1625, MS 3840, Idaho Falls, ID 83415. *Analysis of the Self-Consistent IMEX Method for Tightly Coupled Non-linear Systems.* Preliminary report.

We present a mathematical analysis for our self-consistent Implicit/Explicit (IMEX) method. The self-consistent IMEX algorithm is designed to produce second order time convergent solutions to multiple time scale problems. The algorithm is a combination of an explicit block that solves the non-stiff part and an implicit block that solves the stiff part of the problem. The explicit block is always solved inside the implicit block as part of the nonlinear function evaluation making use of the Jacobian-Free Newton Krylov (JFNK) method. There is a continuous interaction between the two algorithm blocks in our method resulting in an implicitly balanced algorithm in that all the nonlinearities due to coupling of different time terms are converged(eliminating possible order reductions). We note that the classic IMEX methods split the operators such a way that the implicit and explicit blocks are executed independent of each other, and this may lead to non-converged nonlinearities therefore time inaccuracies for certain models. In this study, we provide a mathematical analysis that examines and compares the time convergence behavior of our self-consistent IMEX method versus the classic IMEX methods. We provide computational results to verify our analysis and analytical findings. (Received September 14, 2015)

1116-65-942 **David C Seal*** (seal@usna.edu), 121 Blake Road, Annapolis, MD 21402, and **Scott A Moe** and **James A Rossmanith**. *A simple and effective arbitrary-order shock-capturing limiter for discontinuous Galerkin methods.*

Hyperbolic PDEs often contain shocks and discontinuities in the exact solution, and therefore numerical methods need to be tailored to address this issue. Moreover, the application of high-order numerical methods (that are able to resolve more features with fewer unknowns) exacerbates this issue given that the appearance of Gibb's phenomenon at the location of the discontinuity can lead to non-linear instabilities and failure of the numerical method to produce a solution. In this work, we present a novel shock capturing limiter for the high-order discontinuous Galerkin (DG) method. Our limiter constructs local upper and lower bounds for the solution by sampling nearest neighbors, and then limits the solution to stay within these bounds. It is simple to implement, has minimal communication, is effective at capturing shocks, and retains genuine high-order accuracy of the solution in smooth regimes. Numerical results including problems that require positivity preservation in one and two dimensions on structured and unstructured grids are presented that indicate the robustness of the method. (Received September 21, 2015)

1116-65-1014 **James Patrick King*** (james.king3@cameron.edu), Cameron University, and **Gokul R. Kadel** (gkadel@cameron.edu), Cameron University. *Comparison of Numerical Solutions of Nonlinear Schrödinger Equation.*

In this project we consider time dependent Schrödinger equation that describes the quantum dynamics of many-particle systems under the influence of a variety of forces. A number of numerical techniques will be used to compute the solution. In addition to this, we investigate accuracy, reliability, consistency, stability, and overall cost effectiveness of different methods. (Received September 16, 2015)

1116-65-1275 **Soeren Bartels** and **Andrea Bonito*** (bonito@math.tamu.edu), Texas A&M University, Department of Mathematics, 3368 TAMU, College Station, TX 77845, and **Ricardo H Nochetto**. *Finite Element Approximations of Bilayer Plates.*

The bending of bilayer plates is a mechanism which allows for large deformations via small externally induced lattice mismatches of the underlying materials.

We discuss its mathematical modeling, which consists of a nonlinear fourth order problem with a pointwise isometry constraint. We devise a finite element discretization based on Kirchhoff quadrilaterals and prove its

Gamma-convergence. We propose a gradient flow based iterative method that decreases the energy and study its convergence to stationary configurations. We explore its performance, as well as reduced model capabilities, via several insightful numerical experiments involving large (geometrically nonlinear) deformations.

If time permits, we discuss its application to drug delivery, which requires replacing the gradient flow relaxation by a physical flow. (Received September 18, 2015)

1116-65-1291 **James V Lambers*** (james.lambers@usm.edu), 118 College Dr #5045, Hattiesburg, MS 39406. *Solution of Time-Dependent Nonlinear PDE Through Component-Wise Approximation of Matrix Functions.*

Krylov subspace spectral (KSS) methods are high-order accurate, explicit time-stepping methods for linear PDE with stability characteristic of implicit methods. This "best-of-both-worlds" compromise is achieved by computing each Fourier coefficient of the solution using an individualized approximation, based on techniques from "matrices, moments and quadrature" for computing bilinear forms involving matrix functions. In this talk, it will be shown how this approach can be generalized to obtain high-order accuracy in time, with favorable scalability properties, for nonlinear PDE. (Received September 18, 2015)

1116-65-1417 **Wei Zhu**, **Victoria Chayes**, **Alexandre Tiard**, **Stephanie Sanchez**, **Devin Dahlberg** and **Da Kuang*** (dakuang@math.ucla.edu), 520 Portola Plaza, Room 7354, Department of Mathematics, UCLA, Los Angeles, CA 90095, and **Andrea Bertozzi**, **Stanley Osher** and **Dominique Zosso**. *Nonlocal Total Variation with Primal-Dual Algorithm for Unsupervised Hyperspectral Imagery Analysis.* Preliminary report.

We propose an efficient nonlocal total variational method for unsupervised classification of hyperspectral imagery. We minimize the energy directly using a primal-dual algorithm, which is adapted for the nonlocal gradient and weighted centroid recalculation. By squaring the labeling function in the fidelity term and re-clustering the data points on the simplex, we can develop an unsupervised clustering method with random initialization of the centroids. To better differentiate clusters, we use a linear combination of the cosine and Euclidean distance between spectral signatures instead of the traditional cosine distance. Finally, we speed up the calculation using an approximate nearest neighbor search algorithm for constructing the pairwise weight matrix for the hyperspectral pixel signatures. We demonstrate substantially improved results on six data sets, compared to traditional clustering methods like k-means, non-negative matrix factorization, and the graph-based MBO scheme. (Received September 19, 2015)

1116-65-1470 **Harish P. Bhatt*** (hpb2e@mtmail.mtsu.edu), 2850 Middle TN. Blvd. Apt# D12, Murfreesboro, TN 37130, and **Abdul Q. M. Khaliq**. *A compact fourth-order L-stable scheme for reaction-diffusion systems with nonsmooth data.*

We introduce a novel compact fourth-order L-stable scheme for direct integration of reaction-diffusion problems with nonsmooth data. For an efficient implementation of the algorithm a partial fraction splitting technique is utilized, in which it is required to solve several backward Euler-type linear systems at each time step. Moreover, the design of the algorithm offers parallel implementation on two processor computer so, we implement the proposed algorithm in parallel on two processor utilizing MatlabMPI and obtain that the parallel version is computationally more efficient than the existing schemes considered in this paper. We investigate an amplification factor of the scheme and plot its boundaries of stability regions, which give an indication of the stability of the scheme. Calculation of the local truncation error and an empirical convergence analysis demonstrate the fourth-order accuracy of the proposed scheme. Accuracy, computational efficiency, and reliability of the new scheme are demonstrated with numerical examples and comparing them with existing schemes. (Received September 20, 2015)

1116-65-1574 **Ramjee P Sharma*** (ramjee.sharma@ung.edu), University of North Georgia, 3820 Mundy Mill Rd, Gainesville, GA 30503. *Implementation of Anderson Acceleration to Parallel Pseudo-Spectral Method.* Preliminary report.

Pseudo-spectral methods are widely used in solving non-linear partial differential equations. In this talk we will present techniques to compute large-scale nonlinear problems that arise in fluid dynamics using parallel pseudo-spectral method. The main focus will be on how to deal with the nonlinear parts of the equation, how to apply effective filters to the program and also how to parallelize the legacy codes. In addition, we will also present some results from the implementation of Anderson Acceleration to the parallel pseudo-spectral method. (Received September 20, 2015)

1116-65-1608 **Sara Shirinkam*** (sara.shirinkam@utsa.edu), Department of Mathematics, University of Texas at San Antonio, San Antonio, TX 78249, and **Adel Alaeddini** (adel.alaeddini@utsa.edu), Department of Mechanical Engineering, University of Texas at San Antonio, San Antonio, TX 78249. *An Application of Multicomplex Algebras for Numerical Optimization.*

In this paper, an adaptive methodology is proposed to numerically optimize functions using multicomplex algebras and their corresponding matrix representations. The methodology employs multicomplex Taylor series expansion (MCTSE) and generalized Newton method to adaptively approximate and optimize functions using sufficiently small number of points. Extensive simulation studies are conducted to evaluate the performance of the proposed methodology. The proposed approach can be applied to situations, where number of possible function evaluations is limited while high level of accuracy is needed. (Received September 21, 2015)

1116-65-1620 **Yuhan Ding***, **Sou-Cheng T Choi** and **Fred J Hickernell** (hickernell@iit.edu), Department of Applied Mathematics, Illinois Institute of Technology, E1-208, 10 W. 32nd St., Chicago, IL 60616. *Guaranteed Local Adaptive Interpolation.*

Existing error bounds for function interpolation depend on semi-norms of the function being interpolated. Such semi-norms are often not known a priori. Existing adaptive interpolation methods choose the data sites based on heuristic error estimates—without rigorous justification.

With our collaborators, we have been creating theoretically justified adaptive algorithms for univariate function interpolation, as well as for univariate and multivariate integration and univariate function optimization. Our algorithms determine the effort required from function values, not semi-norms. These algorithms comprise the open source GAIL Matlab toolbox, http://gailgithub.github.io/GAIL_Dev/.

This talk describes a new locally adaptive GAIL algorithm for univariate function interpolation. This algorithm is especially effective when the function being interpolated has a single peak in the domain and is rather flat elsewhere. (Received September 20, 2015)

1116-65-1653 **Duk-Soon Oh*** (duksoon.oh@rutgers.edu), **Olof B. Widlund** (widlund@cims.nyu.edu), **Clark R. Dohrmann** (crdohrm@sandia.gov) and **Stefano Zampini** (stefano.zampini@kaust.edu.sa). *Adaptive BDDC methods for problems posed in $H(div)$.*

A BDDC preconditioner is defined by a coarse component, expressed in terms of primal constraints and a weighted average across the interface between the subdomains, and local components given in terms of Schur complements of local subdomain problems. BDDC methods for vector field problems discretized with Raviart-Thomas finite elements are introduced. Our methods are based on an adaptive selection of primal constraints developed to deal with highly oscillating coefficients. Bounds on the condition number of the preconditioned linear system are also provided which are independent of the values and jumps. (Received September 20, 2015)

1116-65-1927 **Hailiang Liu** and **Terrance Pendleton*** (tlpendle@iastate.edu). *On Invariant-Preserving Finite Difference Schemes for The Camassa-Holm Equation and the Two Component Camassa-Holm System.*

The purpose of this talk is to develop and test novel invariant-preserving finite difference schemes for both the Camassa-Holm (CH) equation and one of its 2-component generalizations (2CH). The considered PDEs are strongly nonlinear, admitting soliton-like peakon solutions which are characterized by a slope discontinuity at the peak in the wave shape, and therefore suitable for modeling both short wave breaking and long wave propagation phenomena. The proposed numerical schemes are shown to preserve two invariants, momentum and energy, hence numerically producing wave solutions with smaller phase error overdone time period compared to those by other conventional methods. We first apply a scheme to the CH equation and showcase the merits of considering such a scheme under a wide class of initial data. We then generalize this scheme to the 2CH equation and test this scheme under several types of initial data. (Received September 21, 2015)

1116-65-1997 **Thomas Trogdon*** (trogdon@cims.nyu.edu), Courant Institute of Mathematical Sciences, 251 Mercer St., New York, NY 10012. *Applications of Riemann–Hilbert problems.*

The theory of Riemann–Hilbert problems is a powerful tool of nonlinear analysis. It gives detailed asymptotic expansions and high-accuracy numerics for many problems in integrable systems and random matrix theory. In this talk I will discuss some new applications of the method and, in particular, discuss its application to the statistical behavior of the conjugate gradient algorithm. (Received September 21, 2015)

1116-65-2106 **Xiaobing Feng**, **Yukun Li** and **Yi Zhang*** (yzhan112@utk.edu), 221 Ayres Hall, Department of Mathematics, 1403 Circle Drive, Knoxville, TN 37996. *Finite Element Methods for the Stochastic Allen-Cahn Equation with Gradient-type Multiplicative Noises.*

We study finite element approximations of the stochastic Allen-Cahn equation with gradient-type multiplicative noises that are white in time and correlated in space. The sharp interface limit as the parameter $\epsilon \to 0$ of the stochastic equation formally approximates a stochastic mean curvature flow which is described by a stochastically perturbed geometric law of the deterministic mean curvature flow. Two fully discrete finite element methods which are based on different time-stepping strategies for the nonlinear term are proposed. Strong convergence with sharp rates for both fully discrete finite element methods is proved with a crucial help of the Hölder continuity in time with respect to the spatial L^2-norm and H^1-seminorm for the strong solution of the stochastic Allen-Cahn equation. It also relies on the fact that high moments of the strong solution are bounded in various spatial and temporal norms. Numerical experiments are provided to gauge the performance of the proposed fully discrete finite element methods and to study the interplay of the geometric evolution and gradient-type noises. (Received September 21, 2015)

1116-65-2223 **Ke Yin*** (kyin@math.ucla.edu), 520 Portola Plz, 6363 Math Science, Los Angeles, CA 90095. *Compressed Wannier modes for imperfect crystals and symmetry-adapted Wannier functions.* Preliminary report.

This talk introduces two recent development of compressed Wannier modes (CWMs). Wannier functions are some unitary transform of the eigenfunctions of the Hamiltonian with translational symmetry. Inspired by sparse solutions to PDEs, we proposed localized Wannier functions for periodic solids from an L1 regularized energy functional. In the first part of the talk, we describe CWMs for imperfect crystals, where the periodic structures are interrupted by an impurity in one unit cell. Since CWMs are localized in space, the modes that are far away enough from the impurity are not affected. So we keep almost all the modes for the corresponding perfect crystal and only modify those that are affected by the impurity. We describes a systematical way of determining old modes that are needed to modify and replacing them by new modes. In the second part of the talk, we discuss the Wannier functions with symmetry. Since arbitrary unitary transform of a set of Wannier functions is an equivalent representation, not all representations have symmetry. We present a technique to calculate symmetry-adapted compressed Wannier functions, which form the irreducible representation of the symmetry group of the crystal lattice. (Received September 22, 2015)

1116-65-2403 **Susanne C. Brenner** and **Eun-Hee Park*** (eh.park@kangwon.ac.kr), School of General Studies, Kangwon National University, Samcheok-si, Gangwon-do 25913, South Korea, and **Li-Yeng Sung**. *A nonoverlapping domain decomposition method for a discontinuous Galerkin method.*

In this talk we will discuss a nonoverlapping domain decomposition method for a discontinuous Galerkin method for the elliptic problem. The formulation is based on dual-primal finite element tearing and interconnecting methodology. Theoretical results on the condition number estimate of the resulting system will be presented along with numerical results. (Received September 22, 2015)

1116-65-2457 **Manuel A. Sanchez-Uribe***, 182 George St, Providence, RI 02912. *A finite element method for high-contrast interface problems with error estimates independent of contrast.*

We define a new finite element method for a steady state elliptic problem with discontinuous diffusion coefficients where the meshes are not aligned with the interface. We prove optimal error estimates in the L^2 norm and H^1 weighted semi-norm independent of the contrast between the coefficients. Numerical experiments validating our theoretical findings are provided. (Received September 22, 2015)

1116-65-2540 **Şeyma N Özcan*** (snozcan@ncsu.edu), Department of Mathematics, SAS Hall, 2311 Stinson Drive, Raleigh, NC 27695, and **Alina Chertock**, **Shumo Cui**, **Alexander Kurganov** and **Eitan Tadmor**. *Well-Balanced Central Upwind Schemes for the Euler Equations with Gravity.*

I will present a new second-order well-balanced central upwind scheme for the Euler equations of gas dynamics with gravity. In many physical applications, the solutions of these systems are small perturbations of the steady-states and resolving these perturbations numerically may not be computationally affordable when the size of the perturbations is smaller than the size of the truncation error. We have developed a well-balanced scheme that exactly preserves some steady-state solutions of the system and thus handles the perturbations accurately and efficiently. The construction of the scheme is based on a special piecewise linear reconstruction of the equilibrium variables instead of conservative ones, as well as a modified evolution in time. We demonstrate a number of examples to show that the new scheme is well-balanced and is capable of capturing small perturbations of the steady-state on a coarse grid both in one and two dimensions. (Received September 22, 2015)

1116-65-2551 **Johnson A Osilagun*** (josilagun@unilag.edu.ng), Department of mathematics, University of Lagos, Lagos, +234, Nigeria. *a new modification of laplace decomposition method for nonlinear differential equations.*

this paper present a new modification of laplace decomposition method in solving nonlinear differential and partial differential equations. the proposed technique does not require the evaluation of adomian polynomials to approximate the nonlinear terms. numerical examples are used to show the reliability of the proposed method in terms of the convergence, accuracy and efficiency of the algorithm (Received September 22, 2015)

1116-65-2630 **Ashley Erin Meek*** (ashley.meek@ttu.edu) and **Victoria E Howle**. *Block Preconditioning for Time-Dependent Coupled Fluid Flow Problems.*

We examine block preconditioners for time-dependent incompressible Navier-Stokes problems and some related coupled problems. In some time-dependent problems, explicit time stepping methods can require much smaller time steps for stability than are needed for reasonable accuracy. This leads to taking many more time steps than would otherwise be needed. With implicit time stepping methods, we can take larger steps, but at the price of needing to solve large linear systems at each time step. We consider implicit Runge-Kutta (IRK) methods. Suppose our PDE has been linearized and discretized with N degrees of freedom. Using an s-stage IRK method leads to an $sN \times sN$ linear system that must be solve at each time step. These linear systems are block $s \times s$ systems, where each block is $N \times N$. We investigate preconditioners for such systems, where we take advantage of the fact that each subblock is related to a linear system from the (coupled) fluid flow equations. (Received September 22, 2015)

1116-65-2752 **Joe F Coyle*** (jcoyle@monmouth.edu), Department of Mathematics, Monmouth University, 400 Cedar Avenue, West Long Branch, NJ 07746. *Multilevel Dual Reordering Strategy for Nonsymmetric Matrices.* Preliminary report.

In many applications the simulations performed by the finite element method lead to a nonysmmetric system matrix. This is often the consequence of nonlocal coupling between the degrees of freedom. Consequently, solving the matrix equation can be unwieldy despite the sparsity of the matrix. As such, preconditioning can be a vital step in the solution process. Two factors that characterize a viable preconditioner are the extent to which it's action on the system matrix relates to that of the system matrix inverse and the number of nonzero entries. Preconditioning related to block LU-type factorization built by employing a multilevel reordering strategy is often a desirable solution. Throughout the process of constructing these preconditioners, a balance between the quality of the preconditioner and the fill-in of the related Schur complement submatrix is needed. In particular, the initial choice of partial reordering and the consequent effects will be considered. (Received September 22, 2015)

1116-65-2773 **Bongsoo Jang*** (bsjang@unist.ac.r), Ulsan, South Korea, and **Hyunju Kim** (hyunju.kim@ngu.edu), Tigerville, SC 29688. *Numerical solution of fractional differential equations by multistage shifted Jacobi spectral method.* Preliminary report.

In this work, a multistage spectral scheme using shifted Jacobi polynomials is introduced to deal with initial value problems(IVPs) of fractional order. In particular, we employ shifted Jacobi polynomials to construct local basis functions in the sense of spectral method. The locally defined approximation space on the first element is reused to approximate a solution on other non-overlapping elements by updating initial conditions. This technique has two major advantages. First, the matrix in the system is local rather than global and thus can be at very little cost comparing with cost using spectral method. By means of the technique, the good accuracy of the approximate solution is guaranteed throughout over a large domain while as existing spectral methods specialized for solving fractional initial value problems need expensive treatments to handle it. We also propose an improved discrete formulation regarding to the global operator called *memory* in the Caputo fractional derivative and this makes the accuracy of the approximate solution to be higher when the fraction order $0 < \nu \ll 1$. The *memory* associated with shifted Jacobi polynomials will be described as an algebraic expression by using the incomplete beta functions, too. (Received September 22, 2015)

1116-65-2797 **Jonathan D Hauenstein*** (hauenstein@nd.edu), **Alessandra Bernardi**, **Noah S Daleo** and **Bernard Mourrain**. *Tensor decomposition via numerical algebraic geometry.*

Tensor decomposition is a fundamental task in multilinear algebra. By taking a geometric approach to tensor decomposition, we propose numerical algebraic geometric approaches to compute both complex and real ranks

of tensors along with corresponding decompositions. Many examples will be provided showing the range of applications. (Received September 22, 2015)

1116-65-2838 **Steven M Wise*** (swise1@utk.edu). *Unconditional Energy Stability and Optimal-Rate Error Analysis of a Second Order Mixed Finite Element Method for the Cahn-Hilliard Equation.*

The Cahn-Hilliard equation is a nonlinear, fourth-order parabolic PDE modeling phase transformations. In this talk, I will describe and analyze an unconditionally stable, second-order-in-time finite element numerical scheme for the Cahn-Hilliard equation in two and three space dimensions. I will prove that our two-step scheme is unconditionally energy stable and unconditionally uniquely solvable. Furthermore, I show that the discrete phase variable is bounded in $L^\infty(0,T;L^\infty)$ and the discrete chemical potential is bounded in $L^\infty(0,T;L^2)$, for any time and space step sizes, in two and three dimensions, and for any finite final time T. Using these stabilities, I will show that the approximations converge with optimal rates in the appropriate energy norms in both two and three dimensions. (Received September 22, 2015)

1116-65-2912 **Mila Nikolova*** (nikolova@cmla.ens-cachan.fr), CMLA CNRS - ENS Cachan, 61, avenue du Président Wilson, 94235 Cachan, France. *Least squares regularized or constrained by L_0: relationship between their global minimizers.* Preliminary report.

When looking for a sparse solution of an under-determined linear system, two desirable models are to find a global minimizer of the least squares regularized by L_0 pseudo-norm using a trade-off parameter β or constrained by L_0 (known also as the K-sparsity constrained problem).

We analyse in depth the relationship between the sets of the global minimizers of these two nonconvex (combinatorial) models. At least partial equivalence between these problems is established in the sense explained next. There exists a strictly decreasing sequence of critical values $\{\beta_k\}$ that partitions the positive axis into a certain number of intervals. For every β inside an interval, there is a K such that the regularized problem and the K-constrained problem share exactly the same set of optimal solutions. Under conditions, quasi complete equivalence holds (except for the points $\beta = \beta_k$). We will present all important points concerning this partial or quasi complete equivalence.

Small-size exact numerical tests illustrate the theoretical findings. By way of conclusion, the K-sparsity problem offers wider possibilities which is not necessarily an advantage. (Received September 23, 2015)

1116-65-2917 **Willi J. Freeden*** (freeden@rhrk.uni-kl.de), MPI-Building 26, Kaiserslautern, Germany, 67663 Kaiserslautern, Germany, and **M. Zuhair Nashed** (m.nashed@ucf.edu), Orlando, FL 32816. *Sampling of bandlimited functions in multi-dimensional Euclidean spaces.*

In this talk, we are concerned with multi-variate Hardy-type lattice point identities from which space-dependent Shannon-type sampling theorems can be obtained by straightforward integration over certain regular regions. An answer is given to the problem of how a signal bandlimited to a regular region in multi-dimensional Euclidean space allows a reconstruction from discrete values in the lattice points of a (general) lattice.

The talk is based on the paper "Multi-variate Hardy-type lattice point summation and Shannon-type sampling" by W. Freeden, M.Z. Nashed, GEM Int J Geomath, 2015, DOI 10.1007/s 131037-015-0076-6. (Received September 23, 2015)

1116-65-2953 **Omid Khanmohamadi*** (okhanmoh@math.fsu.edu), 1017 Academic Way, 208 Love Building, Tallahassee, FL 32306. *Resampling Pseudospectral Methods for PDEs.* Preliminary report.

A resampling pseudospectral method for PDEs is discussed and its behavior is analyzed. In particular, it is shown that this resampling method, combined with generalized Schur unitary triangularization, is capable of accurately approximating the point spectrum of unbounded, differential operators. This is in contrast to collocation methods without resampling, which introduce spurious eigenvalues (due to boundary conditions) into the spectrum of the approximate operator. It is also shown how this method leads to straightforward handling of auxiliary conditions (which may be local or non-local, imposed at the boundary or in the interior of the domain), especially in high-order PDEs, resulting in preservation of spectral accuracy for problems with discontinuous coefficients using domain decomposition. (Received September 23, 2015)

68 ► Computer science

1116-68-96 **Boaz Barak*** (info@boazbarak.org). *A different kind of pseudo.*

In this talk I will describe a different type of "pseudo-randomness" that is the computational analog of Bayesian statistics in the same way that standard pseudorandomness can be considered as the computational analog of frequentist statistics. It can also be thought of as relating to standard pseudorandomness in the same way that proof complexity relates to algorithmic complexity.

A pseudo-distribution X reflects the uncertainty that a computationally bounded observer has about a certain quantity. It can be thought of as the "distribution" that respects all the facts that can be derived about this quantity using a computationally bounded proof system. It is not necessarily an actual distribution and can in fact assign negative probabilities to elements in the domain, as long as this cannot be detected by a bounded observer.

I will formally define pseudo-distributions (w.r.t a particular proof system) and explain how they can be used in the context of analyzing the performance of the Sum-of-Squares algorithm on various computational problems. (Received July 22, 2015)

1116-68-350 **Tamar Lichter** and **Chelsea K Chandler*** (ckc6cz@virginia.edu), 1410 Gordon Ave., Charlottesville, VA 22903, and **Monica Ribero Diaz**. *Personalized Local Recommendations with Collaborative Filtering.* Preliminary report.

As consumers are offered information and services at an unprecedented scale, many businesses have implemented systems that predict user preferences and make personalized local recommendations. Such systems are designed to enhance the user experience and ensure user satisfaction. We used data from the *Yelp Challenge Dataset* to compare several recommendation systems and analyze their performance, employing several unique features of the dataset: geographic diversity, business category information, and review text. The following collaborative filtering models were implemented and/or adapted to take into account these features: *basic offsets*, *latent factors*, *Location-Based Preference-Aware*, *Hidden Factors as Topics*, and a novel *category offsets* model. It was found that the *Hidden Factors as Topics* model significantly outperforms all others when trained and tested on a single city from the dataset. However, when trained and tested on larger subsets of the data, its margin of improvement greatly diminishes. Additionally, depending on the circumstances of a query, it was found that collaborative filtering models should be trained on different subsets of data for efficiency and accuracy. (Received August 26, 2015)

1116-68-507 **Jarod Alper** (jarod.alper@anu.edu.au), **Tristram Bogart*** (tc.bogart22@uniandes.edu.co) and **Mauricio Velasco** (mvelasco@uniandes.edu.co). *A Lower Bound for the Determinantal Complexity of a Hypersurface.*

Given a family of polynomials $\{p_n\}$, how long does it take to compute the values of p_n as a function of n? If $\det_n$ is the determinant of an n by n matrix of indeterminates, then the values of $\det_n$ can be calculated quickly via Gaussian elimination even though the determinant has $n!$ terms. So one way to show that another family $\{p_n\}$ is efficiently calculable is to reduce p_n to $\det_{m(n)}$, where $m(n)$ does not grow too rapidly with n. Leslie Valiant conjectured in 1979 that no efficient reduction is possible for the family of *permanents* $\{\mathrm{perm}_n\}$, which are superficially similar to determinants but much less well-behaved. It is known that a reduction is possible with $m(n)$ exponential in n, but the best known lower bound is quadratic in n. We prove a general result that shows among other things that for perm_3, the known upper bound of 7 is tight. (Received September 04, 2015)

1116-68-1125 **H. A. Akitaya*** (hugo.alves_akitaya@tufts.edu), **K. C. Cheung**, **E. D. Demaine**, **T. Horiyama**, **T. C. Hull**, **J. S. Ku**, **T. Tachi** and **R. Uehara**. *Box Pleating is Hard.*

In their seminal 1996 paper, Bern and Hayes initiated investigation into the computational complexity of origami. At the end of their paper, they pose some interesting open questions to further their work. While most of them have been investigated since, two in particular have remained untouched until now. First, while the gadgets used in their hardness proof for unassigned crease patterns are relatively straightforward, their gadgets for assigned crease patterns are considerably more convoluted, and quite difficult to check. Is there a simpler way to achieve a correct result? Second, their reductions construct creases at a variety of unconstrained angles. Is deciding flat foldability easy under more restrictive inputs? For example box pleating, folding only along creases aligned at multiples of 45° to each other, is a subset of particular interest in transformational robotics and self-assembly. In this work we prove deciding flat foldability of box pleated crease patterns to be NP-hard in both the unassigned and assigned cases, using relatively simple gadgets containing no more than 21 layers at any point. (Received September 17, 2015)

1116-68-1176 **Eric W Weisstein*** (eww@wolfram.com) and **Michael Trott** (mtrott@wolfram.com), Wolfram Research, 100 Trade Center Drive, Champaign, IL 61820. *Recent developments in computable mathematical data: Special functions, function spaces, and the semantic representation of mathematics using Mathematica and Wolfram|Alpha.*

We report on recent developments in the collection, representation, and exposure of mathematical structures in Mathematica and Wolfram|Alpha. Firstly, we present an enhancement and extension of the substantial body of special function identities originally collected on the Wolfram Functions Site. A greatly augmented set of identities (including a number of new functions) has now been integrated into Mathematica V10.3 as MathematicalFunctionData, making finding and working with identities involving more than 300 special functions easier than ever before. Secondly, we discuss a compendium of more than 150 named function spaces we have recently collected, curated, and computationally exposed to Wolfram|Alpha (and Mathematica). This collection represents the most comprehensive catalog of function spaces and their properties in existence. It also provides a testbed of "real" mathematical objects possessing nontrivial properties and relations which is useful to the much larger ultimate goal of designing and implementing a semantic language capable of representing all of mathematics. This larger goal is one important part of the creation of a world heritage digital mathematics library and an area of particular interest and current development at Wolfram Research. (Received September 17, 2015)

1116-68-1207 **Chinmay Hegde*** (chinmay@iastate.edu), ECpE Department, 2205 Coover Hall, Ames, IA 50010. *Learning Structured Data Representations using Approximation.*

Structured data representations (such as sparse, or manifold, representations) have been proven beneficial in a number of applications in machine learning and signal processing. However, these benefits do not come for free! Enforcing complex structures in data typically involves cumbersome and computationally intensive algorithms, limiting their practical usage.

In this talk, I will outline a framework for learning structures in data that attempts to surpass these computational barriers. The framework is inherently combinatorial, and integrates ideas from discrete optimization and approximation algorithms. For several types of structures, the algorithms developed within this framework enjoy a nearly-linear running time, thereby enabling their application to massive datasets. (Received September 17, 2015)

1116-68-1368 **Samanvitha Basole*** (s97basole@gmail.com), **Tim Hsu** (tim.hsu@sjsu.edu) and **Phyllis Lau** (phyllielau@gmail.com). *New geometries for cellular automata.* Preliminary report.

A cellular automaton is a collection of "cells" arranged in a geometric pattern (often the Cayley graph of a group) in which the state of each cell evolves according to some rule based on the current state of its immediate neighborhood. For example, Conway's well-known Game of Life is a cellular automaton on the group $\mathbf{Z} \times \mathbf{Z}$ (i.e., the square grid) that is defined by a simple rule, but can nevertheless simulate a Turing machine (universal computer).

We investigate cellular automata on the group $\left\langle a, b, c \mid 1 = a^2 = b^2 = c^2 \right\rangle$ (i.e., the infinite free trivalent tree). Specifically, using both experiments done with interactive software of our own design and theoretical methods, we describe ways in which natural generalizations of Conway's Game of Life to the infinite trivalent tree seem to be limited in their computational power by the geometry of the tree. We also describe possible future directions. (Received September 22, 2015)

1116-68-1458 **Yu-Min Chung*** (ychung@wm.edu), Department of Mathematics, College of William and Mary, P.O. Box 8795, Williamsburg, VA 23185, and **Sarah Day**. *Persistent Homology based thresholding method and applications.*

An automated image thresholding method based on the persistent homology is presented. The primary difference among traditional methods is that the resultant binary image respects underlying topological features. Furthermore, in the presence of noise, the method provides more information to obtain a better estimate of the Betti numbers. Finally, we will show applications to binary alloy data from Material Science, and firn data, a type of ice, from Climatology. (Received September 19, 2015)

1116-68-1495 **Howard S. Cohl*** (howard.cohl@nist.gov), 100 Bureau Drive, Mail Stop 8910, Gaithersburg, MD 20899, **Moritz Schubotz** (schubotz@tu-berlin.de), Berlin, Germany, **Marjorie A. McClain** (marjorie.mcclain@nist.gov), 100 Bureau Drive, Mail Stop 8910, Gaithersburg, MD 20899, **Bonita V. Saunders** (bonita.saunders@nist.gov), 100 Bureau Drive, Mail Stop 8910, Gaithersburg, MD 20899, and **Cherry Y. Zou** and **Azeem S. Mohammed**. *Orthogonal Polynomial Seeding for the Digital Repository of Mathematical Formulae.*

Our initial NIST Digital Repository of Mathematical Formulae (DRMF) seeding effort has been the Chapter 25 on zeta functions, from the NIST Digital Library of Mathematical Functions (DLMF). The DLMF input LaTeX source already contains some semantic information encoded using a highly customized set of semantic LaTeX macros. This year, we have developed a semantic enrichment process for orthogonal polynomial formula data. The generated context-free semantic information is used to build DRMF orthogonal polynomial formula home pages. We demonstrate this process using selected chapters from the book "Hypergeometric Orthogonal Polynomials and their q-Analogues" (2010) by Koekoek, Lesky and Swarttouw (KLS) as well as an actively maintained addendum to this book by Koornwinder (KLSadd). The generic input KLS and KLSadd LaTeX sources describe the printed representation of the formulae, but does not contain explicit semantic information. (Received September 20, 2015)

1116-68-1565 **Jason S Ku*** (jasonku@mit.edu), Rm. 35-203, 77 Massachusetts Ave., Cambridge, MA 02139. *Generating Crease Patterns from Prescribed Boundary Foldings.*

Given a sheet of paper and a prescribed folding of its boundary, is there a way to fold the paper's interior without stretching so that the boundary lines up with the prescribed boundary folding? For polygonal boundaries nonexpansively folded at finitely many points, a consistent isometric mapping of the polygon interior always exists and is computable in polynomial time. In this talk, we expand on a construction algorithm and explore the families of producible structures. (Received September 20, 2015)

1116-68-1572 **Xin Li*** (lixints@cs.jhu.edu), Department of Computer Science, Johns Hopkins University, 3400 N. Charles St., Baltimore, MD 21209. *Recent developments in explicit constructions of randomness extractors.*

Randomness extractors are fundamental objects in pseudorandomness and theoretical computer science. They are functions that transform biased probability distributions (also known as weak random sources) into nearly uniform probability distributions. While it is usually easy to show the existence of very good randomness extractors by the probabilistic method, in many cases explicit constructions are needed but are hard to achieve.

We will show explicit constructions of randomness extractors in two related well studied models–two independent weak sources and affine sources. In each case we give explicit constructions that almost match the parameters given by the probabilistic method. In particular, the constructions can be used to extract from sources on n bits with entropy $\mathsf{polylog}(n)$, and output almost all the entropy. Previously, even explicit constructions for entropy $n^{0.99}$ are not known. (Received September 20, 2015)

1116-68-2021 **Stephen M. Watt*** (smwatt@uwaterloo.ca), David R. Cheriton School of Computer Science, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada. *Assembling the World's Mathematical Knowledge.*

As is true in many other areas of discovery, mathematical knowledge had been produced for centuries and will continue to be produced for centuries to come. The records have taken many forms, from stone carvings, to manuscripts, to print journals and now digital media. Unlike most other areas, a great deal of mathematical knowledge has a degree of precision and objectivity that both gives it permanent value and makes it susceptible to mechanized treatment. We outline a path to assembling the world's mathematical knowledge, initially in the form of a comprehensive digital library of page images and evolving to a knowledge base to support sophisticated queries and automated reasoning. It is the aim of the nascent International Mathematical Knowledge Trust to provide a framework and to foster a community to make progress in this direction. We can foresee that such a knowledge base will enhance the capacity of individual mathematicians, accelerate discovery and allow new kinds of collaboration. (Received September 21, 2015)

1116-68-2022 **Haozhi Qi**, **Owen Richfield**, **Xiaohui Zeng** and **Michael Zhao*** (m.zhao@utah.edu), 3058 Marriott Honors, 250 S Mario Capecchi Drive, Salt Lake City, UT 84092. *Optimization of a Logo Recognition System.*

We evaluate the performance of a classical image retrieval pipeline (visual bag of words model), using SURF descriptors and hierarchical k-means vector quantization with an inverted file index, and compare this to the performance of two convolutional neural network (AlexNet and GoogLeNet) pipelines when it comes to the task of recognizing logos. We analyze how various parameters of the clustering algorithm affect the accuracy of the visual bag of words model, as well as why the visual bag of words model fails to perform well in this domain. We also provide timing data for a practical use case, where these pipelines are incorporated into a logo recognition app for Android phones. Further directions include, for instance, investigations on how the choice of quantization method affects accuracy, and more scalable ways to incorporate deep learning into the pipeline. (Received September 21, 2015)

1116-68-2153 **Olaf Teschke** (olaf.teschke@fiz-karlsruhe.de), FIZ Karlsruhe, Franklinstrasse 11, 10589 Berlin, Germany, and **Fabian Müller*** (fabian@zentralblatt-math.org), FIZ Karlsruhe, Franklinstrasse 11, D-10589 Berlin, Germany. *Quantity and quality of mathematical information drawn from the literature: experiences from building and connecting EuDML and zbMATH.*

What can be the scope of the future Global Digital Mathematics Library? What will be the facets of information mainly used by mathematicians? How can automated tools and intellectual efforts be optimally combined in deriving and enhancing specialized information? For many decades, services like zbMATH have indexed and reviewed the mathematical literature to support an accessible survey of what has been achieved within the research corpus. The age of digitization has offered much more opportunities to extract and connect information. Many new tools available were just necessary to keep up with the growth of the literature, while others empower completely new features like the connection to mathematical software, mathematical formula search, or semantic retrieval. We report on experiences from developing the EuDML digital mathematics library and zbMATH during the last years, and give an outlook to what can possibly be done in the future, and what efforts may be necessary. (Received September 22, 2015)

1116-68-2189 **Luca Trevisan***, 625 Soda Hall, Computer Science Division, U.C. Berkeley, Berkeley, CA 94720-1776. *Pseudorandom Generators and Derandomization.*

We will define the complexity-theoretic notion of a pseudorandom generator: a procedure that takes a short string of truly random bits and stretches it to a long string of bits that "look random" to a certain class of algorithms.

We will then describe how this notion is related to the problem of deterministically simulating randomized algorithms and of making certain applications of the probabilistic method constructive.

Finally, we will highlight the specific setting of pseudorandom generators that "look random" to memory-bounded algorithms, and describe known results and open problems. (Received September 22, 2015)

1116-68-2254 **Erik D. Demaine*** (edemaine@mit.edu), MIT CSAIL, 32 Vassar St., Cambridge, MA 02139. *Computational Origami is Hard.*

This talk surveys several new and old results about the computational complexity of optimal origami design and origami analysis. For example, it is NP-hard to decide whether a crease pattern folds flat or folds rigidly; to fold a square of paper into the largest scaled copy of a shape/tree; to fold even a 1D crease pattern to minimize the effect of paper thickness; or to refold a roadmap even by simple folds. We will also see complementary positive algorithmic results both to cope with this hardness and to highlight what makes the problems so difficult. (Received September 22, 2015)

1116-68-2268 **Gwen Spencer*** (gwenspencer@gmail.com) and **David Rolnick**. *On the Robust Hardness of Grobner Basis Computation.*

Grobner Basis computation is a classical problem in Computational Algebra. It is well known that computing a Grobner Basis for a general polynomial system is not possible in polynomial time (unless P=NP). What about computing an *Approximate Grobner Basis*? In joint work, we proposed two models of what it means to compute an *Approximate Grobner Basis*. Both models allow an algorithm to selectively ignore some of the polynomials: the algorithm is only responsible for returning a Grobner Basis corresponding to the remaining polynomials. We prove that this approximate problem is still NP-Hard for lexicographic orders, even when the algorithm can ignore a substantial constant fraction of the polynomial system (both notions of "approximate" are parameterized). Our hardness results hold even when the algorithm is only required to work for polynomial systems whose maximum degree is guaranteed to be very low and each polynomial contains at most 3 variables. Our proofs are by reduction and depend on combining positive and negative algorithmic results from combinatorial optimization problems in graph coloring and logic.

This work started through the AMS Mathematics Research Communities Program during Summer 2014. (Received September 22, 2015)

1116-68-2342 **Wolfgang Windsteiger*** (wolfgang.windsteiger@risc.jku.at) and **Bruno Buchberger**. *Theorema: A Tool for Formalizing Mathematics.*

Formalization of some pieces of mathematics can now be done in a user-friendly “natural” style that is both easy to read for humans **and** can be processed by automated reasoners.

Currently, due to the worldwide research effort of the past three decades, there are about twenty software systems for automated reasoning available. For illustration, in this talk, we give some examples of formalization and proof generation in our Theorema system.

We also discuss questions such as, for example:

- What is the difference between writing mathematical formulae in LaTeXand formalization within an automated reasoning system?

- In what ways do formal math knowledge bases go beyond web-accessible down-loadable paper collections (which are quite common by now in most sciences)?

- What is the relationship between the current mathematical software systems (algorithm libraries) like Mathematica etc. and future automated reasoning systems?

- What can be expected from future formal mathematical knowledge bases for math research, math teaching, math application, math archiving and the quality control of mathematical publications?

- Does one have to stick to a particular logical foundation in order to build and use formal math knowledge bases? (Received September 22, 2015)

1116-68-2505 **Gregory V Bard*** (bardg@uwstout.edu), Dept. of Math., Stat., and Comp. Sci., Jarvis Hall Science Wing, Menomonie, WI 54751, and **Theodore McDonough**. *The Two-Time Pad Problem: Plaintext Recovery for One-Time Pads Used Twice.* Preliminary report.

The one-time pad is an encryption scheme used since WWI. It consists of a pad $\vec{k}$, a sequence of independent and uniformly random elements of $\mathbb{Z}_n$, in the possession of both sender and receiver. The sender encodes the plaintext $\vec{p}$ as a sequence from $\mathbb{Z}_n$. Encryption and decryption are addition and subtraction. Specifically, $c_i = p_i + k_i \bmod n$.

While provably secure, the classical proof makes assumptions about the method of use. Each pad ($\vec{k}$) must be used only once—hence the name “one-time pad.” It has been known for a while that the cipher can be broken if a pad is used twice. For example, if two ciphertexts, encrypted using the same pad, are intercepted then historical records indicate that it is feasible to recover the plaintexts and the pad itself. This was done in the 1950s at the National Security Agency (NSA) under the codename “VENONA.”

However, the method by which it was done has not been published, and is an open area of research. Recovering the two plaintexts is called the “two-time pad problem.”

The speaker will highlight some of the interesting mathematical/statistical properties of the two-time pad problem. The talk will be accessible with a moderate knowledge of discrete math. (Received September 22, 2015)

1116-68-2635 **Abbas Mahdi Alhakim*** (aa145@aub.edu.lb). *Properties of Generalized de Bruijn Digraphs.* Preliminary report.

Generalized binary de Bruijn digraphs are regular directed graphs with N nodes, labeled $0, 1, \ldots, N-1$, with edges from i to $2i$ and $2i + 1 \mod N$. Traditional de Bruijn sequences, which have been used as pseudorandom sequences, correspond to Hamiltonian cycles when N is a pure power of 2. We discuss some interesting properties of these digraphs for general N, stressing the similarities with traditional de Bruijn digraphs. For instance, Hamiltonian cycles exist when N is even and they correspond bijectively to Eulerian circuits in digraphs of size $N/2$. Moreover, cycles of all orders exist, two disjoint cycles can be joined into one cycle via the cross-join operation, and we establish that a Hamiltonian cycle can be cross-joined repeatedly to make another arbitrary Hamiltonian cycle. We also show some interesting computational results. (Received September 22, 2015)

1116-68-2783 **Paul E Hand*** (hand@rice.edu), 6100 Main Street, CAAM Dept. MS-134, Houston, TX 77004, and **Choongbum Lee** and **Vladislav Voroninski**. *ShapeFit: Exact location recovery from corrupted pairwise directions.*

We consider the problem of recovering a set of locations given observations of the direction between pairs of these locations. This recovery task arises from the Structure from Motion problem, in which a three-dimensional structure is sought from a collection of two-dimensional images. In this context, the locations of cameras and structure points are to be found from epipolar geometry and point correspondences among images. These correspondences are often incorrect because of lighting, shadows, and the effects of perspective. Hence, the resulting observations of relative directions contain significant corruptions. To solve the location recovery problem in the presence of corrupted relative directions, we introduce a tractable convex program called ShapeFit. Empirically, ShapeFit can succeed on synthetic data with 40% corruption. Rigorously, we prove that ShapeFit can recover a set of locations exactly when a fraction of the measurements are adversarially corrupted and when the data model is random. (Received September 22, 2015)

70 ► *Mechanics of particles and systems*

1116-70-1024 **Tim Ryan Krumwiede*** (krumwiede@math.utk.edu) and **Tim P Schulze** (schulze@math.utk.edu). *Dendritic Growth Shapes in Bond-Counting Models.*

Dendritic growth of crystals can be simulated using nearest- and next-nearest-neighbor bond-counting models with Kinetic Monte-Carlo methods. In order to compare with analogous continuum models, we derive the surface energy function for a broad class of these models. This surface energy can then be used to construct the model's equilibrium shape, from which one can often anticipate subsequent growth behavior. With these tools in hand, we search for models counting nearest- and next-nearest-neighbor bonds that exhibit twelve- and twenty-four-armed dendrites, which have previously been observed using continuum models. We find that no surface energy function in this class using just two-body nearest- and next-nearest-neighbor interactions yields a twelve-armed dendrite, concluding that longer range interactions would be necessary. More generally, it appears that finite cut-off bond-counting models are not able to reproduce the effects of an arbitrarily specified surface energy functions. (Received September 16, 2015)

1116-70-2633 **Alexander M Baez***, abmincorporated@gmail.com, **Carmen Caiseda**, ccaiseda@bayamon.inter.edu, **Padmanabhan Seshaiyer**, padhu@gmu.edu, **Nitin Nellanki**, nellanki@masonlive.gmu.edu, and **Byong Kwon**, bkwon1@masonlive.gmu.edu. *Simulation, visualization and control of quadcopters.*

At any given moment our world encounters challenging events that affect our natural resources, wild-life or human populations. Many companies, in their search for mitigating the impact of these events, have invested in the advancement of technology that will allow them to manage these assignments, including the development of more accurate UAVs (unmanned aerial vehicles). With the use of these vehicles wider perspectives and regions of our planet can be efficiently monitored at a safe distance. The moisture level of crops can be measured, water rafts can be delivered to people in distress at sea or an area can surveyed for suspects. These devices, being radio controlled or autonomous, have the great benefit of being maneuvered into difficult regions, but also demand faster response time in the job appointed. In our collaborative effort to improve the UAV's performance while airborne, we have undergone the task of investigating the flight dynamics of this machine. We have implemented the Newton-Euler equations of quadcopter flight into a MATLAB simulation and visualization with PD Control and conducted case studies on the stability of this UAV. (Received September 22, 2015)

74 ► *Mechanics of deformable solids*

1116-74-623 **Noah A. Weiss*** (weissno@uwstout.edu). *Periodic Array of Partially Insulated Interface Cracks Subjected To Uniform Far Field Heat Flow.*

The analysis of cracks is important for the study of material stability. In this talk, two related thermoelastic problems are considered for a bimaterial. The bimaterial consists of two materials with different elastic and thermal properties, and the constituent materials are bonded together along a straight interface. The bonding is imperfect–cracks are assumed to be periodically spaced along the interface.

The theory of steady-state thermoelasticity is used, which leads to a biharmonic boundary value problem. The boundary conditions are shown to depend on the relation between the thermal properties of the constituent materials. The results from this research are compared with other research that considered isolated interface cracks subjected to far-field heat flow. (Received September 09, 2015)

1116-74-744 **Michael L. Falk*** (mfalk@jhu.edu), **Tonghu Jiang**, **Shiva Rudraraju** and **Krishna Garikipati**. *The materials science of chemically driven elastic incompatibility: A multi-physics study of lithium ion battery electrode Li1+xT2O4.*

Recently, a huge materials space is being explored for cheaper, higher energy density, and reliable battery materials, due to the growing demand of portable electronics and electric vehicles. During charge and discharge cathodes of lithium ion batteries typically undergo first order phase transformations. The resulting two-pahse coexistence can lead to elastic incompatibilities that drive failure and limit lifetime.

In this work, we use a series of computational tools to study the thermodynamics and kinetics of Li1+xTi2O4. Density functional theory (DFT) calculation was used to obtain formation energies of Li1+xTi2O4 with different lithium configurations, and migration barriers for lithium ion transitions. The cluster expansion method is employed to approximate these energies. These are then deployed to develop physics-based parameterizations of the relevant structural and kinetic properties that inform a phase field model in order to simulate this material at macroscopic level. The development of internal stresses during charging and discharging is simulated and analyzed with an eye to understanding how these lead to electrode degradation and failure. (Received September 11, 2015)

1116-74-1878 **Stewart A Silling*** (sasilli@sandia.gov). *Multiscale and Coarse Graining Methods in Peridynamic Mechanics.*

The peridynamic method of solid mechanics is a strongly nonlocal continuum theory that allows potentially great generality in the modeling of defects and material failure. This talk will describe recent advances in the development of a hierarchical multiscale approach in peridynamics that enables the exploration of the transition of small-scale material defect growth to macroscopic failure. Applications of the method include three-dimensional simulation of fractographic features in dynamic brittle fracture, such as the mirror-mist-hackle phenomenon. A coarse-graining method permits accurate derivation of larger-scale material properties from arbitrary small-scale morphology. Possible application to metamaterials will be discussed. (Received September 21, 2015)

76 ► Fluid mechanics

1116-76-208 **Bernard Deconinck*** (deconinc@uw.edu). *High-frequency instabilities of small amplitude water waves.*

Different water wave models are compared using the (in)stabilities of their periodic traveling waves with respect to time-oscillating perturbations. For this comparison, no more than the Hamiltonian of the linearized model is required. In fact most of the information is obtained from the dispersion relation of the linear model. (Received August 14, 2015)

1116-76-248 **John Carter***, Seattle University, **Alex Govan**, Seattle University, **Diane Henderson**, Penn State University, and **Harvey Segur**, University of Colorado at Boulder. *Frequency downshift in a viscous fluid.*

Frequency downshift, i.e. a shift in the spectral peak to a lower frequency, in a train of nearly monochromatic gravity waves was first reported by Lake *et al.* (1977). Even though it is generally agreed upon that frequency downshifting (FD) is related to the Benjamin-Feir instability and many physical phenomena (including wave breaking and wind) have been proposed as mechanisms for FD, its precise cause remains an open question.

Dias *et al.* (2008) added a viscous correction to the Euler equations and derived the dissipative NLS equation (DNLS). In this talk, we introduce a higher-order generalization of the DNLS equation, which we call the viscous Dysthe equation. We outline the derivation of this new equation and present many of its properties. We establish that it predicts FD in both the spectral mean and spectral peak senses. Finally, we demonstrate that predictions obtained from the viscous Dysthe equation accurately model data from experiments in which frequency downshift occurred. (Received August 18, 2015)

1116-76-620 **Fathi M Allan*** (f.allan@uaeu.ac.ae), United Arab Emirates University, AL AIn, 15551, United Arab Emirates, **Mohamed A Hajji** (mahajji@uaeu.ac.ae), United Ararb Emirates University, AL AIn, 15551, United Arab Emirates, and **Qasem A AL Mdallal** (q.almdallal@uaeu.ac.ae), United Ararb Emirates University, Al Ain, 15551, United Arab Emirates. *Mathematical modeling of air flow through a coupled cooled-heated wind tunnel.*

The coupled cooled-heated wind tunnel is a wind tunnel with special features. This wind tunnel consists of two connected parts; the first part will be cooled using special cooling technology and the other part will be heated using the solar energy. The temperature difference will create a flow of air through the tunnel from the cooled region to the heated region.

In this article, we will develop a mathematical model to study the flow phenomena. The mathematical model involves the use of the heat equation to model the air flow through each channel. Suitable boundary conditions are used for each channel part and analytical solution was obtained using the Fourier series. The results obtained represent the velocity vector field and the heat distribution inside each channel. The effect of the temperature difference on the flow field will be presented. The industrial application of the suggested method will be presented and the use of the model in renewable energy application will be discussed. (Received September 09, 2015)

1116-76-621 **Benjamin F Akers*** (benjamin.akers@afit.edu), The Air Force Institute of Technology, WPAFB, OH 45433. *Extremely Steep Traveling Interfacial Waves.*

New methods for computing extremely steep traveling waves at the interface between two fluids are presented. These waves are periodic solutions of the vortex sheet formulation of the potential flow equations. The traveling wave ansatz is developed for such interfaces when parameterized by arclength (Akers, Ambrose & Wright, 2013). Traveling waves are computed which have overturned interfaces. Numerical continuation methods are used to compute the surfaces, in parameter space, where these traveling waves exist. The globally largest traveling water wave is computed (Akers, Ambrose & Wright, 2014). The role of local and global bifurcation theorems in computational explorations of parameter space are highlighted. Three-dimensional computations are discussed. (Received September 09, 2015)

1116-76-645 **Susan Friedlander*** (susanfri@usc.edu), Math Dept, USC, Los Angeles, CA 90089, and **Anthony Suen** (acksuen@ied.edu.hk). *An active scalar model for the Earth's fluid core.*

We discuss the mathematical properties of a three dimensional active scalar equation which was proposed by Moffatt and Loper as a model for geostrophic turbulence and the geodynamo processes in the Earth's fluid core. (Received September 09, 2015)

1116-76-757 **Catherine Sulem*** (sulem@math.toronto.edu), Department of Mathematics, University of Toronto, Toronto, ON M5S2E4, Canada. *normal forms transformations for water waves.*

Normal forms transformations for a dynamical system in a neighborhood of a stationary point retain only the significant nonlinearities, eliminating inessential terms. We consider the equations of water waves in a two-dimensional channel of finite or infinite depth, in the setting of spatially periodic solutions. These equations are considered in the framework of Hamiltonian systems, for which the Hamiltonian energy has a convergent Taylor expansion in canonical variables near the equilibrium solution. We give an analysis of the Birkhoff normal form transformation that eliminates third-order non-resonant terms of the Hamiltonian. We also provide an analysis of the dynamics of remaining resonant triads in certain cases. This is joint work with Walter Craig (McMaster University). (Received September 11, 2015)

1116-76-976 **Walter A. Strauss*** (wstrauss@math.brown.edu). *On the slope of steady water waves.*

Consider the angle of inclination of the profile of a steady 2D inviscid symmetric periodic or solitary water wave subject to gravity. Although the angle surpasses 30 degrees for some irrotational waves close to the extreme wave, Amick proved in 1987 that the angle must be less than 31.15 degrees if the wave is irrotational.

For waves that are not irrotational, the question of whether there is a bound on the angle has been completely open. Of course, the extreme Gerstner wave, which has adverse vorticity, has vertical cusps. Moreover, numerical calculations show also that waves of finite depth with adverse vorticity can overturn. We prove, on the other hand, an upper bound of 45 degrees for a large class of waves with favorable vorticity and finite depth. This is joint work with Miles Wheeler. (Received September 15, 2015)

1116-76-1088 **Xiaoming Wang*** (wxm@math.fsu.edu), Department of Mathematics, Florida State University, Tallahassee, FL 32306. *Flows in Karstic Geometry.*

We present a phase field model for two phase flows in karstic geometry, i.e., situations that involve both flows in porous media and free flows. The model is derived via Onsager's extremum principle. We will discuss the well-posedness, sharp interface limit, numerical analysis and simulation of this model. The talk is based joint work with Daozhi Han and Hao Wu. (Received September 16, 2015)

1116-76-1297 **Katie Oliveras*** (oliveras@seattleu.edu), Seattle university, Mathematics Department, 901 12th Ave, Seattle, WA 98122, and **Vishal Vasan**. *Water Waves: Reconstructing the Surface Elevation from Pressure Data.*

We discuss several new methods to recover the water-wave surface elevation from pressure data obtained at any depth below the fluid surface. The new method requires the numerical solution of a nonlocal nonlinear equation relating the pressure and the surface elevation which is obtained from the Euler formulation of the water-wave problem without approximation. This new approach is compared with other approaches currently used in field observations. (Received September 18, 2015)

1116-76-1316 **Minghao Wu Rostami*** (mwu@wpi.edu), 100 Institute Road, Department of Mathematical Sciences, Worcester, MA 01609, and **Sarah D Olson** (sdolson@wpi.edu), 100 Institute Road, Department of Mathematical Sciences, Worcester, MA 01609. *Efficient simulation of a large number of microswimmers using the fast multipole method.* Preliminary report.

Regularized Stokes formulation has been shown to be very effective at modeling fluid-structure interactions when the fluid is highly viscous. However, its computational cost grows quadratically with the number of particles immersed in the fluid. We demonstrate how fast multipole method can be applied to significantly reduce the computational cost of regularized Stokes method. Numerical results will be presented for simulating the dynamics of a large number of microswimmers immersed in 3D stokes flows. Furthermore, we also investigate the swimming efficiency of the microswimmers when they are placed in various geometric configurations. (Received September 18, 2015)

1116-76-1328 **Shengqian Chen*** (sqchen@math.wisc.edu), 480 Lincoln Drive, Madison, WI 53705, and **S. N. Stechmann** and **A. J. Majda**. *Multi-scale asymptotics for atmospheric waves and precipitation.*

The lack of understanding of the tropical atmosphere is a major hinderance to improve the predictability of the global climate. In tropics, the Madden-Julian Oscillation (MJO) is the dominant component of intraseasonal (30-60 days) variability. The MJO is an equatorial wave envelope of complex convective processes, coupled with planetary-scale circulation anomalies. In this talk, I will present a new model that captures the mechanisms of the interactions between MJO and other tropical and extratropical waves.. By using the method of multis-cale asymptotics with different time scales, simplified asymptotic equations are derived for the resonant interaction of tropical and extratropical waves, such as Rossby waves. The reduced equations is an ODE system for wave amplitudes. The ODE system are shown to illustrate the initiation/termination of MJO. (Received September 18, 2015)

1116-76-1359 **Chaoxu Pei*** (cpei@math.fsu.edu), **Mark Sussman** and **M.Yousuff Hussaini**. *A Space-Time Discontinuous Galerkin Spectral Element Method for the Stefan Problem.*

The Stefan problem is a moving boundary problem that is used to model phase change. It requires solving the heat equations for different phases, i.e. the ice and water phases, while the phase boundary separating the two phases is transported with a velocity that is proportional to the jump of the normal heat flux at the evolving and prior unknown boundary. In other words, the problem requires one to find the solutions in a prior unknown domain and to compute the shape of the unknown domain as a part of the solution. We propose a novel space-time discontinuous Galerkin spectral element method for solving the Stefan problem. Two transformations are introduced to deal with the prior unknown time evolving phase boundary, which combines an Eulerian description with a Lagrangian description. Benchmark tests in one spatial dimension indicate that the method converges with spectral accuracy in both space and time for both the temperature distribution and the interface velocity.
(Received September 18, 2015)

1116-76-1500 **James P Kelliher*** (kelliher@math.ucr.edu). *Aggregation equations and 2D incompressible fluids.* Preliminary report.

In recent works of Bertozzi, Garnett, Laurent, Verdera, and Léger, the inviscid aggregation equations with Newtonian potential have been treated much like an inviscid 2D incompressible fluid to obtain well-posedness and to prove the persistence of regularity of an aggregation patch boundary. We discuss how many other problems of fluids mechanics have a close analog in aggregation equations, and explore some of the complications that arise. We address, in particular, work with Cozzi and Gie to prove the vanishing viscosity limit. (Received September 20, 2015)

1116-76-1761 **Andrew J Wells*** (andrew.wells@physics.ox.ac.uk), AOPP, Clarendon Lab, Dept of Physics, University of Oxford, Oxford, OX1 3PU, United Kingdom, and **Joseph R. Hitchen**, **John S. Wettlaufer** and **Steven A. Orszag**. *Convection in Mushy Sea Ice: Nonlinear Dynamics and Asymptotic Structure.*

Sea ice is an example of a mushy layer: a reactive porous medium of ice crystals bathed in liquid brine. During the growth of young sea ice, buoyancy-driven convection drives the drainage of dense interstitial brine from the ice, controlling buoyancy fluxes for the ocean and biogeochemical transport through the ice interior. Flow-focussing instabilities lead to the development of localised brine drainage channels formed by dissolution of the ice. We review recent work on convection in mushy layers and brine channel dynamics based on a partial differential equation model using continuum conservation laws. A dimensionless Rayleigh number characterises the strength of convection compared to dissipation. We consider the nonlinear dynamics of brine channels, and their stability

as both the Rayleigh number and the spacing between brine channels change. We determine asymptotic scalings for the structure of convective cells in the limit of large Rayleigh number. Finally, we consider the impact of this convective flow on biogeochemical tracer transport through porous sea ice, and determine asymptotic scaling laws for chemical tracer concentration in the ice interior. (Received September 21, 2015)

1116-76-1765 **Alexey Cheskidov** (acheskid@uic.edu) and **Karen Zaya*** (kzaya2@uic.edu). *Lower Bounds of Potential Blow-Up Solutions of the Three-dimensional Navier-Stokes Equations in $\dot{H}^{\frac{3}{2}}$.*

We improve previous known lower bounds for Sobolev norms of potential blow-up solutions to the three-dimensional Navier-Stokes equations in $\dot{H}^{\frac{3}{2}}$. We also present an alternate proof for the lower bound for the $\dot{H}^{\frac{5}{2}}$ blow-up. (Received September 21, 2015)

1116-76-1898 **David W Rees Jones*** (david.reesjones@physics.ox.ac.uk), AOPP, Clarendon Laboratory, Parks Road, University of Oxford, Oxford, OX1 3PU, United Kingdom, and **Grae Worster**, Centre for Mathematical Sciences, Wilberforce Road, University of Cambridge, Cambridge, CB3 0WA, United Kingdom. *From sea ice to water: on the thermodynamic boundary conditions of a solidifying mushy layer with outflow.*

Sea ice is a type of reactive porous medium called a mushy layer, and fluid flows between sea ice and water occur in a variety of contexts. The boundary conditions between a fully liquid region and a mushy layer must respect both thermodynamic and fluid dynamical considerations. Schulze and Worster (2005) derived a thermodynamic boundary condition of 'marginal equilibrium' for a solidifying mushy layer with outflow, which requires that streamlines are tangent to isotherms at the interface. We develop a steady, two-dimensional forced-flow configuration to investigate the fluid dynamical aspects of this boundary condition by extending Stokes equations in a narrow 'transition region' within the mushy layer. We show that the tangential fluid velocity changes rapidly in the transition region to satisfy marginal equilibrium. In sea ice, a buoyancy gradient near liquid brine channels or an external shear flow can drive such tangential flow. We use asymptotic analysis in the limit of small Darcy number to derive a regime diagram for the existence of steady solutions. Thus we demonstrate the robustness of the marginal equilibrium boundary condition and its relevance to fluid flows from mushy sea ice to fully liquid water. (Received September 21, 2015)

1116-76-2009 **Dambaru Bhatta*** (dambaru.bhatta@utrgv.edu). *Adjoint system for a 3D convective flow in an active mushy layer.* Preliminary report.

We consider a three dimensional convective flow in mushy layer which is formed during solidification of binary alloys here. We treat the horizontal mushy layer as an active porous media with variable permeability. The flow in the mushy layer can be described by a system of partial differential equations including the momentum equation governed by the Darcy's law. The linear system for the mushy layer is obtained by perturbing the basic state system and then the adjoint system is derived from this perturbed linear system. (Received September 21, 2015)

1116-76-2129 **Jeffrey K Landgren*** (jeffrey-landgren@uiowa.edu), 14 MacLean Hall, Department of Mathematics, University of Iowa, Iowa City, IA 52242, and **Gerhard Strohmer** (gerhard-strohmer@uiowa.edu), 14 MacLean Hall, Department of Mathematics, University of Iowa, Iowa City, IA 52242. *Modeling the Effects of Sound in Chemical Reactions.* Preliminary report.

The fundamental process that lies at the foundation of batteries, capacitors, and solar cells is the electron transfer process. This takes place at an interface or boundary in each device and is governed by its corresponding chemical reaction. Making these devices more efficient can help decrease our negative impact on the environment. Recent experiments in the field of electrochemistry demonstrate that sound waves act as a catalyst for these electron transfer reactions. A model is developed using an Incompressible Euler Equation, Conservation of Mass Equation, boundary motion equation, and surface tension equation (using mean curvature). Chemically, it is clear that the catalytic phenomenon is derived from the sound waves and how they are affected by the top boundary. When combining these four equations we arrive at a boundary condition involving the top boundary only. We place this condition on the wave equation to understand the interaction that occurs. We establish a self-adjoint operator and further use its inverse. Overall, using the Variational form and the Galerkin Method an approximation converges to the solution of the wave equation. With the help of Matlab these eigenfunctions can be articulated as standing waves. (Received September 21, 2015)

1116-76-2136 **Chris Curtis***, Department of Mathematics & Statistics, 5500 Campanille Dr., San Diego, CA 92182, and **Katie Oliveras**, **Sam Shen** and **Theresa Morrison**. *Nonlinear Waves Over Currents.*

In this talk, we will discuss several different scenarios of nonlinear waves propagating in fluids with background currents. In the first part of the talk, we will look at three dimensional waves propagating over a current moving over varying bathymetry. A higher-order forced Benney-Luke equation is derived. A key result is that while upstream soliton formation is still seen, it is markedly different in character than what one sees via the forced Kadomtsev-Petviashvilli equation.

In the second part of the talk, we look at density stratified fluids with constant shear currents in each layer. We show parameter regions exist in which Kelvin-Helmholtz instabilities are suppressed. In these regions, due to strong differences in the shear strengths, relatively high amplitude and high energy dispersive shock waves appear at the interface between the layers. Both results show strong nonlinear phenomena appear in the presence of currents, and that simple nonlinear models can be readily expanded upon to model physically interesting fluid regimes. (Received September 21, 2015)

1116-76-2230 **Olga Trichtchenko***, o.trichtchenko@ucl.ac.uk, and **Bernard Deconinck** and **Jean-Marc Vanden-Broeck**. *Comparison of Stability of Solutions to Hamiltonian Water Wave Models.*

The goal of this work is to compare and contrast the stability results for solutions to different models for water waves. It is known that high frequency instabilities exist for the nonlinear solutions to Euler's equations describing water waves [1,2], however not all models exhibit these instabilities. We will use a generalization of the theory used to predict their existence in periodic Hamiltonian systems first proposed by MacKay [3], to see which water wave models meet the necessary conditions for instabilities to arise. We will then examine how these instabilities change if different conditions at the surface are included.

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(Received September 22, 2015)

1116-76-2233 **Olga Trichtchenko***, o.trichtchenko@ucl.ac.uk, and **Jean-Marc Vanden-Broeck**, **Emilian Parau** and **Paul Milewski**. *Computing Three-Dimensional Water Waves.*

The goal of this work is to build on previous results [1,2] to produce a more efficient and accurate method for computing solutions to Euler's equations for water waves in three dimensions. We solve the equations via a numerically implemented boundary integral equations method and employ techniques such as parallelization, preconditioning and iterative methods. This work uses the ideas seen in [4], but under a variety of conditions such as the presence of gravity, surface tension and the effects due to ice. In this talk, we will give details of the current method and present the solutions obtained from implementation in Python.

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(Received September 22, 2015)

1116-76-2238 **Jon Wilkening*** (`wilken@math.berkeley.edu`). *Subharmonic stability of standing waves and traveling waves.*

We present new boundary integral and conformal mapping methods for the spatially quasi-periodic Dirichlet-Neumann operator, and use them to investigate the dynamics of standing waves and traveling waves subject to subharmonic perturbation. We combine Floquet theory in time and Bloch theory in space to study the stability of these waves. We also study temporally quasi-periodic perturbations of pure standing waves. Many examples will be given to illustrate the types of behavior that can occur. (Received September 22, 2015)

1116-76-2345 **Gung-Min Gie*** (gungmin.gie@louisville.edu), Department of Mathematics, University of Louisville, Louisville, KY 40292. *Recent progresses in boundary layer analysis.*

In this talk, we review some recent progresses in boundary layer analysis of singular perturbation problems related to the fluids equations. (Received September 22, 2015)

1116-76-2617 **Joey A Cimochowski*** (jcimocho@asu.edu). *Real and Idealized Simulations of Tropical Cyclone Dynamics: The Impact of Environmental Flow.*

Real and idealized simulations of tropical cyclones are performed to explore how their trajectories change as the initial and environmental conditions are varied. In particular, we consider the speed and direction of the cyclone's drift, the presence of a background flow induced by an additional cyclone, and mean winds. Results show that the orientation of the cyclone's secondary circulation, which arises nonlinearly due to the conservation of potential vorticity, is the main ingredient responsible for the cyclone's evolution. These conclusions explain patterns of motion obtained from observations and high resolution parallel simulations of twin cyclones and Hurricane Sandy. (Received September 22, 2015)

1116-76-2643 **Brandon Hoogstra*** (bhoogstr@asu.edu), **Maher Achour**, **Joey Cimochowski** and **Ché Ortega**. *Numerical Solutions of the Barotropic Non-Divergent Vorticity Equation in the Presence of Tropical Cyclones.*

Simulations of twin tropical cyclones using a recent numerical method within an idealized atmospheric model that solves the barotropic non-divergent vorticity equation in the beta plane were investigated. The model yields a two-dimensional physical interpretation of the development and the evolution of twin tropical cyclones. The research analyzes the effect of both the distance between the cyclones and the planetary vorticity upon the propagation of cyclones. The results demonstrate that as the distance between the cyclones decreases, the nonlinear interaction beween the cyclones supersedes the planetary vorticity. (Received September 22, 2015)

1116-76-2817 **Kyle C Armour*** (karmour@uw.edu), **Yavor Kostov**, **Cecilia M Bitz** and **John Marshall**. *Wind-driven expansion of the Antarctic sea-ice cover.* Preliminary report.

The Southern Ocean (SO) has cooled in recent decades, concurrent with an expansion of its sea-ice cover. Here we argue that these changes are a consequence of two mechanisms: (i) the mean overturning circulation of the SO, which has slowed surface warming by upwelling unmodified water from depth; and (ii) separate processes that have given rise to cooling and sea-ice expansion on top of this background of slow warming. Several processes have been proposed, including freshening of the upper ocean, changes in cloud cover, and changes in the breakup of sea ice by ocean waves. However, a competing hypothesis is that changes in the SO surface westerly winds, due to stratospheric ozone depletion, has driven the cooling and sea-ice expansion. We summarize recent work identifying a two-timescale response of the SO to surface wind changes – rapid cooling followed by slow warming – set by ocean temperature gradients. We then show that within comprehensive general circulation models (GCMs), westerly wind changes can drive SO cooling and sea-ice expansion. Further, GCMs that most closely simulate observed SO temperature gradients also most closely capture the observed cooling and sea-ice expansion in response to winds. (Received September 22, 2015)

1116-76-2835 **Robin Ming Chen** (mingchen@pitt.edu), **Samuel Walsh** (walshsa@missouri.edu) and **Miles H. Wheeler*** (mwheeler@cims.nyu.edu). *Stratified solitary waves.*

We consider solitary water waves with a free surface on a stream with arbitrary density and velocity profiles. After proving symmetry results and bounds on the wave speed, and after ruling out the existence of certain types of monotone bores, we construct a continuous curve of large-amplitude solutions. As one moves along this curve, the horizontal fluid velocity comes arbitrarily close to the wave speed. (Received September 22, 2015)

78 ► Optics, electromagnetic theory

1116-78-1413 **Robert P Lipton*** (lipton@math.lsu.edu), Louisiana State University, Department of Mathematics, Room 384 Lockett Hall, Baton Rouge, LA 70803, and **Robert Viator** (rviato2@lsu.edu), Louisiana State University, Department of Mathematics, Room 343 Lockett Hall, Baton Rouge, LA 70803. *High contrast periodic media: Bloch waves and band gaps.*

A new resonance spectrum for quasi-periodic source free modes is identified and used to represent solution operators associated with electromagnetic and acoustic waves inside periodic high contrast media. The spectra is associated with the Neumann Poincare operator defined on the space of quasi-periodic functions. This representation extends Bloch wave band structure to complex coupling constants. The spectral representation delivers explicit convergent power series in the contrast for dispersion relations associated with Bloch waves inside periodic crystals. The representation is used to recover explicit lower bounds on the contrast between material properties that guarantee convergence of the series as well as separation of spectra for Bloch eigenvalues inside high contrast photonic crystals. (Received September 19, 2015)

80 ► Classical thermodynamics, heat transfer

1116-80-2232 **Bacim Alali*** (bacimalali@math.ksu.edu). *Nonlocal diffusion in composites.*
Convergence of a nonlocal diffusion model inside heterogeneous media in the limit of vanishing nonlocality is analyzed. The associated integral operator converges to its local counterpart in the limit of vanishing nonlocality, when the material diffusivity is sufficiently differentiable. However, when the material diffusivity has discontinuities, as in multiphase composites, the nonlocal diffusion operator diverges, in the local limit, at material interfaces. Nonlocal interface jump conditions are introduced which generalize local interface conditions. A nonlocal diffusion model for composite media that is locally consistent with classical diffusion in composites is presented. (Received September 22, 2015)

81 ► Quantum theory

1116-81-86 **Yutaka Shikano*** (yshikano@ims.ac.jp), 38 Nishigo-Naka, Myodaiji, Okazaki, Aichi 4448585, Japan. *On Nonlinear Quantum Walk.* Preliminary report.
The discrete-time quantum walk shows the interesting dynamics in several models. We studied the one-dimensional nonlinear quantum walk. In our nonlinear model, we show that these has the anomalous diffusion characterized by the q-Gaussian distribution. In addition to our publication [Sci. Rep. 4, 4427 (2014)], in this talk, we would like to discuss the origin of the anomalous diffusion in the nonlinear model. (Received July 20, 2015)

1116-81-262 **Takuya Machida*** (tz14040@meiji.ac.jp), , Japan. *Limit distribution of a quantum walk on a two-dimensional square lattice.*
Quantum walks are quantum counterparts of random walks and the behavior of the quantum walkers has been revealed in long-time limit theorems. The first long-time limit distribution of a two-dimensional walk was obtained in 2008 and the walker is characterized by both localization and linear diffusion [1]. On the other hand, a quantum walk presented in my talk delocalizes and its limit distribution, hence, has just a linear diffusion part. We employ two kinds of coin-flip operator and demonstrate a limit distribution for each operator. The limit density functions show features different from the one obtained in the past study. The result in my presentation is based on [2].

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1116-81-513 **Anna Vershynina*** (annavershynina@gmail.com), Zentrum Mathematik, M5, Technische Universität München, Boltzmannstrasse 3, 85748 Garching, Germany. *Entanglement rates for bipartite open systems.*
The problem addressed in this talk is, given some Hamiltonian and dissipative interactions between two subsystems, what is the maximal rate at which an entanglement can be generated in time? We provide an upper bound on the maximal rate at which this irreversible quantum dynamics can generate entanglement in a bipartite system. The relative entropy of entanglement is chosen as a measure of entanglement in an ancilla-free system. We provide an upper bound on the entangling rate which has a logarithmic dependence on a dimension of a smaller system in a bipartite cut. We also investigate the rate of change of quantum mutual information in an ancilla-assisted system and provide an upper bound independent of dimension of ancillas. (Received September 11, 2015)

1116-81-719 **Anna Vershynina*** (annavershynina@gmail.com), Zentrum Mathematik, M5, Technische Universitat Munchen, Boltzmannstrasse 3, 85748 Garching, Germany. *Complete criterion for convex-Gaussian-state detection.*

We present a new criterion that determines whether a fermionic state is a convex combination of pure Gaussian states. This criterion is complete and characterizes the set of convex-Gaussian states from the inside. If a state passes a program it is a convex-Gaussian state and any convex-Gaussian state can be approximated with arbitrary precision by states passing the criterion. The criterion is presented in the form of a sequence of solvable semidefinite programs. It is also complementary to the one developed by de Melo et. al. in 2013 which aims at characterizing the set of convex-Gaussian states from the outside. Here we present an explicit proof that criterion by de Melo et al. is complete, by estimating a distance between an n-extendible state, a state that passes the criterion, to the set of convex-Gaussian states. (Received September 11, 2015)

1116-81-763 **F Alberto Grunbaum*** (grunbaum@math.berkeley.edu), Math Dept, UC Berkeley, Berkeley, CA 94720. *Recovering a quantum network from input-output amplitude measurements.* Preliminary report.

Abstract

I revisit the problem of recovering the transition amplitudes of a finite network from input-output measurements in a quantum set-up. In the classical case this has been discussed in a joint paper with Laura Matusevich in Internet Mathematics vol 3 , pp 233-252, 2006: An identification problem for multiterminal networks, solving for the traffic matrix from input-output measurements, (Received September 11, 2015)

1116-81-764 **Hideo Mitsuhashi*** (mitsu@cc.utsunomiya-u.ac.jp), 350 Minemachi, Utsunomiya, Tochigi 321-8505, Japan, and **Norio Konno** and **Iwao Sato**. *The discrete-time quaternionic quantum walk and the second weighted zeta function on a graph.*

Recently, quaternionic quantum walks was formulated by Konno and various properties of them were studied. We define a discrete-time quaternionic quantum walk on a graph that can be viewed as an extension of the Grover walk on a graph to the case of quaternions, and study the properties of it. We give the unitary condition on the transition matrix of the quaternionic quantum walk. Under some condition, we determine all the right spectra of the transition matrix by some easily derivable parameters from the transition matrix by using of the theory of the second weighted zeta function. (Received September 12, 2015)

1116-81-837 **Martin Stefanak*** (martin.stefanak@fjfi.cvut.cz), Department of Physics, FNSPE CTU in Prague, Brehova 7, Prague 1, 115 19 Prague, Czech Rep, and **Iva Bezdekova** and **Igor Jex**. *Suitable bases for discrete-time quantum walks.*

The analysis of a physical problem simplifies considerably when one uses a suitable coordinate system. We apply this idea to the discrete-time quantum walks and discuss how does the description of the quantum walk simplify when the initial coin state is decomposed in a suitable basis. In particular, the suitable basis allows us to express the limit distributions in a much more convenient form. Consequently, various interesting features which are hidden in the standard basis description are easily identified. The vectors of the suitable basis are selected from states which result in non-generic behaviour of the quantum walk. We show that for the familiar Hadamard walk and the three-state Grover walk the suitable basis can be formed simply from the eigenvectors of the coin operator. On the other hand, for quantum walks with coins given by $2j + 1$-dimensional Wigner rotation matrices the construction of the suitable basis is more involved, however, we find a recipe to select the suitable basis for arbitrary dimension. (Received September 14, 2015)

1116-81-910 **Jose M Vega-Guzman*** (jose.vegaguzman@howard.edu), 2441 Sixth Street NW, Washington, DC 20059. *Schrödinger groups: An application in nonrelativistic quantum squeezing.*

The maximum kinematical invariance group of the quantum harmonic oscillator is discuss from the viewpoint of an Ermakov-type system. As an example, a multi-parameter family of the square integrable oscillator wave functions, which appears to be not obtainable by standard separation of variables is considered. Such family of wave functions is then used to describe the minimum-uncertainty squeezed states for the harmonic oscillator in nonrelativistic quantum mechanics. The invariance group of the generalized driven harmonic oscillator is shown to be isomorphic to the corresponding Schrödinger group of the free particle. (Received September 15, 2015)

1116-81-961 **Seth S Cottrell*** (cottrell@cims.nyu.edu). *Finding Substructures in Highly Symmetric Graphs Using Quantum Walks and an Efficient Technique for Creating Grover-Type Algorithms.*

In this talk the Grover algorithm will be recast as a discrete time quantum walk on a highly symmetric star graph. I will describe the necessary and sufficient conditions for quadratic-speed searches for any connected subgraph. The quantum walk framework allows for a great deal of generalization. This talk will apply a scattering theory approach to find efficient methods for rapidly calculating all of the necessary quantities for arbitrary graphs; simple enough to be done with pen and paper for smaller graphs. These methods can be used to understand the signal response for any graph, or any combination of connected graphs, and to calculate "how different" a subgraph needs to be to ensure it is detectable using the Grover algorithm. (Received September 15, 2015)

1116-81-979 **Babatunde J FALAYE*** (babatunde.falaye@fulafia.edu.ng), ESFM, Instituto Politécnico Nacional, UPALM, México D. F. 07738, México, México D. F., Mexico. *Formula Method for Bound State Problems.*

We present a simple formula for finding bound state solution of any quantum wave equation which can be simplified to the form of $\Psi''(s)+\frac{(k_1-k_2s)}{s(1-k_3s)}\Psi'(s)+\frac{(As^2+Bs+C)}{s^2(1-k_3s)^2}\Psi(s)=0$. The two cases where $k_3=0$ and $k_3\neq 0$ are studied. We derive an expression for the energy spectrum and the wave function in terms of generalized hypergeometric functions ${}_2F_1(\alpha,\beta;\gamma;k_3s)$. In order to show the accuracy of this proposed formula, we resort to obtaining bound state solutions for some existing eigenvalue problems in a rather more simplified way. This method has shown to be accurate, efficient, reliable and very easy to use particularly when applied to a vast number of quantum potential models. (Received September 15, 2015)

1116-81-983 **Phillip R. Dukes*** (phillip.dukes@utrgv.edu), Phillip R. Dukes, University of Texas Rio Grande Valley, Brownsville, TX 78520. *Continuous-time quantum walks over simply connected graphs, amplitudes and invariants.*

We examine the time dependent amplitude $\phi_i(t)$ at each vertex i of a CTQW on a variety of simply connected graphs. The Lissajous curve of the real vs. imaginary parts of each $\phi_i(t)$ reveals interesting shapes of the space of time-accessible amplitudes. We find two invariants of CTQW's. First, considering the rate at which each amplitude evolves in time the quantity $T=\sum_{i=0}^{n-1}|\frac{d\phi_i(t)}{dt}|^2$ is time invariant. The value of T for any initial state can be minimized with respect to a global phase factor $e^{i\theta t}$ to some value T_{min}. An operator for T_{min} is defined. For any simply connected graph g the highest possible value of T_{min} with respect to the initial state is found to be $T_{min}^{max}=\left(\frac{\lambda_{max}}{2}\right)^2$ where λ_{max} is the maximum eigenvalue in the spectrum of g. A second invariant is found in the time-dependent probability distribution $P_i(t)=|\phi_i(t)|^2$ of any initial state satisfying T_{min}^{max}, with these conditions $\sum_{i=0}^{n-1}\left(P_i^{max}-P_i^{min}\right)^2=\frac{4}{n}$ for all simply connected graphs of n vertices. (Received September 16, 2015)

1116-81-1012 **Salvador Elias Venegas-Andraca*** (salvador.venegas-andraca@keble.oxon.org), Ap. postal 12-808, col. Narvarte, 03001 Mexico City, Mexico. *Quantum Walks with Entangled Coins and Walkers in Superposition.*

The role of entanglement in quantum walks is an open area of research. In [1], Venegas-Andraca *et al* introduce the notion of quantum walks using pairs of coins under different degrees of freedom and numerically shows asymptotical properties, particularly the 'three peak localization phenomenon', that were analytically proved later on (the 'three peak localization phenomenon' reflects the degeneracy of some eigenvalue of the quantum walk evolution operator) [2].

We introduce a generalization of quantum walks with entangled coins [1] consisting of a model of discrete quantum walks with coin pairs under various degrees of entanglement and walkers in quantum superposition as initial states. We introduce novel position probability distributions that may be used for algorithm development based on quantum-mechanical phenomena.

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1116-81-1028 **Boris Hanin*** (bhanin@mit.edu), **Steve Zelditch** and **Peng Zhou**. *Nodal Sets of Random Eigenfunctions of the Harmonic Oscillator.*

Random eigenfunctions at energy E of the isotropic harmonic oscillator in R^d have an $U(d)$ symmetry and are in some ways analogous to random spherical harmonics of fixed degree on S^d, whose nodal sets have been the subject of many recent studies. However, there is a fundamentally new aspect to this ensemble, namely the existence of allowed and forbidden regions. In the allowed region, the Hermite functions behave like spherical harmonics, while in the forbidden region, Hermite functions are exponentially decaying and it is unclear to what extent they oscillate and have zeros. The purpose of this talk is to present several results about the expected volume of the zero set of a random Hermite function in both the allowed and forbidden regions. This is joint work with Steve Zelditch and Peng Zhou. (Received September 16, 2015)

1116-81-1034 **Jaroslav Novotny*** (novotny.jaroslav@seznam.cz), Melioracni 207, Prague - Zbraslav, 15600 Prague, Czech Rep, **Gernot Alber**, Darmstadt, Germany, and **Igor Jex**, Prague, Czech Rep. *Generalized Gibbs states in Quantum Markov Processes.*

One of the basic postulates of statistical physics declares that an equilibrium state of a macroscopic system is characterized by the maximum of its entropy under given constrains (usually integrals of motion). The description of such states requires only a small number of parameters and these states take the form of a Gibbs state. Recently it has been found that Gibbs states play an important role in the description of equilibrium quantum states also on smaller scales. However, in which situations and why the maximum entropy principle could be the proper paradigm for constructing the quantum equilibrium state remains rather unclear yet. In our work we study equilibrium states in the context of quantum Markov processes (including both discrete and continues). For a broad class of quantum Markov processes we identify their asymptotic states as well as their integrals of motion and show that equilibration within quantum Markov processes follows a rule which only for a certain subset of quantum Markov processes coincides with the maximum entropy principle. Surprisingly, taking into account mutual relationships between equilibrium states and integrals of motion, one can show that all resulting equilibrium states can be still cast into a generalized Gibbs state form. (Received September 16, 2015)

1116-81-1218 **Jake Farinholt***, Naval Surface Warfare Ctr, Dahlgren Division, 18444 Frontage Road, Suite 327, Building 1470, Dahlgren, VA 22448-5161. *A Geometric Characterization of Quantum Weak Values.*

In 1988, Aharonov *et al.* discovered "weak measurements" in quantum mechanics. Curiously, these measurements can be constructed such that their measurement results, or "weak values," lie far outside the eigenspectrum of the observable being measured; in fact, they can take on any complex value. More explicitly, let $|\varphi\rangle$ denote the state of the quantum system prior to weak measurement (the "pre-selected state"), let M denote the Hermitian observable being weakly measured, and let $|\psi\rangle$ denote the state of the quantum system after a strong measurement (the "post-selected state"). The corresponding weak value is then given by the following function on the vector space of Hermitian operators:

$$A_{|\varphi\rangle,|\psi\rangle}(M) = \frac{\langle\psi|M|\varphi\rangle}{\langle\psi|\varphi\rangle}.$$

We are driven by the following question. For a given complex number α and some arbitrary weak value function $A = A_{|\varphi\rangle,|\psi\rangle}$, what is the pre-image of α under A? It turns out that the solution is fundamentally geometric, and in turn reveals hitherto unseen underlying geometric structure in weak values. In the case of qubits, we provide a complete geometric characterization. (Received September 17, 2015)

1116-81-1292 **Michael Dombroski*** (dombroskistm11@verizon.net). *Further Extending the Preons of Harari, Shupe and Seiberg using Transpose(\) with Cispose(/).* Preliminary report.

Dr. Don Lincoln, a senior physicist at Fermilab, wrote an article in the November 2012 issue of Scientific American. In it he referred to "a theory of sublime simplicity". He was talking about a straight-forward model of "preons" proposed independently in 1979 by Haim Harari, Michael A. Shupe, and Nathan Seiberg. In this paper we empirically extend the work of HSS by using two sets (a,m) of nine 3x3 matrices (whose elements are 3x3 real integer matrices). The "averages" of the integers of each set are 0 or +1/3. This is analogous to the electric charges of HSS. The well-known Transpose(\) with the important new Cispose(/) transformations, are necessary to generate the newly discovered Fermion Matrices and Boson Matrices. Four sets (aa, am, ma, mm) of four matrices each (16 total) demonstrate 8 pairs of groupings, each pair linked together by the same binary-form shape. http://dombroskiSTM.org (Received September 18, 2015)

1116-81-1367 **David E. V. Rose*** (davidero@usc.edu). *Howe dualities and link invariants.*
Howe duality relates the representation theory of sl(n) and sl(m) in a manner akin to the classical Schur-Weyl duality for representations of sl(n) and the symmetric group. In this talk, we'll discuss results (of the speaker, his collaborators, and others) showing how Howe dualities can be used to study quantum link polynomials and link homology theories. Along the way, we'll discuss applications of this framework to skein modules, their categorified counterparts, and Khovanov-Rozansky homology. (Received September 19, 2015)

1116-81-1372 **Hoel Queffelec** and **David E. V. Rose*** (davidero@usc.edu). *Current algebras, Khovanov-Rozansky homology, and annular link invariants.*
We'll discuss recent work of the speaker (joint with Queffelec) which uses trace decategorification of categorified quantum groups to construct an sl(n) homology theory for links in the thickened annulus. This new invariant is of interest both topologically and representation-theoretically, as it carries an action of sl(n). Along the way, we'll see a new construction that highlights the role of current algebras in Khovanov-Rozansky homology, producing a spectral sequence from annular sl(n) link homology to sl(n) Khovanov-Rozansky homology. (Received September 19, 2015)

1116-81-1419 **F Alberto Grunbaum*** (grunbaum@math.berkeley.edu), Math Dept, UC Berkeley, Berkeley, CA 94720. *Bulk-edge correspondence of one dimensional quantum walks.*
This is a report on joint work with C. Cedzich, C. Stahl, L. Velazquez, A. Werner and R. Werner (arXiv 1502.02592v2).

We study symmetry protected topological phases for one dimensional quantum walks. This plays an important role in the classification of quantum matter, e.g. the distinction between topological and ordinary insulators in lattice systems.

This is well understood in the case of translation invariant systems. Our work allows us to deal with non-translation invariant situations. (Received September 19, 2015)

1116-81-1485 **Carlos F. Lardizabal*** (carlos.felipe@ufrgs.br), Universidade Federal do Rio Grande do Sul, UFRGS - Instituto de Matemática, Av. Bento Goncalves 9500, Porto Alegre, RS 91509-900, Brazil. *Hitting times for open quantum random walks.* Preliminary report.
In this work we consider the setting of open quantum random walks (following S. Attal et al.) and discuss a notion of hitting time for the associated sites. The given definition is motivated by a previous work of the author on recurrence and the structure obtained produces a model which extends classical Markov chain results. A basic technique concerns linear algebraic analysis of certain block matrices and a result obtained is related to a formula for mean hitting times. Part of the presentation is a joint work with Rafael R. Souza. (Received September 20, 2015)

1116-81-1703 **Ian Marquette*** (i.marquette@uq.edu.au), The University of Queensland, School of Mathematics and Physics, Brisbane, QLD 4072, Australia. *Ladder Operators for Rationally-Extended Potentials Connected with Exceptional Orthogonal Polynomials and Superintegrability.*
I will review results concerning k-step extension of the harmonic oscillator and the radial oscillator. These 1D exactly solvable systems are related to Hermite and Laguerre exceptional orthogonal polynomials of type III and allow different types of ladder operators. I will show how ladder operators involving no isolated multiplets exist and can be constructed via combinations of Darboux-Crum and Krein-Adler SUSYQM approaches. I will also discuss the application to 2D superintegrable systems and derivation of their energy spectrum using finitely generated polynomial algebras and their finite dimensional unitary representations. I will also discuss how 1-step and 2-step extension of the harmonic oscillator are connected with an Hamiltonian involving the fourth Painlevé transcendent. (Received September 21, 2015)

1116-81-2020 **Chaobin Liu*** (cliu@bowiestate.edu). *Quantum walks in terms of density operators.* Preliminary report.
A new approach to quantum walks is introduced. Considering a quantum system undergoing some unitary discrete-time evolution in a directed graph G, we think of the vertices of G as sites that are occupied by the quantum system, whose internal state is described by density operators. We formulate the unitary transformation that governs the evolution of the system (Quantum walks), i.e., it maps density operators to density operators of the system on graphs. We then present examples of this type of quantum walks in which diverse probability distributions are shown. (Received September 21, 2015)

1116-81-2067 **Nel Abdiel***, University of Iowa, Department of Mathematics, 2222 Old Hwy 218 S, Iowa City, IA 52242, and **Charles Frohman**. *The Localized Skein Algebra as a Frobenius Extension.*

For a surface of finite type, its Skein algebra at a root of unity can be built as a finite extension of its universal character ring by using the threading map introduced by Bonahon and Wong. This extension, however, may have torsion. Localizing these algebras annihilates the torsion and gives rise to a Frobenius extension. (Received September 21, 2015)

1116-81-2181 **Hideaki Obuse*** (`hideaki.obuse@eng.hokudai.ac.jp`), Department of Applied Physics, Hokkaido University, Sapporo, Hokkaido 060-8628, Japan. *Topological phases of a $\mathcal{PT}$ symmetric non-unitary quantum walk.*

Recently, a non-unitary one-dimensional quantum walk dynamics associated with gain and loss is implemented in a coupled fiber loops experiment [A. Regensburger *et al.*, Nature **488**, 167 (2012]. The fact that the absolute value of the eigenvalue of the non-unitary time-evolution operator is kept to be unity suggests that the quantum walk possesses $\mathcal{PT}$ symmetry (combined parity and time-reversal symmetry). In the present work, we directly identify the $\mathcal{PT}$ symmetry operator, and then verify $\mathcal{PT}$ symmetry of the time-evolution operator, which enable us to modify the system by keeping $\mathcal{PT}$ symmetry. We further study topological phases of the $\mathcal{PT}$ symmetric quantum walk, which is related to a topological insulator described by a $\mathcal{PT}$ symmetric non-Hermite Hamiltonian. We numerically confirm that the number of eigenvalues exhibiting localization is consistent with the topological number. We also find that only edge states originating to topological phases break $\mathcal{PT}$ symmetry in the proper setup. This provides a way to observe the highly intense probability of localized states originating to topological phases on the one-dimensional non-unitary quantum walk in the actual experimental setup. (Received September 22, 2015)

1116-81-2770 **Theodore D Drivas*** (`tdrivas2@jhu.edu`) and **Gregory L Eyink**. *Quantum Spontaneous Stochasticity.*

In fluid turbulence, non-uniqueness due to "roughness" of the advecting velocity field in the zero viscosity limit is believed to lead to stochastic motion of classical particles or "classical spontaneous stochasticity". Analogies between stochastic particle motion in turbulence and quantum evolution suggest that there should be "quantum spontaneous stochasticity" (QSS) for particles in rough potentials. For a repulsive cusp potential $V(x) \sim C|x|^{1+\alpha}$, A. Athanassoulis and T. Paul recently showed that the Wigner function for the quantum particle converges in the classical limit $\hbar \to 0$ to a non-trivial probability measure, so that indeterminacy persists. This result assumes, however, an exact power-law potential down to below the Planck length and well below the scale at which non-relativistic Schroedinger breaks down. To address this issue, we show QSS occurs for 1D models of a particle in a repulsive cusp potential mollified at scale ℓ for an initial Gaussian wave-packet centered at 0 and obtain an estimate of the time (depending on ℓ) it takes to see the effects of the classical indeterminacy. We also show that QSS occurs in the scattering of a wave-packet off the rough potential, though the initial conditions must be well prepared. (Received September 22, 2015)

1116-81-2787 **Arindam Mallick** (`marindam@imsc.res.in`), CIT Campus, Taramani, Chennai, Tamil Nadu 600113, India, and **C. M. Chandrashekar*** (`chandru@imsc.res.in`), CIT Campus, Taramani, Chennai, Tamil Nadu 600113, India. *Dirac quantum cellular automaton from split-step quantum walk.* Preliminary report.

Simulations of one quantum system by an other system has an implications in realization of quantum machine that can imitate any quantum systems and solve problems that are not accessible to classical computers. To engineer quantum simulations, the description of quantum system dynamics have been discretized in space and time to represent quantum cellular automata (QCA), a local unitary update rule on a lattice. The operators defining the QCA are not always in an operational form on an other quantum system. In this talk, starting from a split-step discrete-time quantum walk (DTQW) we present the recovery the Dirac quantum cellular automaton (DQCA). This split-step DTQW implementable in different quantum system can efficiently simulate the Dirac equation (DE) and bridge the connection between DE-DQCA-DTQW. We show that all the fine oscillations and higher entanglement observed in DQCA but not in conventional DTQW are completely recovered using split-step DTQW. We will also present the Zitterbewegung oscillations and Klein paradox from the parameters that define split-step DTQW. (Received September 22, 2015)

1116-81-2867 **Peng Xue*** (gnep.eux@gmail.com), Department of Physics, Southeast University, Nanjing, Jiangsu 211189, Peoples Rep of China. *Quantum Simulations and Quantum Measurements via Quantum Walks.*

Firstly we experimentally investigate a photonic quantum walk and observe typical phenomena known from the wave propagation in periodic structures as ballistic spreading. We introduce site-dependent phase defects to the quantum walk which is realized by adding fully controllable polarization-independent phase shifters and observe localization and Bloch oscillations of the photons for moderate as well as Landau-Zener tunneling for strong phase gradients. Furthermore, we demonstrate a quantum walk with time-dependent coin bias. With this technique we realize an experimental single-photon one-dimensional quantum walk with a linearly-ramped time-dependent coin operation and thereby demonstrate two periodic revivals of the walker distribution. Secondly, by introducing site-dependent coin operation we can realize generalized measurements via a one-dimensional photonic quantum walk by implementing two examples, including unambiguous state discrimination of two equally probable single-qubit states and symmetric informationally complete positive operator value measurement on a single qubit. (Received September 22, 2015)

82 ► Statistical mechanics, structure of matter

1116-82-1129 **Thomas Joachim Bothner*** (bothner@umich.edu), 2074 East Hall 530 Church Street, Ann Arbor, MI 48109-1043. *From gap probabilities in random matrix theory to eigenvalue expansions.*

We present a method to derive asymptotics of eigenvalues for trace-class integral operators $K : L^2(J; d\lambda) \circlearrowleft$, acting on a single interval $J \subset \mathbb{R}$, which belong to the ring of integrable operators. Our emphasis lies on the behavior of the spectrum $\{\lambda_i(J)\}_{i=0}^{\infty}$ of K as $|J| \to \infty$ and i is fixed. We show that this behavior is intimately linked to the analysis of the Fredholm determinant $\det(I - \gamma K)|_{L^2(J)}$ as $|J| \to \infty$ and $\gamma \uparrow 1$ in a Stokes type scaling regime. Concrete asymptotic formulæ are obtained for the eigenvalues of Airy and Bessel kernels in random matrix theory as well as kernels which are related to a Painlevé I hierarchy. (Received September 17, 2015)

1116-82-2734 **R. M. Argus*** (rargus@masonlive.gmu.edu), 8256 Vernon Street, Manassas, VA 20109. *Boltzmann-Type Modeling of Two-Dimensional Grain Growth in Polycrystals.* Preliminary report.

We study the mesoscopic behavior of a grain boundary network and propose a novel two-dimensional model describing the evolution of the distribution of misorientations. The model obtained is able to capture both small grain disappearances and neighbor switching events. The collision rate parameters involved can be estimated numerically from a large-scale simulation. From this we are able to predict steady-state statistics as well as coarsening rates for normal isotropic grain growth. (Received September 22, 2015)

1116-82-2810 **Reza R Ahangar*** (reza.ahangar@tamuk.edu), 700 University BLVD, Texas A&M University - Kingsville, Kingsville, TX 78363. *Complex Matter Space and Relativistic Quantum Mechanics.*

The Special Theory of Relativity cannot recognize speed faster than the speed of light. New assumption will be postulated that matter has two intrinsic components, i) mass, and ii) charge, that is M=m+iq . The mass will be measured by real number system and charge by an imaginary unit. We will use the Complex Matter Space to present the Relativistic Quantum Mechanics . We are hoping that this approach will help us to present a general view of energy and momentum in Complex Matter Space and lead to a better understanding toward the conversion of mass and energy equation, unifying the forces, and unifying relativity and quantum mechanics. (Received September 22, 2015)

85 ► Astronomy and astrophysics

1116-85-429 **Chrisopher J Winfield*** (cjwinfield01@alaska.edu), Dept. of Mathematics and Statistics, University of Alaska Fairbanks, P.O. Box 756660, Fairbanks, AK 99775. *Continuum Eigenmodes in Some Linear Stellar Models.* Preliminary report.

We apply parallel approaches in the study of continuous spectra to adiabatic stellar models. We seek continuum eigenmodes for the Linear Adiabatic Wave Equation (LAWE) in both finite difference and linear differential equations. In particular, we apply methods of Jacobi matrices in finite difference equations and methods of subordinancy theory in ordinary differential equations. We find certain pressure-density conditions which admit positive-measured sets of continuous oscillation spectra under plausible conditions on density and pressure. We arrive at cases of unbounded oscillations and computational or, perhaps, dynamic instability. (Received September 01, 2015)

86 ► Geophysics

1116-86-315 **Till Wagner** and **Ian Eisenman***, 9500 Gilman Dr, La Jolla, CA 92093-0230. *How climate model complexity influences the sea ice stability.*

Two types of idealized climate models find bifurcations and associated instabilities during the retreat of sea ice under global warming: (i) latitudinally-varying annual-mean diffusive energy balance models (EBMs) and (ii) seasonally-varying single-column models (SCMs). Comprehensive global climate models, however, typically find no such instabilities. To bridge this gap, we develop an idealized model that includes both latitudinal and seasonal variations. The model reduces to a standard EBM or SCM as limiting cases in the parameter regime. We find that the stability of the sea ice cover vastly increases with the inclusion of spatial communication via meridional heat transport or a seasonal cycle in solar forcing, being most stable when both are included. This implies that the sea ice cover may be substantially more stable than has been suggested in previous idealized modeling studies. (Received August 24, 2015)

1116-86-1087 **Jennifer K Hutchings***, jhutchings@coas.oregonstate.edu, and **Andrew Roberts**, **Cathleen A Geiger** and **Jacqueline Richter-Menge**. *Spatial scaling of sea ice deformation.*

Horizontal deformation, divergence and shear, modifies the sea ice thickness distribution through ridging and lead opening. Hence it has profound effects on the survivability of pack ice in summer. We demonstrate the scaling properties of sea ice deformation with an array of drifting buoys in the Beaufort Sea.. Deformation is a multi-fractal process, and is scale invariant over spatial scales of 10-1000 km and temporal scales of hours to a day. However there is coupling between spatio-temporal scaling. Sea ice deformation displays coherence between scales of roughly 100 to 1000 km and synoptic time scales of days to weeks. The transition from a winter to spring ice pack is observed as a loss of coherence at greater than synoptic time scales, and changes in coherence are related to weather. At smaller spatiotemporal scales coherence is lost, with deformation tending to a white noise process. The lack of coherence at small scales suggests it is inappropriate to think of sea ice deformation as having a decorrelation length scale. Localization of deformation is observed to retain its character over the winter-spring transition. This has implications for model parameterization of thickness redistribution.
(Received September 16, 2015)

1116-86-1269 **J V Lukovich*** (`jennifer.lukovich@umanitoba.ca`), 125 Dysart Road, Winnipeg, MB R3T 2N2, and **J K Hutchings** (`jhutchings@coas.oregonstate.edu`), **K M Golden** (`golden@math.utah.edu`), **N B Murphy** (`nbmurphy@math.uci.edu`), **H Dinh** (`hdinh2707@gmail.com`) and **E Fang**. *Sea ice dispersion and anomalous diffusion: patterns and paradigms.*

Accelerated change in sea ice dynamics in the Arctic and an underestimation of this change in IPCC models emphasizes the importance of understanding transitions in the dynamical characteristics of the ice drift field. Central to this understanding is the identification of flow topology and distinct dynamical regimes, which provide alternative characterizations to sea ice concentration, extent, and age. Lagrangian dispersion statistics and, in particular, temporal scaling laws provide diagnostic tools for the identification of dynamical regimes and the dispersive nature of these regimes, which provides insight into the stirring and mixing characteristics of the ice drift field.

We use the mean squared displacement of individual sea ice floes, which scales as time raised to an exponent, to establish a correspondence between flow topology and the scaling exponent, which characterizes distinct dynamical regimes and anomalous diffusive flow patterns. We will also examine temporal scaling maps and anomalous diffusion as a way of characterizing compressible and incompressible flow regimes of sea ice dispersion, for different ice types and zones with varying sea ice compactness and strengths. (Received September 18, 2015)

1116-86-1319 **Randall J LeVeque*** (`rjl@uw.edu`), Seattle, WA 98195. *Algorithms for Probabilistic Tsunami Hazard Assessment.* Preliminary report.

Probabilistic Tsunami Hazard Assessment (PTHA) for a coastal community or harbor can be performed by running a tsunami propagation/inundation code with initial seafloor deformations sampled from some presumed

probability distribution of possible earthquakes. Standard approaches use logic trees developed by consensus among seismologists, but an alternative is to generate stochastic realizations based on the expected spatial correlation of slip on a fault plane, e.g. using Karhunen-Loeve expansions. Efficient techniques are then needed to sample this high-dimensional space when each tsunami simulation can take hours of computing time. Some new approaches will be discussed along with an introduction to the finite volume method and adaptive mesh refinement used in the GeoClaw tsunami model. This software, developed by the speaker in collaboration with many others, is being used for tsunami hazard assessment projects in Washington State and beyond. (Received September 18, 2015)

1116-86-1877 **D. Sulsky***, Department of Mathematics and Statistics, University of New Mexico, Albuquerque, NM 87131, and **H. Tran** and **H. Schreyer**. *A multiscale, anisotropic, elastic-decohesive constitutive relation for modeling sea ice.*

Satellite imagery indicates that much of the winter Arctic ice deformation is concentrated in linear features, like cracks. The aim of this research is to build on a previously formulated elastic-decohesive constitutive model that predicts the initiation, orientation and extent of cracks and tie it more closely to the thermodynamics and the distribution of ice thickness. The classical rule-of-mixtures is applied for the ice 'composite' having an oriented distribution of thickness to derive the moduli and the strengths of the equivalent material. At failure, a decohesive constitutive relation based on the traction on a potential crack plane is employed in the anisotropic material. Examples are given to illustrate aspects of the model when simulating the failure of sea ice. (Received September 21, 2015)

1116-86-2179 **Rolando Cardenas*** (rcardenas4@yisd.net), 8100 Turquoise Street, El Paso, TX 79904. *The Software Development for a Three Dimensional Gravity Inversion and Application to Study of The Border Ranges Fault System, South-Central Alaska.*

The Border Ranges Fault System (BRFS is an important petroleum province within south-central Alaska. A primary goal of my research is to test several plausible models of structure along the BRFS using a novel three-dimensional inversion technique utilizing gravity data, constrained with other geophysical, borehole and surface geological information. This research involves the development of three-dimensional inversion modeling software. The novel inversion approach directly models known geology with "a priori" uncertainties assigned to the geologic model. This technique was developed to evaluate three-dimensional structure in regions of complex and poorly known geology. The software computes the density solution of a geologic structure by utilizing its location within the gravity field as well as the gridded surface files of known topography and subsurface units. The total gravitational effect of each body is calculated with a series of semi-infinite vertical line elements which improves the computational efficiency of computing forward models of structures with extremely complex geometry. The inversion algorithm considers "a priori" geophysical constraints and uncertainties due to gravity measurements, surface file inconsistencies, and forward calculations in the model solution. (Received September 22, 2015)

1116-86-2334 **Reed Ogrosky*** (ogrosky@math.wisc.edu) and **Samuel Stechmann**. *Modeling and data analysis of large-scale rainfall events and convection in the tropics.*

Rainfall and clouds, i.e. convection, in the tropics occur on many temporal and spatial scales. Increasing our understanding of tropical convection is essential due both to its large economic and societal impacts in the tropics as well as its close connections to events in the midlatitudes and beyond. I will present results from both deterministic and stochastic models for several large-scale phenomena in the tropical atmosphere that are coupled with rainfall patterns, including the Walker circulation and the Madden-Julian oscillation. It will be shown that these results agree remarkably well with observed events and accurately capture typical event lifetime, propagation characteristics, frequency, intermittency, and strength. This agreement is found using a data analysis technique based on solutions to the shallow water equations frequently used in studying the tropical atmosphere. Additional applications of the data analysis method will also be discussed, including identifying the signals of convectively coupled equatorial waves in observational data. (Received September 22, 2015)

1116-86-2557 **Adam H Monahan***, monahana@uvic.ca, and **Amber Holdsworth** and **Timothy Rees**. *The Probability Distribution of Near-Surface Wind Speed in Stably Stratified Conditions.*

The variability of near-surface winds exerts a leading order influence on surface fluxes of mass, energy, and momentum - and is in turn influenced by these surface fluxes. While there is a long history of empirically-based probabilistic models of near-surface wind variability, relatively little physical attention has been paid to this problem until recently.

In this talk, I will discuss how we have been using approaches from nonlinear time series, dynamical systems, and stochastic differential equations in the development of physically-based probabilistic models of near-surface wind variability, with a focus on the influence of near-surface stratification. Conditions of stable stratification (such as are common over sea ice) will be shown to be particularly interesting: we will demonstrate that observations of the temperature and wind structure in these conditions are characterized by two distinct states (the very stable and weakly stable boundary layers). Idealized models of the near-surface momentum and energy budgets will be used to study the physical origin of these regimes and of transitions between them. In particular, we will discuss a destabilizing feedback resulting from the existence of a maximum sustainable turbulent heat flux under stable stratification. (Received September 22, 2015)

1116-86-2670 **N Benjamin Murphy*** (nbmurphy@math.uci.edu), 340 Rowland Hall, University of California, Irvine, Irvine, CA 92697-3875. *Spectral analysis of transport in sea ice.*
Sea ice is a multiscale composite which mediates a broad range of geophysical processes in the polar marine environment and plays a key role in climate. The composite structure of sea ice ranges from sub-millimeter brine inclusions to kilometer sized melt ponds atop vast ice floes. Fluid flow through porous sea ice helps control the drainage of melt ponds which, in turn, determine the albedo of the ice pack, a key parameter in climate modeling. The analytic continuation method provides a rigorous approach to treating the transport properties of such composites, as well as the advection enhanced diffusive transport of tracers and sea ice floes. The method provides Stieltjes integral representations for the associated bulk transport coefficients, involving the spectral measure of a random matrix which depends only on composite geometry. In this talk we will look at transport in sea ice through the lens of random matrix theory. We will discuss connectedness-driven transitions in its microstructural transport properties, in terms of transitions in the statistical properties of the eigenvalues of the matrix as well as the delocalization of its eigenvectors – analogous to Anderson localization in quantum systems. The spectral description of advective-diffusion will also be discussed. (Received September 22, 2015)

90 ► Operations research, mathematical programming

1116-90-200 **Qi Yang*** (yangq@usc.edu), **Alejandro Camacho**, **Piyali Mukherjee** and **Rafael Aguayo**. *Detecting Foot-Chases from Police Body-Worn Video.*
Existing methods to record interactions between the public and police officers are unable to capture the entirety of police-public interactions. In order to provide a comprehensive understanding of these interactions, the Los Angeles Police Department (LAPD) intends to utilize *Body-Worn Video* (BWV) collected from cameras fastened to their officers. BWV provides a novel means to collect fine-grained information about police-public interactions. The purpose of this project is to identify specific features from videos, in particular foot-chases, using machine-learning algorithms. Our proposed algorithm uses semi-supervised methods such as the detection of point-features and their classification via support-vector machines. Our training dataset consists of 100 training videos (20 foot-chase & 80 non-foot-chase) and a test dataset of 60 LAPD videos (4 foot-chase & 56 non-foot-chase). We achieved results of 91.6% testing accuracy. This is joint work with Hayden Schaeffer and P. Jeffrey Brantingham. (Received August 13, 2015)

1116-90-520 **Alexander J Zaslavski*** (ajzasl@tx.technion.ac.il), Technion-Israel Institute of Technology, 32000 Haifa, Israel. *Approximate solutions of common fixed point problems.*
The common fixed point problem is to find a common fixed point of a finite family of mappings in metric spaces. In this talk our goal is to obtain its approximate solution in the presence of computational errors. (Received September 05, 2015)

1116-90-569 **Ram Verma*** (ram.verma@unt.edu). *Minmax Fractional Integral Programming Problems on Univexities.* Preliminary report.
In this communication, we investigate the problem of minimizing a maximum of several time dependent ratios involving integral type models. We start off establishing some optimality conditions based on the generalized univexities, and then consider the Wolfe type dual model, Mond type dual model, and mixed type dual model leading to weak, strong and strict converse duality theorems using the generalized univexity assumptions. The established findings have significant applications to multitime multiobjective variational problems as well as multiobjective control problems. (Received September 07, 2015)

1116-90-1232 **Zachary Feinstein*** (zfeinstein@ese.wustl.edu) and **Birgit Rudloff**. *A recursive algorithm for set-valued risk measures and relation to set-valued Bellman's principle.*

A method for calculating multiportfolio time consistent set-valued risk measures in discrete time is presented. Market models for d assets with transaction costs or illiquidity and possible trading constraints are considered on a finite probability space. The set of capital requirements at each time and state are calculated recursively backwards in time along the event tree. We motivate why the proposed procedure can be seen as a set-valued Bellman's principle. We give conditions under which the backwards calculation of the sets reduces to solving a sequence of linear and convex vector optimization problems. Numerical examples are given and include superhedging under illiquidity, the set-valued entropic risk measure, and the multiportfolio time consistent version of the relaxed worst case risk measure and of the set-valued average value at risk. (Received September 18, 2015)

1116-90-1320 **James Saunderson*** (jamesfs@uw.edu) and **Hamza Fawzi** (hfawzi@mit.edu). *Matrix geometric means and semidefinite optimization.*

The weighted geometric mean of two positive scalars has a natural generalization to a pair of positive definite matrices. It is jointly matrix concave in its two arguments, a fact which leads to the joint concavity/convexity of many remarkable functions arising in matrix analysis and quantum information theory. We show how to express the (hypograph of the) weighted matrix geometric mean in terms of the feasible region of a semidefinite optimization problem, whenever the weight is rational. The size of our semidefinite description depends only on the logarithm of the denominator of the rational weight. This allows us to use standard software for semidefinite optimization to approximately solve optimization problems involving the quantum relative entropy function, among others. (Received September 18, 2015)

1116-90-1353 **Igor Mikolic-Torreira*** (imikolic@rand.org), RAND Corporation, 1200 South Hayes Street, Arlington, VA 22202, and **Ronald H Nickel** (nickelr@cna.org) and **Jon W Tolle**. *Computing Aviation Sparing Policies: Solving a Large Nonlinear Integer Program.*

Aircraft carriers stock a large number of spare parts to support the various types of aircraft embarked on the ship. The sparing policy determines the spares that will be stocked on the ship to keep the embarked aircraft ready to fly. The objective of this work is to find a minimum-cost sparing policy that meets the readiness requirements of the embarked aircraft. This is a very large, nonlinear, integer optimization problem. The cost function is piecewise linear and convex while the constraint mapping is highly nonlinear and non-convex. The distinguishing characteristics of this problem from an optimization viewpoint are that a large number of decision variables are required to be integer and that the nonlinear constraint functions are are very difficult (and expensive) to evaluate and their derivatives are not available. We employ a pattern search method to each iteration of an interior point-type algorithm to solve the relaxed version of the problem. From the solution found by the pattern search on each interior point iteration, we begin another pattern search on the integer lattice to find a good integer solution. (Received September 18, 2015)

1116-90-1722 **J.Y. Bello Cruz*** (yunier@ufg.br), Rua 262 #45, Apt. 304, Bl. 2B, Universitario, Goiania, Goias 74615300, Brazil, and **T.T.A. Nghia**. *On the complexity of the proximal gradient iteration for nonsmooth convex minimization problems in Hilbert spaces.*

In this talk we present the convergence and complexity analysis of the iterates in the proximal gradient method with linesearches. When the stepsizes generated by the linesearch are bounded below by a positive number, our analysis shows that the expected error from the cost value at the k-th iteration to the optimal value is $\mathcal{O}(k^{-1})$ in Hilbert spaces and $o(k^{-1})$ in finite dimensions, which improves the complexity of the first-order algorithm presented in the literature. It is worth emphasizing that the global Lipschitz continuity assumption on the gradient of f is sufficient but not necessary for the boundedness from below of the stepsizes aforementioned. Moreover, we show that if the gradient of f is locally Lipchiptz the stepsizes generated by the linesearch are bounded below by a positive number. Furthermore, we answer the main question here: "Can we have the complexity $o(k^{-1})$ when $\liminf_{k\to\infty} \alpha_k = 0$?" with an example. (Received September 21, 2015)

1116-90-2001 **Robert Lion Gottwald**, **Courtney Y. Kempton**, **David Y. Leffler** and **Li Qian*** (li.qian14@myhunter.cuny.edu). *Problem Specific Primal Heuristics for Supply Chain Management in a General MIP Solving Framework.* Preliminary report.

Supply chain management (SCM) is the management of the flow of goods and products through a network consisting of transportation and production. Due to the vast number of integral variables involved in the mixed-integer programming formulations of SCM, even state-of-the-art mixed-integer programming (MIP) solvers often fail to find good solutions within a reasonable amount of time. We propose three new primal heuristics aimed at

utilizing the SCM-specific problem structure to improve the solving process of SCM problems. The methods were developed and tested within SCIP (a MIP solver developed at Zuse Institute Berlin) on four different categories of test instances representing real-world SCM problems. In addition to the development of these heuristics we test the correlation of a large set of features with solution quality. In our computational experiments, two of the new heuristics, Strong Rounding and Time-Horizon Sub-MIP, were able to improve the primal integral on the majority of our test instances. Furthermore, our analysis of solution features found the median of delivered demand rate per material to be a good indicator of solution quality. (Received September 21, 2015)

1116-90-2162 **Yun Lu*** (lu@kutztown.edu), Department of Mathematics, Kutztown University of PA, Kutztown, PA 19530, and **Francis Vasko**. *A Metaheuristic for the Multidimensional Multiple Choice Knapsack Problem.* Preliminary report.

A metaheuristic based on the relationship between teachers and learners has recently been proposed to solve continuous nonlinear optimization problems. It is of particular interest because it requires no parameter fine-tuning other than determining the population size and convergence criteria. In this paper, we enhance the performance of the TLBO method by introducing "a local neighborhood search on the best solution" before the teaching phase of TLBO. We use it to solve the problems from the literature for multiple-choice multidimensional knapsack problem (MMKP), and demonstrate that TLBO outperforms the best published solution approaches for the MMKP. (Received September 22, 2015)

1116-90-2657 **Cosmin G Petra*** (petra@mcs.anl.gov), 9700 S. Cass Avenue, Bldg 240, Lemont, IL 60439. *Scalable optimization of complex energy systems under uncertainty using high-performance computers.*

Complex energy systems, such as the U.S. power grid, are affected by increased uncertainty of its target power sources, due for example to increasing penetration of wind power coupled with the physical impossibility of very precise wind forecast. Optimization of such systems under uncertainty results in extremely large optimization problems that can be solved only by means of high-performance computing (HPC). We present scalable algorithms and implementations for the solution of stochastic linear and nonlinear programming problems with recourse. Our computational approach is based on interior point methods and implements specialized distributed memory linear algebra. We present and discuss numerical simulations of electricity dispatch models for the State of Illinois obtained on leadership HPC platforms of the U.S. Department of Energy. (Received September 22, 2015)

1116-90-2851 **Jesica Bauer*** (jbauer@carroll.edu). *Mathematics in Service to the Community: Mathematical Modeling for the Helena Food Share.*

The Helena Food Share (HFS) is a non-profit organization in Montana which provides over 5,000 pounds of food to the over 1,500 families in the Helena area each month. Like many non-profits, HFS faces issues keeping needed food stocked, storing it efficiently, and distributing volunteers to keep the system running at peak efficiency. In this talk, we discuss the methods for posing the challenges HFS faces in an optimization framework so that we can apply linear programming techniques to help address their problems. Finally, we will discuss challenges we encounter in adapting our mathematical solutions to fit the needs of the Helena Food Share. (Received September 22, 2015)

1116-90-2892 **Aleksandr Y Aravkin** (sasha.aravkin@gmail.com), University of Washington, Applied Math, Seattle, WA 98195, **James V Burke*** (jvburke@uw.edu), Uiniversity of Washington, Math, Seattle, 98195, **Dmitriy Drusvyatskiy** (ddrusv@uw.edu), University of Washington, Math, Seattle, WA 98195, **Michael P Friedlander** (mpf@math.ucdavis.edu), University of California, Davis, Math, Davis, CA 95616, and **Scott Roy** (scott.michael.roy@gmail.com), University of Washington, Math, Seattle, WA 98195. *Optimal value function methods for numerical optimization.*

Convex optimization problems arising in applications often have favorable objective functions and complicated constraints, making first-order methods not immediately applicable. One approach is to exchange the objective and the constraint functions, leading to a parametric family of efficiently solvable optimization problems. A zero-finding procedure, based on inexact function evaluations and possibly inexact derivative information, leads to an approximate solution of the original problem. In this tslk, we take a fresh new look at this framework focusing on particular applications and the resulting iteration bounds. Properties of the value function and insensitivity of the method to conditioning of the underlying problem play an important role. Examples illustrate the results. (Received September 22, 2015)

1116-90-2946 **RAM N MOAHPATRA*** (ramm1627@gmail.com), Mathematics Department, University of Central Florida, Orlando, FL 32816, and **RAM U VERMA** (verma99@msn.com), Department of Mathematics, University of North Texas, Denton, Denton, TX 72601. *Mathematical Programming Based on Sufficient Optimality Conditions and Second Order Invex Functions.*

Based on a comprehensive second order generalization of invexities, which encompass most of the existing generalized invexity concepts in the literature, a wide range of parametric sufficient optimality conditions leading to the solvabilty for multiobjective fractional programming problems are established with some other related results.To the best of our knowledge, the results obtained seem to be most advanced on generalized higher order invexities. (Received September 23, 2015)

1116-90-2967 **Xin Li*** (xin.li@ucf.edu). *On an alternating direction method for solving a weighted low-rank approximation problem.* Preliminary report.

For a given matrix, we study a version of its low rank approximation under a weighted Frobenius norm. It is known that, due to the presence of the weight, there is no closed form formula for the solution to this problem in general. In this talk, I will discuss an algorithm based on the alternating direction method (ADM) and present some recent results on its convergence. (Received September 23, 2015)

91 ► Game theory, economics, social and behavioral sciences

1116-91-184 **Carole Bernard** and **Stephan Sturm*** (ssturm@wpi.edu), Department of Mathematical Sciences, 100 Institute Road, Worcester, MA 02111. *Rationalizing Behavioral Portfolio Choice.* Preliminary report.

Classical portfolio optimization theory postulates that investors' preferences are rational and the optimization criterion is expected utility, for some increasing and concave utility function. This contrasts with with empirical finding of cognitive psychology. In particular, small extreme events are usually overweighted by investors, losses and gains far away from the reference point have less impact and, losses are usually feared more than gains. These findings lay the basis for the theory behavioral portfolio choice. In this talk we try to answer the question if (resp. under which conditions), a given behavioral portfolio choice in a general incomplete semimartingale market can be replicated in the rational expected utility framework. (Received August 11, 2015)

1116-91-267 **Madeleine Weinstein*** (mweinstein@hmc.edu). *Invariance of the Sprague-Grundy Function for Variants of Wythoff's Game.*

We prove three conjectures of Fraenkel and Ho regarding two classes of variants of Wythoff's game. The two classes of variants of Wythoff's game feature restrictions of the diagonal moves. Each conjecture states that the Sprague-Grundy function is invariant up to a certain nim-value for a subset of that class of variant of Wythoff's game. For one class of variants of Wythoff's game, we prove that the invariance of the Sprague-Grundy function extends beyond what was conjectured by Fraenkel and Ho. (Received August 19, 2015)

1116-91-286 **yuhki hosoya***, 1-50-1, Mutsuurahigashi, Kanazawa-ku, Yokohama, Kanagawa 236-8501, Japan. *the relationship between revealed preference and the slutsky matrix.*

This study provides a calculation method for utility function from a smooth demand function whose Slutsky matrix is negative semi-definite and symmetric. Moreover, this study presents an axiom of demand functions, and show that under the strong axiom, this axiom is equivalent to the existence of the corresponding continuous preference relation. If the demand function obeys this axiom, then such a preference relation is unique, and our calculating utility function represents its preference relation. these results are obtained even if the demand function is not income-Lipschitzian. Further, this study shows that the mapping from demand function into continuous preference relation is continuous, which assures the applicability of our results for econometrics. Moreover, this study shows that if this demand function satisfies the rank condition, then our utility function is smooth. Lastly, this study shows that under an additional axiom, the above results hold even if the demand function has a corner solution. (Received August 22, 2015)

1116-91-494 **Arash Fahim*** (fahim@math.fsu.edu), 1017 Academic Way, 208 J. Love Building, Department of Mathematics, Tallahassee, FL 32306, and **Nizar Touzi** (nizar.touzi@polytechnique.edu), Centre de Mathematiques Appliquees, Ecole Polytechnique, UMR CNRS 7641, 91128 Palaiseau, Cedex, France. *Impact of the Carbon Market on Production Emissions.*

Since the creation of carbon emission markets, many questions have arisen about their effectiveness on reducing the pollution. We investigate the effect of carbon market in the production of a large polluter in two cases: when the firm cannot affect the risk premium of the emission market, and when it can change the risk premium by its production. In this simple model, we ignore any possible investment of the firm in pollution reducing technologies. We formulate the problem of optimal production by a stochastic optimization problem. Then, we show that, as expected, the market reduces the optimal production policy in the first case if the firm is not given a generous initial cheap allowance package. However, when the large producer activities can change the market risk premium, the cut on the production and consequently pollution cannot be guaranteed. In fact, there are cases in this model when the optimal production is always larger than expected, and an increase in production, and thus pollution, can increase the profit of the firm. We conclude that some of the parameters of the market which contribute to this effect can be wisely controlled by the regulators in order to diminish this manipulative behavior of the firm. (Received September 04, 2015)

1116-91-1018 **Birgit Rudloff*** (brudloff@wu.ac.at), Vienna University of Economics and Business, Institute for Statistics and Mathematics, Vienna, Austria, and **Zachary Feinstein** and **Stefan Weber**. *Measures of Systemic Risk.*

Systemic risk refers to the risk that the financial system is susceptible to failures due to the characteristics of the system itself. The tremendous cost of this type of risk requires the design and implementation of tools for the efficient macroprudential regulation of financial institutions. We propose a novel approach to measuring systemic risk. Key to our construction is a rigorous derivation of systemic risk measures from the structure of the underlying system and the objectives of a financial regulator. In contrast to most of the literature, feedback effects of capital charges onto the system can be considered. Systemic risk is measured by the set of allocations of additional capital that lead to acceptable outcomes. We explain the conceptual framework and the definition of systemic risk measures, provide an algorithm for their computation, and illustrate their application in numerical case studies. We apply our methodology to systemic risk aggregation extending Chen, Iyengar & Moallemi (2013) and to network models as suggested in the seminal paper of Eisenberg & Noe (2001) and their generalizations as in Cifuentes, Shin & Ferrucci (2005). (Received September 16, 2015)

1116-91-1187 **Albert Cohen***, albert@math.msu.edu, and **Nick Costanzino**. *Bond and CDS Pricing with Stochastic Recovery.*

The quantitative finance literature tries to decompose the risk premia of corporate debt through a number of risk drivers. This helps quantify the exposure to each risk factor and gives the investor a program to hedge away any unwanted risk. The typical risk drivers are default risk, interest rate risk, liquidity risk, and contagion risk. Recovery risk as a source of risk premia has not received much attention so far, most likely due to the difficulties around decomposing the expected loss. Thus, an investor has no way to quantify their exposure to recovery risk, and no way to determine how to hedge away the unwanted risk. This view is supported by a recent empirical study which shows that investors are taking on a significant amount of recovery risk for which they are not being properly compensated.

Classical structural models like Merton and Black-Cox provide an internally consistent way to price credit risk, especially default risk, in many financial instruments. We present here a methodology that enables separation of the recovery risk premium from the default risk premium in these two models. (Received September 17, 2015)

1116-91-1204 **Christopher Cox** (cocox@andrew.cmu.edu), **Jessica De Silva*** (jessica.desilva@huskers.unl.edu), **Philip DeOrsey** (pdeorsey@ehc.edu), **Franklin H.J. Kenter** (franklin.h.kenter@rice.edu), **Troy Retter** (tretter@emory.edu) and **Josh Tobin** (rjtobin@ucsd.edu). *How to Make the Perfect Fireworks Display: Two Strategies for* Hanabi.

A participant's perspective is given on the mathematical, professional, and social components of GRWC, as well as results on a research project with a unique origin. One of many traditional social festivities at GRWC is game night, where we played a cooperative card game known as *Hanabi*. A few games and strategic conversations later, *Hanabi* became its own research project. In *Hanabi*, a player can not see the cards in her hand, and must rely on the actions of the other players to gain information about her cards. Based on ideas used in hat guessing games,

we developed two strategies for *Hanabi* which performed well in computer simulations. (Received September 17, 2015)

1116-91-1219 **Anh V. Nguyen** (anh.v.nguyen@tcu.edu), **Jasmeet S. Saini*** (jssaini@uncg.edu), **Jan Rychtar** (rychtar@uncg.edu) and **Jonathan T. Rowell** (jtrowell@uncg.edu). *Cooperation in Finite Populations: Being Alone Helps.*

We consider the evolution of cooperation in finite populations and we model a scenario where two individuals can interact only if both intend to do so with their counterpart. This feature allows a possibility for individuals to remain alone for a given round and not interact with anybody. Such an individual receives a baseline payoff rather than one based upon a matrix game. We provide sufficient conditions on the payoff matrix that will guarantee fixation probabilities to be monotone relative to the baseline payoff. We then apply the findings to the Prisoner's Dilemma and Hawk-Dove games. In both cases, the possibility that an individual might remain alone increases the chances that cooperation or non-aggression fixes within the population. Moreover, weak selection models overlap with our model, and we consider how one can generalize our model even further. (Received September 18, 2015)

1116-91-1221 **Timmy Ma*** (timmym@math.uci.edu), Department of Mathematics, University of California, Irvine, Irvine, CA 92697, and **Natalia Komarova**. *Regularization of languages: a new mathematical framework of learning from an inconsistent source.* Preliminary report.

Continuing the discussion of how children can modify and regularize linguistic inputs from adults, we study the key features of the regularization of language. We present a new interpretation of existing algorithms to model and investigate the process of a learner learning from an inconsistent source. Our model allows us to analyze and present a theoretical explanation of a frequency boosting property, whereby the learner surpasses the fluency of the source by increasing the frequency of the most common input. (Received September 18, 2015)

1116-91-1422 **Emmanuel Ncheuguim*** (ekengnin@svsu.edu), **Joseph Ofori-Dankwa** and **Seth Appiah-Kubi**. *The Truncated Levy Flight Model: A Comparative Analysis of its Utility in Modeling the Standard and Poor's 500 and the Ghana Stock Exchange.* Preliminary report.

The Truncated Levy Flight (TLF) model has been successfully used to model the return distribution of stock markets in developed economies and a few developing economies such as India. Our primary purpose was to use the TLF to model the S&P 500 and the firms operating in the Ghana Stock Exchange. We assess the predictive efficacy of the TLF model by comparing a simulation of S&P 500 index and that of firms in the stock market in Ghana, using data from the same time period (June 2007 to September, 2013). We find that the Levy models relatively accurately model the return distributions of the S&P 500 but do not accurately model the return distributions of firms in the Ghana stock market. We highlight the research implications of these findings and call for further research using data from emerging economies such as those in sub-Saharan Africa. (Received September 19, 2015)

1116-91-1551 **Junjian Yang*** (junjian.yang@univie.ac.at), Oskar-Morgenstern-Platz, 1, A-1190 Vienna, Austria. *On the existence of shadow price processes.*

In a financial market with a continuous price process and proportional transaction costs, we investigate the problem of utility maximization of terminal wealth. We give sufficient conditions for the existence of a shadow price process, i.e., a least favorable frictionless market leading to the same optimal strategy and utility as in the original market under transaction costs. Examples and counterexamples will be given. Special emphasis will be put on financial models based on fractional Brownian motion. This is based on joint work with Christoph Czichowsky and Walter Schachermayer. (Received September 20, 2015)

1116-91-1568 **Carter Claiborne Price*** (price@rand.org), Washington, DC. *Modeling Health Care Reform.*

Informed public policy discussions related to reforming complex systems requires detailed analysis. This presentation will discuss the construction of models used to assess the impact of the Affordable Care Act (ACA) as well as specific analysis related to the expansion of Medicaid eligibility. Because the ACA was more than a small perturbation of existing health insurance policy, intricate models are required to understand the implications for individuals, firms, insurance providers, and both the federal and state governments. RAND has developed an agent-based model to study the implications of health care reform and has continued to develop the model as the implementation of health care reform evolves. The analysis expansion of the Medicaid program as part of the ACA shows how mathematical modeling can meaningfully inform public policy decisions. Issues related to modeling, implementation, and presentation of the ACA will be discussed. (Received September 20, 2015)

1116-91-1634 **Nina Galanter*** (galanter@grinnell.edu), **Dennis Silva, Jr.** (dssilva@wpi.edu), **Jonathan Rowell** (jtrowell@uncg.edu) and **Jan Rychtář** (rychtar@uncg.edu). *The Territorial Raider Model with Strategic Movement and Multi-Group Interactions.*

We analyzed the territorial raider game, a graph based competition for resources, with strategic movement. First we investigated the game in which players are treated as individual organisms. Utilizing a machine learning algorithm, we discovered that the only strict nash equilibrium strategy sets occur when all players raid one another and players do not compete with one another. This indicates equilibria are generated by derangement functions of a graph. Thus, we found that a graph will permit a derangement if and only if it permits a strict Nash equilibrium. We then extended the game to the case where players are "hives" or "armies" which can divide themselves among multiple territories. We examined this division of armies both in the discrete and continuous cases. Our results include Nash equilibria for regular graphs and regular bipartite graphs in both of these cases. Our results suggest that while group entities defend in more cases than in the individual organism game, the portion of a group defending varies based on the degree of vertices and the advantage given to owners in protecting resources. (Received September 20, 2015)

1116-91-2100 **Tomasz R Bielecki*** (bielecki@iit.edu), 10 W 32nd Street, E1 Bldg, Room 208, Chicago, IL 60616, **Igor Cialenco**, 10 W 32nd Street, E1 Bldg, Room 208, Chicago, IL 60616, and **Tao Chen**, 10 W 32nd Street, E1 Bldg, Room 208, Chicago, IL 60616.
Dynamic Conic Finance via Backward Stochastic Difference Equations.

We present an arbitrage free framework for modeling bid and ask prices of dividend paying securities in discrete time using theory of dynamic acceptability indices given in terms of solutions of backward stochastic difference. We introduce pricing operators that are defined in terms of dynamic acceptability indices. We define bid and ask prices for underlying securities and then for derivatives in this market. We discuss related hedging issues in terms of control problems for g-expectations. (Received September 22, 2015)

1116-91-2537 **John K Osoinach*** (josoinach@udallas.edu), The University of Dallas, 1845 E. Northgate Dr., Irving, TX 75062, and **D Paul Phillips** (phillips@udallas.edu), The University of Dallas, 1845 E. Northgate Dr., Irving, TX 75062. *Searching With Lie Patterns of Infinite Length.* Preliminary report.

In the continuous version of the well-known Rényi-Ulam liar game, a Questioner is required to find a subset $A \subseteq [0, 1)$ of smallest Lebesgue measure that contains a number x known only to a Responder. The Questioner asks the Responder questions of the form, "is $x \in T$?" for subsets $T \subseteq [0, 1)$. The Responder's answers to these questions need not be truthful, but the choice to lie or be truthful is restricted to a set of allowable lie patterns X, known to both players at the beginning of the game. We analyze the variation of this game when the Questioner is allowed an infinite sequence of questions, so that the length of each lie pattern allowed is infinite. We show that the Questioner has a strategy that identifies a subset $A \subseteq [0, 1)$ containing x whose Lebesgue measure equals the measure of X. We also show that when restricted to asking comparison questions, the Questioner can find a subset $A \subseteq [0, 1)$ containing x whose Lebesgue measure exceeds the measure of X by ϵ, for any given $\epsilon > 0$. (Received September 22, 2015)

1116-91-2978 **Haijun Li*** (lih@math.wsu.edu), Department of Mathematics and Statistics, Washington State University, Pullman, WA 99164. *Regularly Varying Asymptotics for Tail Risk*

A risk measure is a functional of loss variables satisfying a set of operational axioms. These axioms reflect the risk perception of agents (or regulators) involved in the situation under consideration. It follows from duality theory that a coherent risk measure of loss X arises as the supremum of expected values of loss X under various scenarios. In this talk, we will discuss some fundamental ideas to derive asymptotics of coherent risk and its variants for losses that satisfy some tail stability patterns. These asymptotics provide a statistically tractable tool in analyzing tail risk. The method is based on theory of regular variation, and both univariate and multivariate cases will be discussed. (Received September 28, 2015)

92 ► Biology and other natural sciences

1116-92-29 **David J Wollkind***, Department of Mathematics, Washington State University, Pullman, WA 99164-3113, **Inthira Chaiya** (aon_seni@hotmail.com), Department of Mathematics, Mahidol University, Rama 6 Road, Bangkok, 10400, Thailand, **Richard A Cangelosi** (cangelosi@gonzaga.edu), Department of Mathematics, Gonzaga University, 502 E. Boone Ave, Spokane, WA 99258, **Bonni J Kealy-Dichone** (dichone@gonzaga.edu), Department of Mathematics, Gonzaga University, 502 E. Boone Ave, Spokane, WA 99258, and **Chontita Rattanakul** (g4136815@yahoo.com), Department of Mathematics, Mahidol University, Rama 6 Road, Bangkok, 10400, Thailand. *Vegetative rhombic pattern formation driven by root suction for an interaction-diffusion plant-ground water model system in an arid flat environment.*

A rhombic planform nonlinear cross-diffusive instability analysis is applied to an interaction-diffusion plant-ground water model system in an arid flat environment containing a root suction effect. A threshold-dependent paradigm is introduced to interpret stable rhombic patterns driven by this plant root suction effect in the ground water equation. The results of that analysis are represented by plots in a root suction coefficient versus rainfall rate dimensionless parameter space. From those plots regions corresponding to bare ground and vegetative patterns consisting of isolated patches, rhombic arrays of pseudo spots or gaps separated by an intermediate rectangular state, and homogeneous distributions from low to high density are identified in this parameter space. Then that morphological sequence, produced upon traversing an experimentally determined root suction characteristic curve, is compared with observational evidence relevant to the occurrence of leopard, pearled, or labyrinthine-type tiger bush; used to motivate an aridity classification scheme; and placed in the context of some recent nonlinear vegetative pattern formation studies.
(Received June 03, 2015)

1116-92-116 **Tarig Mohamed Ali** (ta_rig92@yahoo.com), School Of Distance Education, Universiti Sains Malaysia, 11800 Penang, Penang, Malaysia, **Mohamed Faisal Abd Karim** (faisal@usm.my), School of Distance Education, Universiti Sains Malaysia, 11800 Penang, Penang, Malaysia, and **Anton Abdulbasah Kamil*** (anton@usm.my), School of Distance Education, Universiti Sains Malaysia, 11800 Penang, Penang, Malaysia. *Sensitivity Analysis of Mathematical Model for Dengue fever Transmission.*

An epidemiological model describing a dengue disease transmission is formulated together with the associated basic reproduction number. The model is based on monitoring the dynamics of the humans and mosquitoes populations. The human population is classified into three epidemiological states, the susceptible, infected, and recovered humans. The mosquito's populations is subdivided into three classes of the aquatic stage or larva mosquitoes, uninfected female mosquitoes, and infected female mosquitoes. A sensitivity analysis is carried out to study how sensitive is the model to a particular parameter. Using Mathematica as a computational tool, a parameter is varied over a wide range to determine the relative importance of the model parameters to the disease propagation and control. Numerical result of sensitivity indices shows that the availabity of humans is the most sensitive. And the natural death of larvae is less sensitive. (Received July 30, 2015)

1116-92-128 **Andrea Vazquez Quiles*** (andreavazquez054@gmail.com), PO BOX 2227, Toa Baja, PR 00951. *Cyclophosphamide induced loss in the murine olfactory systems.*

Chemotherapy is one of the most widely renown treatments of cancer, attempting the stop of cancer development through the use of drugs. Cyclophosphamide (CYP) is usually its primary agent, and known to have long term side effects, such as fatigue, hair loss and disruption in the sense of taste. The main reason for the latter is that CYP targets cells with high turnover rate,(not cancer directly) that are all cells that proliferate quickly. If the sense of smell depends on the presence of olfactory neurons that undergo replacement similar to the taste system; could CYP affect the main olfactory epithelium (MOE) and the vomeronasal organ (VNO)? To verify this, approximately 60 male mice received a single intraperitoneal injection of CYP, 16 were given saline, and they were sacrificed 1 to 105 days post injection. The heads were sectioned and the sections were processed with Ki67 antibody to label any cells undergoing division (G1/S/G2/mitosis). Clear differences were observed between the MOE and the VNO, but both tissues demonstrated a decrease in Ki67 labeling, especially in days 2/14 & 60. There was evident recovery on the day 30. So far, data suggests that the tissue was very affected by the CYP and that the MOE was more affected than the VNO. (Received August 03, 2015)

1116-92-131 **Vanessa Trijoulet*** (vanessa.trijoulet@strath.ac.uk), LT 838, 26 Richmond Street, Glasgow, G31 2HA, United Kingdom, and **Robin M Cook**. *Estimation of grey seal predation mortality on the three main commercial demersal species in West of Scotland and implications for stock assessments and MSY calculation.*

Since the 80s the groundfish stocks have decreased around the UK, while grey seal population has doubled. Seal diet studies have shown that the weight of cod consumed by grey seals in West of Scotland (VIa) can exceed the cod spawning stock biomass. This has created conflicts between fishermen and conservationists as regards to the role grey seals may have played in the stock depletion. So it is necessary to quantify seal predation on groundfish stocks to improve seal and fisheries management.

A Bayesian model has been developed to estimate grey seal predation on cod, haddock and whiting. This model is a common fish assessment model where seal predation is part of the total mortality on fish. The model outputs were used to run a steady state equilibrium model which estimates fishing yield for different levels of fishing and seal predation.

Grey seal mortality has been estimated as 0.39, 0.09, and 0.12 for cod, haddock and whiting respectively. A decrease in grey seal predation induces an increase in for cod and whiting, but no impact exists for haddock. A reduction in cod fishing mortality of 50% would maintain the current fishing yield and enable a better recovery of the stock. An increase in the current fishing mortality for haddock and whiting is necessary to reach FMSY. (Received August 04, 2015)

1116-92-137 **Benjamin Levy***, levy@math.utk.edu, and **Suzanne Lenhart**, **Charles Collins**, **Rene Salinas**, **Marguerite Madden**, **Joseph Corn** and **William Stiver**. *Modeling Feral Hogs in Great Smoky Mountains National Park to Evaluate Control Efforts and Analyze the Population's Niche.*

Feral Hogs (Sus scrofa) are an invasive species that have occupied the Great Smoky Mountains National Park since the early 1900s. Recent studies have revitalized interest in the pest and have produced useful data. Two models were created and analyzed using detailed data on vegetation, mast and harvest history. The first model is discrete in time and space and was formulated to represent hog dynamics in the park. The second is a spatial model of the niche of the population that relates known presence locations to environmental predictors. Together these projects asses the importance of the existing control program and predict suitable locations for hog presence in the Park. (Received August 04, 2015)

1116-92-170 **Fiona Zhang**, **Benjamin Morin*** (brmorin@asu.edu), **Eli Fenichel** and **Gerardo Chowell**. *An Economic-Epidemiological Model with Personal Vaccination Efficacy Memory.*

Mathematical models have been used to, predict epidemic outcomes, optimize public policy, and understand transmission dynamics generally of influenza. A prevalent form of modern disease prevention is vaccination. Decisions to vaccinate take into account costs (i.e., time and money) and benefits (i.e., reduced chances of infection). The model studied here considers memory in the form of decision-based outcomes; vaccination history as a weight on the decision to vaccinate before each epidemic. We use an SEIR (influenza-like) compartmental model of differential equations with a subset of the population undertaking vaccination. Individuals make decisions based on a utility function that takes into account vaccination cost, disease cost, and an individual's disease-vaccination history, e.g., how often vaccination has resulted in successful disease prevention. We've found that in terms of vaccination coverage that memory has resulted in both oscillatory and convergent behaviors. We analyze the sensitivity of outcomes with respect to both economic and epidemiological parameters, the "length" of an individual's memory, the way he or she uses that memory to inform projections on the future, and how incorporating the disease-vaccination history of peers influences one's decisions. (Received August 11, 2015)

1116-92-185 **Kevin Long**, **Joanna A. Bieri*** (joanna_bieri@redlands.edu), **Chandani Dissanayake**, **Richard A. Erickson** and **Wayne E. Thogmartin**. *A continuous energy-based model for the migration of species in a network.* Preliminary report.

Understanding the impact of migratory habitats on the survival of species is an important part of making successful management decisions. Migration is a complicated process, and mathematical models offer a way to understand the importance of different parts of a migratory path. A continuous model for migrating species has been developed that tracks energy requirements of species along the migratory paths, allowing for full annual cycle migration. We begin by developing a network that consists of nodes and paths. At the nodes, the population is allowed to grow or decay based on logistic growth and predator-prey interactions with food stores. Along the path we use a partial differential equation to model the population density and energy of animals. When energy stores are large, the animals move along the migratory path with a range of speeds; however, the model requires the animals to stop if energy drops below a critical value. Once stopped, energy stores are replenished based on food availability along the path, and the animals resume migration only after energy levels are above the critical point. This model is intended to be general, not species specific, so that it can be applied to a wide range of species with a range of migratory patterns. (Received August 11, 2015)

1116-92-216 **Eric Shea-Brown*** (etsb@uw.edu), Box 353925, U. Washington, Seattle, WA 98195, and **Yu Hu**, **Nathan Kutz**, **Steven Brunton**, **Stefan Mihalas** and **Nick CAin**. *Assembling collective activity in neural circuits.*

Experimental breakthroughs are yielding an unprecedented view of the brain's connectivity and of its coherent dynamics. But how does the former lead to the latter? We use graphical and point process methods to reveal the contribution of successively more-complex network features to coherent spiking. (Received August 14, 2015)

1116-92-222 **Ryan Norris**, **Julia Earl**, **Paula Federico**, **Christine Sample*** (samplec@emmanuel.edu), **Ruscena Wiederholt**, **Jay Diffendorfer** and **John Fryxell**. *A fundamental modeling framework for spatio-temporal population dynamics.*

Mathematical models have made critical contributions to understanding the processes that drive the abundance and distribution of organisms in space and time. However, variations among the approaches pose a challenge in synthesizing results, as well as make it difficult to apply species-specific models to different ecological systems. Our objective is to develop a single mathematical framework that is flexible enough to capture the spatio-temporal dynamics in a wide variety of ecological systems. To do this, we adopt a network modeling approach. Nodes of a weighted and directed graph represent habitats with unique demographic attributes. Edges represent potential for movement between habitats. Population growth and movement in the network are simulated using discrete time steps. We demonstrate that this unified modeling framework can accommodate different spatially-structured populations. We also show how the model can be used to test, for example, the importance of a particular habitat on the survival of a migratory population. Results from such perturbation analysis can help inform management and conservation decisions. (Received August 14, 2015)

1116-92-279 **Ilya Shmulevich*** (is@ieee.org), 401 Terry Ave N, Seattle, WA 98109. *Probabilistic Boolean Networks as Models of Gene Regulatory Networks.*

I will present Probabilistic Boolean Networks (PBNs), which are models of genetic regulatory networks that i) incorporate rule-based dependencies between genes; ii) allow the systematic study of global system dynamics; iii) are able to cope with uncertainty; iv) permit the quantification of the relative influence and sensitivity of genes in their interactions with other genes. PBNs share the appealing rule-based properties of Boolean networks, but are robust in the face of uncertainty.

The dynamics of PBNs can be studied in the context of Markov Chains, with standard Boolean networks being special cases. I will also discuss the relationship between PBNs and Bayesian networks – a family of graphical models that explicitly represent probabilistic relationships between the variables. A major objective is the development of computational tools for the identification of potential targets for therapeutic intervention in diseases such as cancer. I will describe several approaches for finding the best genes with which to intervene in order to elicit desirable network behavior. (Received August 21, 2015)

1116-92-414 **Patrick De Leenheer*** (deleenhp@math.oregonstate.edu), Department of Mathematics, Kidder Hall, Corvallis, OR 97330. *Marine protected areas with mobile predator and prey.*

Marine protected areas (MPAs) are regions in the ocean where fishing is restricted or prohibited. The effects of MPA size, shape, and other characteristics on fish populations are still poorly understood. Conversely, the ecological characteristics of the protected fish can impact the effectiveness of MPAs. Here we investigate how predator-prey interactions and fish mobility influence MPA effectiveness, measured as the ratio of the steady state fish densities inside and outside the MPA. In particular, we consider whether fish mobility has an equalizing effect in the sense that the fish densities inside and outside the MPA tend to each other. We also show that increased fish mobility tends to stabilize the system. (Received August 31, 2015)

1116-92-419 **David B Damiano** and **Melissa R McGuirl*** (melissa_mcguirl@brown.edu). *A Topological Analysis of Targeted In-111 Uptake in SPECT Images of Murine Tumors.*

In this talk we employ computational topology methods to quantify heterogeneous uptake behavior across time series of single-photon emission computed tomography (SPECT) images of murine tumors. This behavior cannot be captured by standard aggregate measures such as percent injected dose per gram or tumor-to-heart ratio. Inspired by Morse Theory, we analyze critical points of each tumor image. To quantify the uptake behavior in neighborhoods of local maxima, we utilize a modified form of zeroth order persistence diagrams as well as develop the novel concept of childhood diagrams. Statistical methods are applied to time series persistence and childhood diagrams to detect heterogeneity of uptake within and across study groups. This behavior is explained in terms of the underlying biological mechanisms. (Received August 31, 2015)

1116-92-445 **Sebastian J. Schreiber*** (sschreiber@ucdavis.edu), Department of Evolution and Ecology, University of California, Davis, **Andrea Pickart**, U.S. Fish and Wildlife Service, **Annie Eicher**, H.T. Harvey and Associates, and **Jennifer Wheeler**, Bureau of Land Managment. *Short term climatic rescue of an endangered species? Insights from integral operators.*

Empirical measurements in demographic studies often include continuous traits (e.g. size, pathogen load) of individuals. Using classical statistical methods (e.g. generalized linear models), one can use this continuous trait data to parameterize integral operators (aka Integral Projection Models - IPMs) to describe year to year changes in demography. Coupling these demographic models with climate data allows one to make inferences about the effect of climate on population growth and extinction risk. In this study, IPMs were used to asses the roles of climate and a pathogen on the demography of the endangered plant species Menzies' wallflower (Erysimum menziesii). Data came from a decadal USFWS study following nearly 12 thousand individuals from germination to death, and a century's worth of NOAA weather data. These models suggest that decadal oscillations about a century trend in warming temperatures and interactions with a fungal-like pathogen may have resulted in a short-term climatic rescue of this endangered species. (Received September 01, 2015)

1116-92-450 **A. Bass Bagayogo*** (abagayogo@ustboniface.ca), 200 Avenue de la Cathédrale, Winnipeg, Manitoba R2H 0H7, Canada. *Mathematics of Granular Materials and the Future of this Natural Resource.*

Granular materials are simple: large conglomerations of discrete macroscopic particles. Despite this seeming simplicity, granular materials behave differently from any of the other standard and familiar forms of matter: solids, liquids or gases, and should therefore be considered as an additional state of matter in its own right. In this talk I will first address the mathematics behind the granular fluid, gas and solid in term of Navier-Stokes and Boltzmann equations and showing some numerical simulations results. In the second point I will focus on the specific case of sands used for constructions, computers, mobile phones and others new technologies. I will make some practical suggestions for an optimal sand mining for a better preservation of sands, which has become one of the most widely consumed natural resource. (Received September 02, 2015)

1116-92-471 **Suzanne L Robertson*** (srobertson7@vcu.edu) and **Kevin Caillouet**. *The effect of avian stage-dependent vector exposure on enzootic West Nile virus transmission.*

West Nile virus (WNV) outbreaks have been widely associated with the end of the avian nesting season. In this talk we develop and evaluate a novel mathematical model of enzootic WNV transmission to gain insight into the ecological mechanisms responsible for the timing and magnitude of seasonal outbreaks. We incorporate avian (host) stage-structure (nestling, fledgling, and adult) and within-species heterogeneity in the form of stage-specific mosquito (vector) biting rates. We determine the extent to which changes in host stage abundance throughout the season, along with the differential exposure of these stages to mosquito bites, affect WNV transmission dynamics. (Received September 03, 2015)

1116-92-487 **Christina J Edholm***, 203 Avery Hall, Lincoln, NE 68588, and **Chris Guiver**, **Richard Rebarber**, **Brigitte Tenhumberg**, **Stephanie Lloyd**, **Yu Jin**, **Jim Powell** and **Stuart Townley**. *Management of Diaprepes Root Weevil.* Preliminary report.

Diaprepes Root Weevils are an invasive species having a substantial negative impact on citrus tree growth in regions, such as Florida and California. At the larva stage of the life cycle Diaprepes Root Weevils cause destruction of citrus trees at the root level resulting in destruction of citrus crops. The detrimental economic effect for farmers motivates research into how to minimize the economic loss due to the Diaprepes Root Weevil. For our work, we used optimal control theory to determine levels of pesticide or biological control to apply to the Diaprepes Root Weevil to reduce the economic loss. We minimize a cost functional, which takes into account the cost of applying the control and the damage done by the weevils, determining how much control to apply over time. Our model takes into account the life-span of the nematodes. We have also considered a model which incorporates the spatial spread of the weevil into the problem. (Received September 03, 2015)

1116-92-501 **David Paez**, **Vanja Dukic**, **Jonathan Dushoff**, **Arietta Fleming-Davies** and **Greg Dwyer*** (gdwyer@uchicago.edu). *Combining Models and Experiments to Understand How Evolution Affects Insect Outbreaks.* Preliminary report.

Cyclic outbreaks of defoliating insects severely damage forests, damaging valuable timber and contributing to climate change. Observations of high virus mortality observed during outbreaks, and the ability of simple insect-pathogen models to qualitatively reproduce outbreak data, suggests that viruses may drive outbreaks. The strong selection imposed by viruses on their hosts, however, suggests that selection may also play a role, but the spatial scales involved make it difficult to test this hypothesis directly. To test for effects of natural selection on insect outbreaks, we instead constructed a mathematical model that allows for increased resistance due to virus spread during outbreaks, and for reduced resistance due to a cost of resistance during population troughs. We then estimated the parameters of the model using small scale field experiments with a baculovirus of the gypsy moth, we inserted the parameter estimates into the models, and we compared the resulting model predictions to data on gypsy moth outbreaks. The model that includes the effects of natural selection provides a much better explanation for outbreak data than do models that do not include selection, suggesting that selection plays an important role in driving outbreaks of this important forest pest. (Received September 04, 2015)

1116-92-589 **Suzanne M. O'Regan*** (soregan@nimbios.org) and **John M. Drake**. *Leading indicators of bifurcations in epidemiological systems.*

Epidemiological systems may exhibit bifurcations such as infectious disease emergence and elimination. These bifurcations may be anticipated because prior to reaching the dynamical threshold, the system gradually loses stability ('critical slowing down'). Non-parametric approaches that are independent of model-fitting would advance infectious disease forecasting significantly. We consider compartmental epidemiological SIS and SIR models that are slowly forced through a critical transition. We develop expressions for the behavior of several candidate indicators during the approach to emergence or elimination. We show that moving-window estimates of the candidate indicators may be used for anticipating critical transitions in infectious disease systems. Although leading indicators of elimination were highly predictive, the approach to emergence was much more difficult to detect. It is hoped that these results, which show the anticipation of critical transitions in infectious disease systems to be theoretically possible, may be used to guide the construction of online algorithms for processing surveillance data. (Received September 20, 2015)

1116-92-610 **James T Thorson*** (james.thorson@noaa.gov), 2725 Montlake Blvd E, Seattle, WA 98102. *What can we learn about community dynamics and climate impacts from spatiotemporal models? A case study of freshwater fishes.*

Many natural communities are responding rapidly to climate changes. However, species interactions and habitat heterogeneity also affect community dynamics, such that spatial variation may confound or invalidate tests for climate impacts. It is therefore necessary to analyze climate impacts on fish communities while accounting for spatial and temporal patterns in community dynamics. As one example, Lake Aleknagik is rearing habitat for juvenile sockeye salmon in the Wood River system of Bristol Bay. Fish surveys are available annually 1963-2014 for multiple species at 11 sites across the lake. To explore climate impacts in this community data set, we develop spatial dynamic factor analysis (SDFA). SDFA estimates the sensitivity of population density to changing water temperature for each species, and simultaneously estimates density-dependent variation in one or more "factors" to account for residual spatiotemporal community dynamics. This analysis indicates positive and statistically significant impacts of rising temperatures on three- and nine-spine stickleback and char, and negative impacts on juvenile sockeye and sculpin densities. It also provides an easily interpreted summary of species associations while visualizing spatiotemporal variation in species' dynamics. (Received September 08, 2015)

1116-92-671 **Jane M Heffernan*** (jmheffer@yorku.ca), Mathematics & Statistics, Centre for Disease Modelling, York University, Toronto, ON M3J 1P3, Canada. *Modelling HIV infection in-host: Assumptions and bifurcations.*

Mathematical modelling studies of HIV infection in-host typically involve the basic virus of dynamics, a system of three ordinary differential equations that tracks uninfected and infected T-cell populations and the HIV viral load. Much has been learned about HIV and HIV infection dynamics using this model, however, it ignores specific attributes of the immune system and immune response, and makes simplifying assumptions on the underlying biological processes. We study models of HIV infection that extend the basic model to include immune system characteristics. We will present examples that result in Hopf and/or backward bifurcations. Relationships to HIV infection in-host will be discussed. (Received September 10, 2015)

1116-92-679 **Carina Curto**, **Elizabeth Gross**, **Jack Jeffries**, **Katherine Morrison**, **Mohamed Omar**, **Zvi Rosen**, **Anne Shiu*** (annejls@math.tamu.edu) and **Nora Youngs**. *Algebraic signatures of convex and non-convex neural codes.*

Neural codes allow the brain to represent, process, and store information about the world. Combinatorial codes, comprised of binary patterns of neural activity, encode information via the collective behavior of populations of neurons. A code is called convex if its codewords correspond to regions defined by an arrangement of convex open sets in Euclidean space. Convex codes have been observed experimentally in many brain areas, including sensory cortices and the hippocampus, where neurons exhibit convex receptive fields. What makes a neural code convex? That is, how can we tell from the intrinsic structure of a code if there exists a corresponding arrangement of convex open sets? This talk describes how to use tools from combinatorics and commutative algebra to uncover a variety of signatures of convex and non-convex codes. (Received September 10, 2015)

1116-92-709 **Areej M. Alshorman*** (amalshor@oakland.edu), Department of Mathematics and Statistics, Oakland University, Rochester, MI 48309, and **Chathuri Samarasinghe**, **Wenlian Lu** and **Libin Rong**. *An HIV model with age-structured latently infected cells.*

Highly active antiretroviral therapy can suppress viral load in many HIV-infected patients to below the detection limit of standard assays but cannot eradicate the virus because of the existence of pro-virus residing in latently infected $CD4^+$ T cells. The activation rate of latently infected cells depends on the age of latent infection. In this work, we develop a model of HIV infection including age-structured latently infected cells. We mathematically analyze the model and use numerical simulation to show that the model can explain the persistence of low-level viremia and the latent reservoir stability in patients on therapy. Sensitivity tests suggest that the model is robust to the change of most parameters but is sensitive to the relative magnitude of the net generation rate and the long-term activation rate of latently infected cells. To reduce the sensitivity, we extend the model to include homeostatic proliferation of latently infected cells. The new model is robust in reproducing the long-term dynamics of the virus and latently infected cells observed in patients receiving prolonged therapy. This work provides a modeling framework that can be used to evaluate treatment strategies targeting functional cure for HIV without continuous and lifetime therapy. (Received September 10, 2015)

1116-92-718 **James N Ianelli*** (jim.ianelli@noaa.gov), NOAA, Building 4, 7600 Sand Point Way NE, Seattle, WA 98115. *Modeling innovations for fisheries assessments and management: are there any?* Preliminary report.

Modern fisheries modeling practices for management purposes require extensive specifications of statistical uncertainty, both structural and in estimation. Evaluating risk is an important part of providing management advice (on catch limits etc) and use of "ensemble" approaches including complex ecosystem models is growing. Such methods have drawn parallels to hurricane track predictions but in our resource setting we never know precisely the actual impact nor it's intensity. However, observations on how managers react to uncertain outcomes and the relative impacts are rarely evaluated. We argue that one area where applied resource management scientists can benefit is through meta-analysis of the interaction of available data, how they are analyzed and ultimately principles that affect decisions. Domestic examples from Alaskan fisheries are contrasted with experience in international resource management arenas. (Received September 11, 2015)

1116-92-726 **Sebastian J. Schreiber***, University of California, Davis, and **Mathieu Faure**, Aix-Marseille School of Economics. *Establishment of sexual invaders: Insights from frequency-dependent branching processes.*

A biological invasion corresponds to a species establishing itself in a new environment. While most invasion attempts fail, the successful ones (e.g. zebra mussel, chestnut blight) can dramatically impact their new environment. As invasions initially consist of a small number of individuals, success or failure is a highly stochastic process. For asexual populations, branching processes provide a useful approximation for the invasion dynamics and (generically) exhibit a fundamental dichotomy: extinction in finite time or unbounded growth which (i.e. successful establishment). Unbounded growth only occurs with positive probability if individuals on average replace themselves. In contrast, for sexual populations, individuals must mate to reproduce and, consequently, exhibit frequency-dependent interactions. I will describe a general class of Markov processes that account for these frequency-dependent interactions. Using the method of "mean limit ODEs", I will present results that determine whether unbounded growth occurs with positive probability or not, and characterize the asymptotic dynamics on the event of unbounded growth. These results lead to a new type of bifurcation diagrams which highlight under which conditions successful invasions are less or more likely. (Received September 11, 2015)

1116-92-761 **Xiuquan Wang*** (xiuquan0418@gmail.com), **John D. Reeve**, **Mingqing Xiao**, **Dashun Xu** and **James T. Cronin**. *Insect Drift Movement Modeling and Parameter Estimations via Boundary Characteristics.*

A fundamental goal of insect ecology is to examine how dispersal affects the distribution and dynamics of insects across natural landscapes. Insect dispersal is typically a combination of random movements and biased ones, in response to cues in the surrounding environment. Although it is straightforward to extend diffusion models to represent these more complicated patterns of movement, much less is known about how to estimate the key parameters or rate constants in these models. In this paper we present some important characteristics of insect biased movement in a rectangular domain of two-dimensional space, and show that if insects are released at the center of a rectangle, then the ratios of the mean accumulated density, the flux density, and the mean first passage time of opposite boundaries are constants, which are determined by the ratios of actual drift coefficients in horizontal and vertical directions, respectively. Different from existing approaches, these characteristics greatly simplify the estimation of the parameters (diffusion rate, advection coefficients, and death rate) and make quantification of dispersal more approachable. (Received September 11, 2015)

1116-92-775 **Yang Kuang*** (kuang@asu.edu). *Dynamics and implications of some clinical data validated prostate cancer growth models.* Preliminary report.

Prostate dependence on androgen makes androgen deprivation therapy (ADT) an important option for treatment of prostate cancer. The progression of ADT is monitored by measurements of prostate specific antigen (PSA). We introduce three models that consider one to three types of prostate cancer cells. We extend an existing model that used measurements of patient androgen levels to accurately fit measured serum PSA levels undergoing intermittent androgen deprivation (IAD) therapy. Our model is able to fit both measured PSA and androgen levels reasonably. We present some routine mathematical analysis of these models, including a global stability result for the simplest model. We analyze steady state solutions using relevant parameters that were fitted to specific patients and explore the biological and medical implications of our mathematical findings. We also discuss some plausible biological hypotheses for the development of castration resistance. (Received September 12, 2015)

1116-92-776 **Marisa P Draper**, **Maranda M Pepe**, **Dylana A Wilhelm**, **Lihua Chen**, **Patrice M Ludwig**, **Christine L May** and **Anthony Tongen*** (tongenal@jmu.edu), 800 S. Main St; MSC 1911, Department of Mathematics and Statistics, James Madison University, Harrisonburg, VA 22807. *Mathematical Modeling of the James Spinymussel.* Preliminary report.

The James Spinymussel (*Pleurobema collina*) is endangered and is at the top of Virginia's conservation list. This species plays a critical role in the environment by filtering and cleaning water while providing shelter and food for macroinvertebrates. However, conservation efforts are complicated by the mussels' burrowing behavior, camouflage, and complex life cycle. The goal of this research was to estimate detection probabilities that could be used to determine whether the species is present in an area and to track individually marked mussels to test for source-sink dynamics. Using existing literature and mark-recapture field data, these goals were accomplished by evaluating dispersion type, clustering trends, odds of detection based on environmental factors, substrate preferences, and matrix population models. These analyses serve as the foundation of mathematical models used to aid in the recovery of the James Spinymussel. (Received September 12, 2015)

1116-92-883 **Lori Beth Ziegelmeier*** (lziegel1@macalester.edu), 1600 Grand Avenue, Saint Paul, MN 55104, and **Chad M. Topaz** and **Tom Halverson**. *Topological Data Analysis of Biological Aggregation Models.*

We apply tools from topological data analysis to two mathematical models inspired by biological aggregations such as bird flocks, fish schools, and insect swarms. Our data consists of numerical simulation output from the models of Vicsek and D'Orsogna. These models are dynamical systems describing the movement of agents who interact via alignment, attraction, and/or repulsion. Each simulation time frame is a point cloud in position-velocity space. We analyze the topological structure of these point clouds, interpreting the persistent homology by calculating the first few Betti numbers. These Betti numbers count connected components, topological circles, and trapped volumes present in the data. To interpret our results, we introduce a visualization that displays Betti numbers over simulation time and topological persistence scale. We compare our topological results to order parameters typically used to quantify the global behavior of aggregations, such as polarization and angular momentum. The topological calculations reveal events and structure not captured by the order parameters. (Received September 14, 2015)

1116-92-952 **Jan Rychtar*** (rychtar@uncg.edu), Department of Mathematics and Statistics, The University of North Carolina at Greensbor, Greensboro, NC 27402. *Evolutionary dynamics in finite structured populations.*

Evolution in finite populations is often modeled using the classical Moran process. Over the last ten years this methodology has been extended to structured populations using evolutionary graph theory. An important question in any such population, is whether a rare mutant has a higher or lower chance of fixating (the fixation probability) than the Moran probability, i.e. that from the original Moran model, which represents an unstructured population. As evolutionary graph theory has developed, different ways of considering the interactions between individuals through a graph and an associated matrix of weights have been considered, as have a number of important dynamics. In this talk we present the development on evolutionary graph theory in light of these extensions. We will give general criteria for when an evolutionary graph satisfies the Moran probability for the set of six common evolutionary dynamics. (Received September 15, 2015)

1116-92-1053 **Fred Brauer*** (brauer@math.ubc.ca), Department of Mathematics, University of British Columbia, Vancouver, BC V6H 4C3, Canada. *A new formulation of a simple epidemic model.*

We consider an epidemic model in which all disease transmission is through shedding of virus by infectives and acquisition by susceptibles, rather than by direct contact. This leads to an SIVR (susceptible-infectious-virus-removed) model for which we can determine the basic reproduction number and the final size relation. We extend the model to an age of infection model with virus shedding a function of the age of infection. (Received September 16, 2015)

1116-92-1065 **Erin N. Bodine*** (boinee@rhodes.edu), Rhodes College, 2000 N. Parkway, Memphis, TN 38112, and **K. Lars Monia**. *A Model of Proton Therapy using Discrete Diffusion.*

Proton therapy is a type of radiation therapy used in the treatment of cancer. It is advantageous over other types of radiotherapy (e.g., x-ray and electron) in that proton therapy provides more localized particle exposure significantly reducing damage to tissue outside the target area which in turn reduces unwanted side effects. We have developed a discrete difference equation patch model with discrete diffusion to simulate tumor growth over one-dimensional space, where each patch represents tissue at a particular depth below the skin's surface. We use a clinical solution approximation of the Bethe-Bloch formula to simulate the dose exposure at each depth during a single proton treatment session in the absence of any other types of therapy. To demonstrate the utility of the model, we parameterize it using data from in vitro and clinical studies of Hepatocellular carcinoma. Using the parameterized model, we compare the results of treatment courses (multiple treatments sessions) used in clinical practice where two of the treatment courses use conformal proton therapy which targets the tumor from multiple angles. Our results suggest that conformal proton therapy provides better control of the targeted tumor and should be recommended for use when feasible. (Received September 16, 2015)

1116-92-1126 **Olcay Akman*** (oakman@ilstu.edu), Department of Mathematics, Box 4520, Normal, IL 61790. *Computing Intensive Methods in ODE Modeling.*

We introduce and implement Engineered Genetic Algorithm and Particle Swarm Optimization to select parameters for compartmental models. We examine the performances of both techniques and compare our results to those obtained with Engineered Genetic Algorithm (Akman and Schaefer, 2014). (Received September 17, 2015)

1116-92-1135 **Eric Alan Eager*** (eeager@uwlax.edu), 1725 State St., La Crosse, WI 54601. *Stochastic Integral Projection Models: Construction, Simulation and Analysis.*

In this talk we will motivate the use of stochastic integral projection models to study the dynamics of populations with continuous stage structure subject to environmental variability. In using disturbance specialist plants as our case study, we show how populations that use delayed reproduction as a means to combat environmental variability give rise to nonlinear integral projection models whose long-term trajectories converge in measure to an invariant measure, independent of non-zero initial condition. We then discuss the sensitivity of this measure to various characteristics of the environmental variability, and show that long-term measures of population viability have a non-monotone relationship with many of these characteristics. (Received September 17, 2015)

1116-92-1139 **Scott Hottovy*** (shottovy@math.wisc.edu), Department of Mathematics, 480 Lincoln Dr., University of Wisconsin, Madison, WI 53706, and **Samuel N. Stechmann**. *A Spatiotemporal Stochastic Model for Tropical Precipitation and Water Vapor Dynamics.*

A linear stochastic model is presented for the dynamics of water vapor and tropical convection. Despite its linear formulation, the model reproduces a wide variety of observational statistics from disparate perspectives, including

(i) a cloud cluster area distribution with an approximate power law, (ii) a power spectrum of spatiotemporal red noise, as in the "background spectrum" of tropical convection, and (iii) a suite of statistics that resemble the statistical physics concepts of critical phenomena and phase transitions. The form of the model is a damped version of the two-dimensional stochastic heat equation. Exact analytical solutions are available for many statistics, and numerical realizations can be generated for minimal computational cost and for any desired time step. Given the simple form of the model, the results suggest that tropical convection may behave in a relatively simple, random way. Finally, relationships are also drawn with traditional statistical mechanics models (e.g. Ising model). Potential applications of the model include several situations where realistic cloud fields must be generated for minimal cost, such as cloud parameterizations for climate models or radiative transfer models. (Received September 17, 2015)

1116-92-1153 **James P Peirce*** (`jpeirce@uwlax.edu`), La Crosse, WI 54602, and **Greg Sandland** and **Mary O'Driscoll**. *Outbreak of waterfowl disease in the Upper Mississippi River: Analysis of a stochastic temperature-driven model.* Preliminary report.

For the past decade, thousands of migrating waterfowl have died after consuming parasite-infected snails in the upper Mississippi River. Trophic transmission occurs during seasonal waterfowl migrations, which can depend intimately on temperature. We developed an annual model for waterfowl disease where transmission depends on stochastic water temperatures gleaned from empirical studies. By running simulations from annual temperature profiles selected randomly from a normal distribution, we quantified the association between the number of infected hosts and annual average temperatures. Recent empirical work has demonstrated that parasites only transmitted within a certain temperature range. And, in fact, transmission status changes only when temperature remains within or outside the range for a certain number of days. We will discuss results on the effect accrual time across a temperature range has on the magnitude of waterfowl mortality. (Received September 17, 2015)

1116-92-1185 **Timothy C Reluga*** (`timothy@reluga.org`). *A theory of optimal antibiotic resistance management.* Preliminary report.

Evolution kills people. The increasing prevalence of antibiotic resistance in particular has lead to increasing mortality from bacterial infections. In response, scientists are seeking new antibiotics and clinicians are seeking new usage strategies to make better use of the drugs we already have, while ethicists ponder balancing the conflicting preferences of individuals and communities. One thing that seems largely missing from the conversation is a simple theory of how optimal antibiotic resistance management should work. In this talk, I'll solve a simple optimal-control theory of antibiotic usage in the presence of resistance, contrast the solution with optimal harvesting theory, and discuss the implications for management. (Received September 17, 2015)

1116-92-1206 **Courtney L Davis*** (`courtney.davis2@pepperdine.edu`), Pepperdine University, NASC 4321, 24255 Pacific Coast Highway, Malibu, CA 90263. *Identifying Dysentery Vaccine Targets with a Clinically Parameterized Mathematical Model of Shigella Immunity.* Preliminary report.

We clinically parameterize a mathematical model of the immune response against Shigella, a dysentery-causing bacteria that kills 600,000 people worldwide each year. Using Latin hypercube sampling and Monte Carlo parameter estimation, we fit our model to human immune data from two Shigella vaccine trials and a rechallenge study in which antibody and B-cell responses against Shigella's membrane proteins were recorded. The clinically grounded model is used to mathematically investigate which key immune mechanisms and bacterial targets confer immunity against Shigella and to predict which immune components should be elicited to create a protective vaccine against Shigella. The model shows that, on average, humans would be highly symptomatic following a humoral immune response against only Shigella's membrane proteins due to an uncontrolled infection of gut epithelial cells that is present across all best-fit model parameterizations. Thus, our modeling results predict that a vaccine targeting only displayed membrane proteins will not be protective against Shigella. Using sensitivity analysis, we explore which model parameter values must be altered to prevent the destructive epithelial invasion by Shigella bacteria and identify key parameter groups as potential vaccine targets. (Received September 17, 2015)

1116-92-1246 **Timothy D Comar*** (`tcomar@ben.edu`), Department of Mathematics, Benedictine University, 5700 College RD, Lisle, IL 60532, and **Olcay Akman** and **Daniel Hrozencik**. *Sensitivity Analysis and the Probability of Pest Eradication or Permanence in a Stochastic Model for Integrated Pest Management.*

We further explore the impulsive differential equations (IDE) models for integrated pest management we developed in [1]. This deterministic model includes stage structure for both predator and prey, and the stochastic version incorporates competing stochastic elements in the birth rate of the prey.Here we prove the conditions under which solutions to the deterministic model are permanent, this corresponds to an economically viable solution in which levels are of the pest species are maintained at a sufficiently low level to minimize crop damage and a negative economic impacts. Using the results in [1] about locally asymptotic stability, we determine the probabilities of having a pest eradication solution or a permanent solutions when the birth rates are randomly chosen from particular probability distributions. We also perform some sensitivity analysis to certain parameters in the model.

[1] Olcay Akman, Dana Cairns, Timothy D. Comar & Daniel Hrozencik (2014) Integrated Pest Management with a Mixed Birth Rate for Prey Species, Letters in Biomathematics, 1:1, 87-95, DOI: 10.1080/23737867.2014. 11432419 (Received September 18, 2015)

1116-92-1264 **Jessica M Conway***, jmconway@psu.edu, and **Alan S Perelson**. *Residual viremia in treated HIV+ patients: simple model insights.*

Antiretroviral therapy (ART) effectively controls HIV infection, suppressing HIV viral loads. However, in HIV-infected patients on ART, some residual virus remains, below the level of detection. The source of this viremia is an area of debate: does it derive from ongoing rounds of viral replication, activation of infected cells in the latent reservoir, or some combination of the two? Observations support both sides. For example, emergent drug resistance, which results from mutation during viral replication, is rare, implying that viremia derives HIV archived in the latent reservoir, but evidence of short-term evolution remains, implying ongoing viral replication. We will discuss a simple deterministic model with its stochastic, branching process, analogue to gain insight into residual viremia dynamics in HIV-infected patients. We show that the contribution of viral replication to residual viremia may be non-negligible, permitting some short-term viral evolution. But even if that contribution is significant, long-term evolution can still be limited: results suggest de novo emergence of drug resistance is rare. Thus our simple modeling suggests reconciles the seemingly contradictory observations on residual viremia. (Received September 18, 2015)

1116-92-1302 **Carolyn L Talcott*** (`clt@csl.sri.com`), SRI International, 333 Ravenswood Avenue, Menlo Park, CA 90425. *Datum Logic: A Formal Executable Semantics for Experimental Evidence.*

Executable symbolic models of signal transduction have been successfully used to analyze networks of biological reactions. Such models can provide insights into how cells work, and a means to understand and predict the effects of perturbations and mutations, key for cellular understanding of disease and therapeutics. Pathway Logic (PL) is a formal system for representing and reasoning with executable models of cellular processes. Developing models requires significant expertise and time to collect, organize and interpret experimental evidence; and to infer rules representing hypothesized biochemical reaction that make up a signaling network. There is a great need for tools to help automate the curation of executable models.

The problem of automatically constructing executable models from experimental evidence has several aspects including: (1) formal representation of experimental findings, (2) formal representation of rules as elements of executable models, (3) extracting findings from papers, and (4) algorithms for inferring rules from findings and for assembly of executable models. The PL representation system is a solution for (2). Datum Logic is a solution to (1,4). We will describe the representation, and an approach to inferring rules from datums. (Received September 18, 2015)

1116-92-1308 **Daniel Coombs*** (`coombs@math.ubc.ca`). *Interpretation and modelling with super-resolution microscopy.*

New microscopic imaging techniques yield precise positional information of fluorescent markers down to the scale of tens of nanometers and provide beautiful qualitative images of cellular structures. In this talk I will discuss our ongoing work with one such technique, Stochastic Optical Reconstruction Microscopy. I will describe the technique, highlighting a particular challenge to obtaining quantitative information from the data, describe how we are addressing that challenge using a hidden Markov model, and also point out some interesting problems that are not completely resolved. The work will be illustrated using experimental data from cell-surface receptors on B cells and cardiac myocytes and I will outline how the microscopic data is informing new models of signaling in both cases. This is joint work with Alejandra Herrera, Libin Abraham and Ki-Woong Sung and members of the Edwin Moore, Keng Chou and Michael Gold labs at UBC. (Received September 18, 2015)

1116-92-1337 **Ram C Neupane*** (ram.neupane@aggiemail.usu.edu), 3 Aggie Village Apt. E, Logan, UT 84341. *Bird-Driven Dispersal of Trees: Multi-Scale Modeling and Analysis.*

The distribution of many tree species is strongly determined by the behavior and range of vertebrate dispersers, particularly birds. Many models for seed dispersal exist, and are built around the assumption that seeds undergo a random walk while they are being carried by vertebrates, either in the digestive tract or during the process of seed storage (caching). We use a PDF of seed handling (caching and digesting) times to model non-constant seed settling during dispersal, and model the random component of seed movement using ecological diffusion, in which animals make movement choices based on local habitat type instead of population gradients. We introduce multiple scales and apply the method of homogenization to determine leading order solutions for the seed digestion kernel (SDK). Using an integrodifference equation (IDE) model for adult trees, we investigate the rate of forest migration. The existing theory for predicting spread rates in IDE does not apply when dispersal kernels are anisotropic. However, the homogenized SDK is isotropic on large scales and depends only on harmonically averaged motilities and modal rates of digestion. We show that speeds calculated using the harmonic average motility accurately predict rates of invasion for the spatially variable system. (Received September 18, 2015)

1116-92-1361 **Suzanne Lenhart*** (lenhart@math.utk.edu), University of Tennessee, Math Dept., and NIMBioS, Knoxville, TN 37996-1320, **Kelly Sturner**, NIMBioS, and **Virginia Parkman**, University of Tennessee, Vols Teach and NIMBioS. *NIMBIoS activities connecting math and science in middle school.*

We present activities for middle school students and teachers that we have developed at the National Institute for Mathematical and Biological Synthesis (NIMBioS) to show the usefulness of mathematics to the sciences. The first activity illustrates the importance of random sampling and how it helps eliminate possible bias. The second activity engages students in how to use math to model a forest. Making a special tape to measure tree diameter, which connects diameter with circumference, will be shown. Activities were developed with both Common Core Mathematics standards and Next Generation Science standards in mind. (Received September 18, 2015)

1116-92-1442 **Kamuela E Yong*** (kamuela.yong@hawaii.edu), **Edgar Díaz Herrera** and **Carlos Castillo-Chavez**. *From bee species aggregation to models of disease avoidance: The* Ben-Hur *effect.*

The movie *Ben-Hur* highlights the dynamics of contagion associated with leprosy, a pattern of forced aggregation driven by the emergence of symptoms and the fear of contagion. The 2014 Ebola outbreaks reaffirmed the dynamics of redistribution among symptomatic and asymptomatic or non-infected individuals as a way to avoid contagion. In this manuscript, we explore the establishment of clusters of infection via density-dependence avoidance (diffusive instability). We illustrate this possibility in two ways: using a phenomenological driven model where disease incidence is assumed to be a decreasing function of the size of the symptomatic population and with a model that accounts for the deliberate movement of individuals in response to a gradient of symptomatic infectious individuals. The results in this manuscript are preliminary but indicative of the role that behavior, here modeled in crude simplistic ways, may have on disease dynamics, particularly on the spatial redistribution of epidemiological classes. (Received September 19, 2015)

1116-92-1489 **Junping Shi*** (jxshix@wm.edu), Department of Mathematics, College of William and Mary, Williamsburg, VA 23187, and **Xiaoli Wang** and **Guohong Zhang**. *Interaction of water and biomass: rich dynamics in a simple model.*

Pattern formation of water-biomass interaction systems in the semi-arid climatic zone have been considered by many ecologists and mathematicians. Here we propose a new model of water and plant interaction with plant death rate decreasing for higher plant density. We rigorously analyze the corresponding ODE model, which reveals rich dynamics including backward equilibrium transcritical bifurcation, saddle-node bifurcations for equilibria and limit cycles, Hopf bifurcations, limit cycle bubble/heart, homoclinic bifurcation, and Bogdanov-Takens bifurcation. This model could serve as an explanation of the sudden desertification of arid regions. (Received September 20, 2015)

1116-92-1555 **Rachel A Schomaker*** (schomakerrachel@gmail.com), 111 Lake Hollingsworth Dr., Lakeland, FL 33801, and **MaLyn Lawhorn**. *Comparative Analysis of Transcriptomic Data Accounting for Variation in Gene Flexibility.* Preliminary report.

Comparative transcriptomic data can be used to examine similarities and differences in the gene expression of organisms or cells, which can be beneficial when trying to discover treatments for cancer or mental health diseases. Typically, two independent experiments are performed that each identify differences in gene expression between two experimental conditions. The differences are compared between experiments to test for significant overlap in differentially expressed genes. Traditionally, all genes are treated equal without taking into consideration that genes may have varying numbers of transcription factor binding sites, leading to different variability in gene expression and may overstate the degree of genetic overlap due to the simplifying assumption that all genes are equal. The purpose of this study was to create a computer simulation that considers varying numbers of transcription factor binding sites of genes and generates random gene expression profiles to generate a null expectation of transcriptome overlap for genes with different genetic architectures. When compared to empirical data, results suggested that traditional methods for measuring gene overlap may need to be reevaluated and more stringent criteria need to be applied when comparing transcriptomes. (Received September 20, 2015)

1116-92-1629 **Georgiy P Karev***, karev@ncbi.nlm.nih.gov, and **Irina P Kareva**. *Modeling of Extinction of Inhomogeneous Population.* Preliminary report.

We consider two types of inhomogeneous subexponential models of population extinction. In the first type of models we assume that the population is composed from independent clones, each of which decreases according to the power equation. We show that the current distribution of clones provides the minimum of the relative Tsallis entropy given the q-mean value of the death rate at each time moment before the population extinction. In the second type of models we assume that the total size of population decreases according the power model. We show that these models have a canonical representation in the form of frequency-dependent inhomogeneous models (F-model). The notion of "internal time" can be naturally defined. According to this time scale each clone develops as if it does not depend either on other clones, or on the population at whole. The internal time tends to infinity as the "common time" tends to a finite moment of population extinction. The system dynamics is such that the minimum of the KL-divergence between the initial and current distributions is achieved at each moment of internal time given the mean value of the death rate. Some interpretations of these results are given. (Received September 20, 2015)

1116-92-1642 **Najat Ziyadi***, Department of Mathematics, Morgan State University, 1700 East Cold Spring Lane, Baltimore, MD 21251. *A mathematical model of human papillomavirus (HPV) in African American Men and Women populations.*

In this talk, we introduce two-sex mathematical HPV epidemic models (with and without vaccination) with "fitted" logistic demographic equation to study HPV in African American men and women. We compute the basic reproduction number and use it to show that R0<1 in the African American population. We use sensitivity analysis to illustrate the impact of each model parameter on R0. In addition, we obtain that adopting a HPV vaccination policy lowers the number of HPV infections in the African American population. (Received September 20, 2015)

1116-92-1759 **Patrick Davis*** (davis1pt@cmich.edu), Central Michigan University, 214 Pearce Hall, Mount Pleasant, MI 48859. *Effect of Delayed Dispersal in an Infectious Disease Model of a Large Metapopulation.* Preliminary report.

Basic compartmental models for an infectious disease like the Kermack-McKendrick model take into account various properties of the disease, but ignore the effect of the underlying population spatial configuration. Consequentially, some disease models have been developed where the population is divided and movement is permitted between distinct subpopulations; however, these models fail to adequately address real-life dispersal dynamics which may include delays. We propose and analyze a model of infectious disease in a large metapopulation that uses delay differential equations to account for delayed dispersal. (Received September 21, 2015)

1116-92-1768 **Erica J. Graham*** (ejgraham@brynmawr.edu) and **James F. Selgrade**. *Modeling ovulatory dysfunction through mechanisms of reproductive hormone regulation.*

Reproductive hormones belong to a tightly regulated system of feedback between the brain and ovaries. Crosstalk between different hormones set the stage for the oscillatory behavior characteristic of the menstrual cycle. In the case of polycystic ovary syndrome (PCOS), a common cause of infertility, increased ovarian androgen production can disrupt the cycle. Further, elevated insulin is an important cause of the change in androgens. We develop a deterministic model of ovarian steroid production coupled with hormone interactions during the ovulatory cycle. Steroid dynamics are central to follicle growth and maturation, as well as to regulation of essential hormones produced in the brain. We therefore focus on modeling mechanisms of intracellular steroid production as influenced by insulin. The model exhibits stable periodic behavior and provides a good fit to clinical data during a normal ovulatory cycle. We discuss model behavior under both physiological and pathological circumstances using simulation and bifurcation results. Finally, we discuss implications for ovulatory dysfunction in the context of PCOS. (Received September 21, 2015)

1116-92-1783 **Angela Peace*** (a.peace@ttu.edu). *Modeling the effects of co-occurring nutrient and contaminant stressors in aquatic systems.*

Bioaccumulation of toxic compounds in aquatic food chains can pose risk to ecosystem conservation as well as wildlife and human health. Ecotoxicological modeling aims to predict how contaminants cycle through aquatic food systems. There is increasing evidence that considering resource stoichiometry and nutrient availability will improve risk assessment protocols in ecotoxicology. The interactive effects of nutrient availability and MeHg concentration may play a significant role in bioaccumulation. We develop aquatic stoichiometric food chain ODE models that incorporate the effects of nutrient availability, as well as, track MeHg through two trophic levels, primary producers and grazers. Model analysis and simulations predict that stoichiometric constraints of food quality can affect the accumulation of MeHg in Daphnia. Scenarios of Somatic Growth Dilution, where Daphnia experience a greater than proportional gain in biomass relative to MeHg under high Phosphorus concentrations are observed. These modeling efforts improve our understanding of the processes governing the trophic transfer of nutrients, energy, and toxins and offer insight on the importance of elemental food quality in ecotoxicological testing protocols for assessing risk of exposures to toxins. (Received September 21, 2015)

1116-92-1790 **Javier Arsuaga***, jarsuaga@ucdavis.edu, and **Georgina Gonzalez** and **Sergio Ardanza-Trevijano**, sardanza@unav.es. *Analysis of cancer genomics data using computational topology: applications to breast cancer.*

Cancer genomes are characterized by their genomic instability and the presence of chromosome aberrations (i.e. morphological alterations of the genome). In our previous work we have shown that the β_0 number can be used to identify copy number chromosome aberrations, such as amplifications and deletions, associated with the different molecular subtypes of breast cancer. In this work I will discuss the applications and interpretation of β_1 in the identification of copy number changes in breast cancer with emphasis in aberrations found in the Her2 amplified subtype. (Received September 21, 2015)

1116-92-1794 **Mary Therese Padberg*** (padbergmt@gmail.com), **Isabel Darcy**, **Stephen Levene**, **Stefan Giovan** and **Rob Scharein**. *Determining Geometric Structures of Protein-Bound DNA using Modeling Software.* Preliminary report.

The complex relationship between proteins and DNA allows our cells to perform their various functions: gene expression, DNA replication, and regulation of cellular functions among them. In order for these processes to occur, proteins must first interact with DNA through a binding process. In this talk we focus on proteins that bind, cut, and religate (i.e. 'reconnect') DNA. When proteins bind to segments of DNA (creating protein-bound DNA) we assume the protein to be a ball and the DNA to be strings within the ball. Thus we can identify the protein-bound DNA as a mathematical tangle. This tangle type describes the topology of the DNA, whereas the geometry of the DNA is described by the spatial location of the DNA base pairs. Recent successes of laboratory experiments have allowed scientists to determine the tangle type of the protein-bound DNA. However, in many cases the limitations of available experiments have prevented us from determining a geometric structure for the protein-bound DNA segments whose topology is known. In this talk we will present new software, along with some preliminary results, that allows us to take a known topological structure of protein-bound DNA and find a potential geometric structure associated with it. (Received September 21, 2015)

1116-92-1798 **Evan D Dienstman*** (eddienstman@email.wm.edu), 32 Tulip Drive, Newtown, PA 18940. *Using statistical measurements to accurately predict septic events in premature infants.* Preliminary report.

Because of their underdeveloped immune systems, premature babies are at an increased risk to contract many illnesses. Thus, early detection of a disease is vital to saving a premature baby's life. Current methods of detecting illnesses, however, have been inadequate, providing many false positives and insufficient amount of warning time. However, patterns in the heart rate of babies have shown signs of predicting the onset of sepsis in premature infants. Research conducted by Prof. Delos and others suggest that low variability and clusters of decelerations in an infant's heart rate indicate a future septic event. Additionally, low variability may be linked to gram-positive bacteria and clusters of decelerations many be linked to gram-negative bacteria. If this statement is true, then not only will the heart rate of an infant predict the onset of sepsis, but also provide a diagnosis for the baby. Over 12 terabytes of data has already been collected on premature babies' heart rate and breathing. Unfortunately, only looking for low variability and clusters of decelerations would be inadequate since most babies experience some low variability and decelerations in their heart rate at some point. Therefore, sophisticated statistical measurements are necessary to quantify this data. (Received September 21, 2015)

1116-92-1821 **Paul F Tupper***, Department of Mathematics, 8888 University Drive, Burnaby, BC , Canada. *Eye Tracking Studies of Category Learning: Fitting Complex Models to Individuals.*

The Cognitive Science Lab at Simon Fraser University conducts experiments in which human subjects are asked to categorize a series of images based on criteria that are not initially specified to the subject. At the beginning of a trial, a subject must simply guess the correct category, but is given feedback on performance. Within an hour, most subjects learn the correct rule for categorization. The data collected includes the guesses of the subjects, the timing of the guesses, and eye tracking data, i.e. where on a video screen the subject's gaze is fixated at every point in time.

We have constructed a model that is able to reproduce many features of this data set, while trying to maintain neuropsychological plausibility. I'll talk about some of the challenges of fitting this model to individual subjects (rather than averages over subjects, as is usually done) and in interpreting the resulting distribution of parameters.

This is joint work with Jordan Barnes and Mark Blair (SFU, Psychology). (Received September 21, 2015)

1116-92-1868 **Mimi Tsuruga*** (mtsuruga@math.ucdavis.edu), Department of Mathematics, UC Davis, One Shields Ave, Davis, CA 95616, and **Javier Arsuaga**, **Michael Steiner** and **Nils Baas**. *Classification of breast cancer subtypes using signaling pathways and persistence homology.*

Signaling pathways can be described as graphs that model biological molecular interactions which lead to changes in gene expression. One challenge is to develop a pathway analysis approach that can distinguish cancer subtypes. In our work, we map gene expression data from microarray studies of breast cancer patients with diagnosed subtypes onto the nodes of a pathway to obtain a directed graph G with weighted nodes. We construct a point cloud C from G then use persistence homology to analyze C. (Received September 21, 2015)

1116-92-1911 **Austin J Phillips*** (ajphil90@uw.edu), Quantitative Ecology and Resource Management, Box 352182, University of Washington, Seattle, WA 98195. *Will transient spatial dynamics help or hinder species responding to climate change?*

Transient dynamics encompass the behavior of a dynamical system before it settles down to an equilibrium, limit cycle, or other asymptotic behavior. In ecology, important types of transients include attenuation (when a population declines initially but grows in the long run) and amplification (when a population increases initially but goes extinct in the long run). Climate change is moving many species' suitable habitats, creating non-equilibrium conditions that can lead to transient spatial dynamics as species track their habitats. I will use an integrodifference model of a population tracking its moving habitat to determine the conditions under which attenuation or amplification can occur. The model quickly leads to an integral equation; by comparing the eigenvalues and operator norms of the associated integral operator, I will determine which population properties influence the potential for transient dynamics. In the process, I will explore analytical and numerical approaches to calculating the required operator norms. (Received September 21, 2015)

1116-92-1950 **Eric Numfor*** (enumfor@gru.edu) and **Jemal Mohammed-Awel**. *Optimal Insecticide Treated Bed-net Coverage and Malaria Treatment in a Malaria-HIV Co-infection Model.*

We propose and study a mathematical model for malaria-HIV co-infection transmission and control in which malaria treatment and insecticide-treated nets are incorporated. The existence of a backward bifurcation is established, and the occurrence of such backward bifurcation is influenced by disease-induced mortality, treated bed-net coverage and malaria treatment parameters. To further assess the impact of malaria treatment and insecticide-treated bed-net coverage, an optimal control problem is formulated with malaria treatment and insecticide-treated nets as control functions. Using reasonable parameter values, numerical simulations suggest the possibility of eliminating malaria and reducing HIV prevalence significantly. (Received September 21, 2015)

1116-92-2119 **Lauren M Childs*** (lchilds@hsph.harvard.edu) and **Caroline Buckee**. *Modeling the impact of coinfection on persistence and infectivity of malaria.*

Each year nearly 200 million people are infected with the malaria parasite, *Plasmodium falciparum*. One of its most notable features is the variable course and duration of infection experienced by different individuals, ranging from high parasite density, acute and often severe infections to persistent, chronic infections that are often undetectable by standard methods. Levels of acute and chronic infections vary, and what disturbs the delicate balance between parasite growth and immune control, leading to bursts of parasite growth or clearance of an infection, remains an open question. Here, we develop a difference equation model of blood-stage parasite dynamics including innate and adaptive immune responses. We analyze simulated output to examine how coinfecting genotypes, particularly ones that elicit overlapping immune responses, impact infection length and infectiousness. We find that the level of both innate and adaptive immune responses present at the time of coinfection as well as the similarity of the coinfecting genotypes significantly alters the duration of infection, particularly in chronic infections. Timing of coinfection also influences the infectivity of the coinfecting genotypes, likely altering transmission patterns at a population level. (Received September 21, 2015)

1116-92-2123 **Nicolette Meshkat*** (nmeshkat@scu.edu) and **Seth Sullivant** (smsulli2@ncsu.edu). *Structural Identifiability of Biological Models.*

The parameter identifiability problem in biological modeling concerns finding which unknown parameters of a model can be determined from data. An important step in this problem is to determine the structural identifiability of the model, which concerns identifiability of the model parameters under the ideal circumstances of perfect data, i.e. data that is noise-free and of any time duration required. If all of the parameters can be determined from perfect data, then the model is said to be structurally identifiable. However, many models arising in systems biology are structurally unidentifiable, which means that some of the parameters of the model can take on an infinite number of values and yet yield the same input-output data, even under the ideal circumstances of perfect data. We explore the structural identifiability problem using a differential algebra approach and apply tools from computational algebra to find sufficient conditions for identifiability. (Received September 21, 2015)

1116-92-2143 **Demetrios Gatziolis***, 620 SW Main Street, Suite 400, Portland, OR 97205. *Voxel-based assessment of sunlight distribution in forests using LiDAR data.*

The spatial distribution, timing, and intensity of sunlight within forests is associated with numerous environmental and ecological processes including tree growth, regeneration, and woody debris decomposition. Owing to diurnal and seasonal cycles in solar illumination and vegetation heterogeneity, spatially explicit and consistently accurate assessments of sunlight have been notoriously challenging. High-density Light Detection and Ranging (LiDAR) data acquired over forested landscapes offer detailed representations of dominant objects, typically tree crowns and surfaces. Using a novel, fully automated approach, this study relies on LiDAR data organized in voxel space and ray tracing to determine the illumination regime of any location within a forest at any time. A series of optimizations self-adaptive to vegetation conditions, low-level C code, and execution in parallel enable efficient processing of massive amounts of LiDAR data for multiple solar positions. Processing outputs include visualizations and fine-resolution illumination and thermal energy summaries for user-specified time periods and intervals. Estimates obtained by using this approach exhibited remarkable agreement with in-situ observations of light availability for a variety of forest structure conditions. (Received September 21, 2015)

1116-92-2147 **Kelly Ruth Buch*** (kbuch@siue.edu), 601 Aladar Dr, O'Fallon, IL 62269, **Abena Serwaa Bonsu Annor** (bridgeta4@att.net), 11966 Donlin Dr, Wellington, FL 33414, and **Daniel Rodriguez Pinzon** (da.rodriguez1253@uniandes.edu.co), , Colombia. *Female Centered Mate Selections as an Explanatory Mechanism for Dimorphic Solutions in a Rock-Paper-Scissors Game.* Preliminary report.

Side-blotched lizards, *Uta stansburiana*, exhibit trimorphic male throat-colors (orange, blue, or yellow). In terms of mating, the males participate in an apparent game of rock-paper-scissors determined by throat color (i.e., a cyclic dominance chain). Mathematical models of this behavior predict stable monomorphic and trimorphic populations. However, researchers have observed stable dimorphic populations of orange and blue males. Furthermore, it is postulated that the only large-scale, long-term, stable solutions exclude the yellow throat type. We propose a new mathematical model accounting for the female population available for mating that may exhibits such behavior. We discuss the conditions under which particular population configurations are stable and flow attractive. We use these results to motivate conservative methods that may mitigate biodiversity loss by preventing the decline of a particular monomorphic or dimorphic population. (Received September 21, 2015)

1116-92-2168 **Eric J Kostelich*** (kostelich@asu.edu), School of Mathematical & Statistical Sciences, Tempe, AZ 85287, **Yang Kuang** (kuang@asu.edu), School of Mathematical & Statistical Sciences, Tempe, AZ 85287, and **Javier Baez** (jbaez2@asu.edu), School of Mathematical & Statistical Sciences, Tempe, AZ 85287. *Data Assimilation in Mathematical Models of Cancer Growth and Treatment.* Preliminary report.

This talk will consider some applications of data assimilation on models of tumor growth and treatment. The ensemble Kalman filter and its variants provide a computationally efficient way to estimate initial conditions and parameters and their associated uncertainties in in dynamical systems. Questions of identifiability and bias in the model variables also can be addressed. These concepts will be illustrated using clinical trial data with a differential equation model of prostate cancer growth and treatment. (Received September 22, 2015)

1116-92-2172 **Jean F Liénard*** (jean.lienard@wsu.edu), 14204 NE Salmon Creek Ave, Vancouver, WA 9868. *A data-intensive model forecasting forest response to climate-related stress.*

Understanding and predicting how forest distributions will respond to ongoing and anticipated climate change is a challenge with great ecological, economic, and cultural implications. However, our ability to predict how climate change will affect forests at the landscape scale is limited. Here I present a novel scaling approach based on species tolerance traits. The ongoing USDA forest inventory provides detailed records of forested plots regularly distributed across the whole US, and their geographical locations can be cross-linked with climate datasets and soil moisture maps. A data-intensive statistical analysis reveals that at the continental scale, forest shade and drought tolerances are strongly correlated with climatic variables. The newly-found relationships between tolerance and climate is used to develop, apply and evaluate a Tolerance Distribution Model (TDM). Finally, the TDM is used to forecast the response of forested areas to 17 climate change scenarios, allowing the identification of regions that are consistently vulnerable to anticipated drought-related stress. (Received September 22, 2015)

1116-92-2202 **Nikolay S. Strigul*** (nick.strigul@wsu.edu), 14204 NE Salmon Creek Ave, Vancouver, WA 98686. *Data-intensive modeling of forest dynamics using time inhomogeneous Markov chains.*

Existing forest inventory datasets offer unprecedented opportunities to model forest dynamics under evolving environmental conditions but they are analytically challenging due to the large number of records and irregular sampling intervals. In this presentation, I introduce the data-intensive inhomogeneous Markov chain model of forest biomass based on data-mining of forest inventory databases. The methodology involves the following steps: 1) parameterization of transition matrices using Gibbs sampling, 2) formalization of disturbance regimes and growth scenarios and 3) simulation of transient dynamics and stationary states. This methodology is applied to predict climate change effects on biomass of North American forests over the next 100 years. The consequences of global warming scenarios including changes in forest fire rate as well as possible growth enhancements due to increasing CO2 and temperature are estimated for the broad range of feasible climate change scenarios. The model predicts consistent short-term increases in biomass for all scenarios. Overall, the original data-intensive methodology provides both descriptions of the short-term dynamics as well as predictions of forest development on a longer timescale. (Received September 22, 2015)

1116-92-2257 **Michael Marcondes de Freitas*** (marcfrei@math.ku.dk), Department of Mathematical Sciences, University of Copenhagen, Universitetsparken 5, 2100 Copenhagen Ø, Denmark, and **Elisenda Feliu** and **Carsten Wiuf**. *Obtaining Qualitative Properties of Chemical Reaction Networks from Simplified Models.*

We present two graphical procedures to simplify reaction networks, namely, removing so-called intermediates and catalysts. These are shown not to break known necessary or sufficient conditions for *persistence*, the property that species concentrations remain bounded away from zero as long as they were all positive in the beginning. For cascades of a large class of post-translational modification (PTM) systems, this approach allows us to prove that persistence is equivalent to easily checkable strong connectivity properties of the underlying network.

To briefly illustrate the scope and reach of our method, consider a one-site phosphorylation process as modelled by the reaction network

$$\begin{array}{ccccc} E+S_0 & \leftrightarrow & ES_0 & \to & E+S_1 \\ F+S_1 & \leftrightarrow & FS_1 & \to & F+S_0\,, \end{array}$$

where S_0 and S_1 are nonphosphorylated and phosphorylated forms of a protein, E and F enzymes, and ES_0 and FS_1 intermediate steps. Persistence for this PTM system may be understood via our model simplification approach as a consequence of strong connectedness of its underlying substrate model $S_0 \leftrightarrow S_1$.

The removal of intermediates is also shown not to break known conditions for global convergence. (Received September 22, 2015)

1116-92-2266 **Emily Chae Castner*** (castn22e@mtholyoke.edu), 55 Fire Road 10, Lancaster, MA 01523, and **Brent R Davis** and **Joseph P Rusinko**. *A distance-based method for phylogenetic tree reconstruction using algebraic geometry.* Preliminary report.

Using algebraic geometry and optimization software, we present a new method for phylogenetic quartet reconstruction. Representing tree topologies as varieties and genetic data as points, we determine how well the data fits a Markov model on the associated tree topology by minimizing the distance from the point to the variety.

We implement this for the heterogeneous Jukes-Cantor, Kimura 2- and 3-parameter, and general Markov models of evolution. The Kimura 3-parameter model is most accurate on data simulated under the same model. We see that the Jukes-Cantor model is almost as accurate, even with model misspecification on all data, and is by far the fastest. (Received September 22, 2015)

1116-92-2275 **Beyza Aslan*** (beyza.aslan@unf.edu), University of North Florida, Department of Mathematics and Statistics, 1 UNF Dr., Bldg 14/2731, Jacksonville, FL 32224, and **Anthony Perszyk**. *Pattern recognition to improve diagnostic process for late-diagnosed late onset MADD patients.*

Multiple acyl-CoA dehydrogenation deficiency (MADD), or commonly referred to as glutaric academia type 2 (GA2), is a genetic metabolic disorder affecting amino acid, fatty acid, and choline mechanisms. It is passed on in an autosomal-recessive manner. While most cases present themselves at birth or at an early age, it is also quite possible to get a diagnosis well into adulthood. For these late-onset patients, the road to diagnosis is often long, painful, and frustrating. In addition, due to late diagnosis they can also suffer from long-lasting effects of their worsening symptoms. The goal of this work is to determine clinical patterns by utilizing the already existing clinical data for patients who are diagnosed very late after the onset of their symptoms. We take a graphical approach and present a new way to look at data with the hope that, in the future, this might help in pattern recognition and facilitate early diagnosis. Data related to age at the onset of symptoms, age at diagnosis, gender, and various common symptoms are studied. (Received September 22, 2015)

1116-92-2307 **Timothée Poisot*** (tim@poisotlab.io), Montréal, QC H2V2S9, Canada. *The small data era of ecology.*

In addition to its roots in natural history, ecology is becoming an increasingly computational science. Whereas other natural sciences (physics, genomics, chemistry) have to deal with "big data", ecologists are facing a different challenge altogether: because biodiversity is a complex object, and because its sampling in the field is costly and time-consuming, ecologists must deal with low-volume, high-noise, heterogeneous datasets. Yet this does not mean that data-intensive ecological science is currently an unreachable goal: I will present case studies of reconstructing "synthetic" datasets, and showcase how these can help address questions at scales that are too large to be sampled over the course of a lifetime. (Received September 22, 2015)

1116-92-2347 **Channing Stephanie Parker*** (parkercs@dukes.jmu.edu) and **Kathryn Rose Voss** (vosskr@dukes.jmu.edu). *Statistical models for estimating copy numbers of transposable elements using high-throughput DNA sequencing data.* Preliminary report.

The freshwater zooplankton *Mesocyclops edax* exhibits the trait of chromatin diminution, in which it deletes 80% of its DNA in somatic cells. Genome-wide comparison of the somatic genome (3 Gb) with the germline genome (15 Gb) shows that much of the deleted DNA comes from transposable elements. Transposable elements are regions of DNA that replicate themselves within the genome leaving multiple copies of the original sequence. Modern DNA sequencing methods produces millions of short reads of the DNA sequence randomly distributed across the genome. We use statistical models of the depth of coverage of these reads to the genome to gain probabilistic information about the number of copies of any particular transposable element. This information can then be used to explore the evolutionary history of that element. (Received September 22, 2015)

1116-92-2374 **Sarah Bartlett Minucci*** (sarah.minucci@gmail.com), LU Box 2040, 1120 North Ocoee Street, Cleveland, TN 37311, and **Stephen J. Merrill**. *The relationship between leptin and inflammation in adipose tissue determines critical points in excess nutrition in women.*

Research shows a significant relationship between leptin, a hormone involved in energy intake and expenditure, and inflammation in adipose tissue, the main depot of fat storage. These findings suggest an important factor in the drastic weight increase associated with obesity: a cycle of inflammation due to increases in leptin levels. This inflammation and subsequent weight gain, as well as difficulty in losing weight, could help explain why lifestyle changes are often not enough to mitigate obesity. The pleiotropic role of leptin not only points to its influence in obesity, but also its comorbidities, including type 2 diabetes and heart disease as well as in general immune system dysfunction. In fact, leptin seems to be a crucial factor in the prevalence of autoimmune diseases in women, especially women with greater amounts of adipose tissue. Through construction of a mathematical model of the relationships between leptin, inflammation, and adipose tissue, we can better understand the role of leptin in adipose tissue inflammation, specifically in women. Insight into these relationships is necessary in better treating obesity, understanding the sexual dimorphism of immune system dysfunction, and determining risk for autoimmune diseases and obesity-related health complications. (Received September 22, 2015)

1116-92-2379 **Chindu Mohanakumar** (cmohanakumar@ufl.edu), **Annabel E. Offer*** (annabel.offer@ttu.edu) and **Jennifer Rodriguez** (jrodri98@asu.edu). *Mathematical model for time to Neuronal Apoptosis due to accrual of DNA DSBs.*

We propose a mechanism to explain neuronal aging by tracking the number of non-transient DNA double-strand breaks (DSBs) and repairs over time that may lead to apoptosis. Neuronal apoptosis depends on the amount of space between DSBs as well as time. We derive three models to track the effect of neurodegeneration: a system of autonomous Ordinary Differential Equations (ODEs), a probability model to track the spatial requirement, and a stochastic model that incorporates both the ODE temporal dynamics and a spatial probability model. Using these models, we estimate a distribution for the lifespan of a neuron and explore the effect of parameters on time to death. We identify three possible causes of premature neuronal apoptosis: problems with coding critical repair proteins, issues with the neuron detecting DSBs, and issues with the neuron responding to DSBs. (Received September 22, 2015)

1116-92-2380 **Simon Joyce*** (joyce@math.binghamton.edu), 14 Washington Ave, Apt. 302, Endicott, NY 13760. *New Results in a Boolean Model of Gene Regulatory Networks.* Preliminary report.

Signed directed graphs are often used as a model for gene regulatory networks. If increasing the expression level of gene i has the effect of increasing (decreasing) the expression level of gene j, this is represented by a positive (negative) arc from i to j. In the model I'll be discussing, each gene is assigned a boolean variable s_i to represent its expression level, where $s_i = -1$ if the gene products of gene i are absent or inactive, and $s_i = 1$ if they are present and active. We then represent the expression level of n genes with a vector $\mathbf{x} \in \{1, -1\}^n$. In state $\mathbf{x}$, the expression levels may be changing. A function $\mathbf{f} : \{1, -1\}^n \to \{1, -1\}^n$ is used to represent this, where $f_j(\mathbf{x}) \neq x_j$ if the expression level of gene j is changing. We infer the influence of gene i on other genes by comparing $\mathbf{f}(\mathbf{x})$ to $\mathbf{f}(\mathbf{y})$, where $\mathbf{x}$ and $\mathbf{y}$ differ only in the ith coordinate. Doing this, we derive a signed directed graph $\mathcal{I}_{\mathbf{f}}$, the gene regulatory network. I will present some facts on the relationship between $\mathbf{f}$ and $\mathcal{I}_{\mathbf{f}}$ and my recent results. (Received September 22, 2015)

1116-92-2383 **Kevin B Flores***, Department of Mathematics, Center for Research in Scientific Computation, North Carolina State University, Raleigh, NC 27695. *Statistical validation of continuously structured population models for Daphnia magna.*

Data measurements of biological systems are often indirect and may be limited by clinical or experimental constraints. I will show how dynamic mathematical models can be used to aid interpretation of biological data, focusing specifically on the population dynamics of Daphnia magna, an ecologically important organism in the context of toxicology. A concern for environmental hazard assessments is that hazard predictions for population/ecosystems are derived solely from the evaluation of toxicity data at the organism level. I will discuss results from a collaboration with toxicologists at NCSU in which we developed a structured population model that can be used to propagate the assessment of Daphnia magna organismal responses, i.e., to environmental change, to the population level, thereby enabling the causal association of organismal responses to ecosystems adversity. (Received September 22, 2015)

1116-92-2442 **Brian Dennis*** (brian@uidaho.edu). *Allee effects and resilience in stochastic populations.*

Allee effects, or positive functional relationships between a population's density (or size) and its per unit abundance growth rate, are now considered to be a widespread influence on the growth of ecological populations. Here I analyze how stochasticity and Allee effects combine to impact population persistence. I compare the deterministic and stochastic properties of four models: a logistic model (without Allee effects), and three versions of the original model of Allee effects proposed by Vito Volterra representing a weak Allee effect, a strong Allee effect, and a storng Allee effect with immigration. The diffusion process approach is employed, with the focus on the properties of stationary distributions and of the mean first passage times. I show that stochasticity amplifies the risks arising from Allee effects, mainly by prolonging the amount of time a population spends at low abundance levels. Even weak Allee effects become consequential when the ubiquitous stochastic forces affecting natural populations are accounted for. Although current concepts of ecological resilience are bound up in the properties of deterministic basins of attraction, a complete understanding of alternative stable states in ecological systems must include stochasticity. (Received September 22, 2015)

1116-92-2449 **Libin Rong***, Department of Mathematics and Statistics, Oakland University, Rochester, MI 48309. *Modeling HIV treatment and slow depletion of target cells.*

Highly active antiretroviral therapy can effectively control HIV replication in many infected individuals. Some data suggested that viral decay dynamics may depend on the stages of the viral replication cycle inhibited by different classes of drugs. In this talk, I will use a mathematical model including multiple infection stages to study the effect of various drug classes on the viral load dynamics under treatment. The model will be used to explain the discrepancy of the viral load change observed in patients receiving raltegravir and efavirenz based therapy. I will also introduce a model on the basis of a new mechanism to explain the slow time scale of CD4+ T cell decline during chronic HIV infection. Modeling prediction will be compared with long-term CD4+ T cell data in untreated HIV patients. (Received September 22, 2015)

1116-92-2471 **Caitlin A Kennedy*** (kennedyc2@hawkmail.newpaltz.edu). *Mean field modeling of neural population interactions.*

Bursting (defined as a period of high firing rate followed by a period of quiescence) has been observed experimentally in groups of neurons in certain brain regions (such as the thalamus, the hippocampus, or the midbrain) during normal or pathological behavior. Biophysical membrane- potential models of single cell bursting involve at least three equations; extending such models to study the network behavior of coupled populations would involve thousands of equations and can be very expensive computationally.

Using a mean field approach, we construct a two-dimensional population model that retains crucial biophysical aspects. We then use this system as a building block for modeling brain regulatory networks. We study synchronization and mechanisms that trigger and stop transitions between tonic and phasic population firing. Our model helps contextualize and understand the factors involved in regulating burst firing, and how it may modulate distinct aspects of behavior. (Received September 22, 2015)

1116-92-2476 **Joanna R Herron*** (herronj1@hawkmail.newpaltz.edu). *Modeling synaptic control of obsessive compulsive behavior.*

The neuronal circuit that controls the execution of stereotyped behaviors involves three major regions of the brain: the cortex, the striatum and the thalamus (the CSTC pathway). Coordinated interplay between activation and inhibition within the CSTC pathway is crucial for proper thought-processing and movement execution. However, there is no clear understanding of basic mechanisms generating hyperactivity in the CSTC pathway – a hallmark feature of patients with increased anxiety and motor activity, like the ones affected by obsessive compulsive disorder.

We build a coupled nonlinear model of neural and synaptic activity, that captures salient information in the CSTC circuit provided by basic empirical studies in rodents, and by imaging studies in humans. Using methods from nonlinear dynamics and bifurcation theory, we study the system's temporal behavior and its dependence on parameters. We verify and interpret current molecular theories on the role of CSTC regulation in the formation of obsession and compulsions. (Received September 22, 2015)

1116-92-2481 **David Koslicki*** (david.koslicki@math.oregonstate.edu), Mathematics Department, 354 Kidder hall, Oregon State University, Corvallis, OR 97331, and **Simon Foucart** (foucart@tamu), Texas A&M University, Department of Mathematics, 3368 TAMU, College Station, TX 77843. *Optimizing biodiversity in metagenomics via compressed sensing.* Preliminary report.

Metagenomics is the study of microbial DNA that is extracted directly from a community of organisms in a given environment. Metagenomic analysis has clarified diverse processes ranging from global nutrient cycling to human disease and has proven to be a powerful tool for understanding the ubiquitous communities of bacteria that exist in our world, many of which can be studied only via their DNA. This pursuit presents a number of unique challenges including producing massive amounts of data that can be only approximately compared to very incomplete databases. We will present an approach based on compressed sensing, and discuss an extension that involves optimizing the biological diversity of a given sample. This is based on a recently proposed generalization of biodiversity metrics introduced by Leinster and Cobbold (2014). (Received September 22, 2015)

1116-92-2490 **José M. Ponciano*** (josemi@ufl.edu), Carr Hall 882 Newell Dr, Gainesville, FL 32611. *A population biology interpretation of Bayesian Nonparametric Inference from Gene Genealogies.* Preliminary report.

Using a nonparametric Bayesian approach Palacios and Minin (2013) dramatically improved the accuracy, precision and biological adequacy of Bayesian inference of population size trajectories from gene genealogies.These authors proposed an extension of a Gaussian Process (GP) nonparametric inferential method for the intensity function of non-homogeneous Poisson processes. The authors' prior does not assume a form on the population trajectory. Their approach works so well and provides such a profound understanding of the biological process, that the question arises as to how truly 'biology-free' their approach really is. Using well-known concepts of stochastic population dynamics, here I demonstrate that in fact, Palacios and Minin's GP model can be cast as a stochastic, parametric population growth model with density dependence and environmental noise. Making this link between population genetics and stochastic population dynamics modeling provides novel insights into eliciting biologically meaningful priors for the trajectory of the effective population size. The results presented here also bring new understanding of GP as models for the evolution of a trait. Thus, our ecological interpretation of their prior adds to the conceptual and scientific value of these authors' approach. (Received September 22, 2015)

1116-92-2503 **Reginald L. McGee*** (mcgee.278@mbi.osu.edu), The Ohio State University, 1735 Neil Avenue, Columbus, OH 43210, and **Ann E. Rundell** and **Gregery T. Buzzard**. *Reductions in dynamic uncertainty for a B cell antigen receptor signaling model using a MINE criterion.*

Mathematical modeling is a powerful tool in systems biology; we focus here both on model development and on improving the reliability of model predictions by reducing the uncertainty in model dynamics through experimental design. Model-based experimental design is a process by which experiments can be systematically chosen to reduce dynamic uncertainty in a given model. We discuss the Maximally Informative Next Experiment (MINE) method for experimental design and present a convergence result for MINE with nonlinear models. As an application, we apply the method to a B cell antigen receptor signaling model, previously used to study the effects of inhibition of key kinases on downstream signaling factors. This nonlinear dynamical system model has been expanded to include structure for the NFAT pathway, but there is limited data to identify parameters and reduce the existing uncertainty in the dynamics. The MINE criterion sequentially determines experiments that can be conducted to best refine the dynamics for this added signaling pathway. (Received September 22, 2015)

1116-92-2526 **John G Alford***, jalford@shsu.edu, and **Edward Swim** and **Alacia Voth**. *Mathematical Modeling of Androgen Deprivation Therapy for Advanced Prostate Cancer.* Preliminary report.

One of the most important treatments for advanced prostate cancer has become androgen deprivation therapy (ADT). We present three models of ADT: continuous androgen suppression (CAS), intermittent androgen suppression (IAS), and periodic androgen suppression. These models quantify the serum prostate-specific antigen (PSA) levels typically used as a biomarker for cancer levels and treatment protocols. Currently, many patients receive CAS therapy; however, many patients undergo a relapse after several years and experience adverse side effects while receiving treatment. IAS therapy may delay the time to relapse and/or reduce the economic costs and adverse side effects of treatment. For each model, we compute and analyze parameter sensitivity which provides insight to effective data collection in future clinical trials. The PSA levels exhibit (approximately) periodic behavior prior to relapse in the IAS model and the periodic model exhibits similar qualitative behavior. Using the periodic model, we derive theoretical parameter bounds for which relapse will occur. Finally, we derive formulas to approximate the relapse time in both the continuous and periodic models and rank the parameter influence on relapse time using relative sensitivity analysis. (Received September 22, 2015)

1116-92-2533 **M M Rahman*** (mrahman@unf.edu), 1 UNF DRIVE, DEPARTMENT OF MATH & STATS, UNIV. OF NORTH FLORIDA, JACKSONVILLE, FL 32216. *Wave propagation in noisy systems near saddle node on limit cycle bifurcation.* Preliminary report.

We develop and apply a method of stochastic approximation to a canonical model arises in a circular process in mathematical neuroscience that has a parametric noise. We also investigates the role of noise in the circular process. (Received September 22, 2015)

1116-92-2668 **Rebecca E Gasper*** (rebeccagasper@creighton.edu). *Stochastic Gating in a Peripheral Auditory Neuron: Effects on Post Stimulus Time and Firing Efficiency of Action Potentials.*

Random effects in voltage change in the auditory neurons has been documented since at least 1995. A reaction-diffusion PDE is used in place of a system of Stochastic DEs to model randomness in NaV channel gating. The result is a stunning visual representation of the probability density function, along with necessary numerical data for the spread of firing times and firing efficiency for a given stimulus protocol. A PDE has the advantages of giving additional information about states, such as flow into a firing region (the firing rate), and accommodating clinical uncertainty of initial conditions with an initial probability distribution. This method can be applied to nearly any ODE (SDE), but is especially useful for a large class of action potential models. (Received September 22, 2015)

1116-92-2699 **Jeff Sharpe*** (jsharpe@knights.ucf.edu). *Population dynamics for stray cats.*
We formulate and analyze a mathematical model which describes the population dynamics of feral cats. The model includes three categories: kittens, adult female and adult males. Kittens are born at a rate proportional to the adult female population. Adults compete both with members of their own sex and members of the opposite sex for resources. A net reproduction number R_0 is defined. If $R_0 < 1$, then the population goes extinct. If $R_0 > 1$, then the population can persist at a positive and locally asymptotically stable equilibrium. Extensions to the model include the movement of adult males in a spatial habitat and the spread of feline leukemia. These extensions will be mentioned. The results presented here represent joint work with Dr. Andrew Nevai. (Received September 22, 2015)

1116-92-2700 **Mariel Vazquez*** (mariel@math.ucdavis.edu), Mathematics Department, University of California, Davis, One Shields Ave, Davis, CA 95616. *DNA unlinking.*
Chromosomes are long DNA molecules encoding the genetic code of an organism. Cellular processes such as DNA replication and recombination change the topology of circular DNA, in particular newly replicated circular chromosomes are topologically linked. This poses a topological problem to the cell. Returning the chromosomes to an unlinked state is essential to cell survival. The cell uses enzymes to achieve this goal. We model the action of enzymes as band surgeries, use tools from low-dimensional topology to establish unlinking pathways and topological mechanisms, and present a computer implementation to find the most likely pathway. (Received September 22, 2015)

1116-92-2714 **Bernadette J Stolz*** (bernadette.stolz@lincoln.ox.ac.uk), **Heather A Harrington** and **Mason A Porter**. *Analysis of fMRI data using methods from network theory and persistent homology (Preliminary Report).* Preliminary report.
The human brain can be studied using networks. One can define the nodes to be different brain regions and the edges between them to be weighted by a measure of similarity of time series of the brain regions to create a so-called *functional network*. This can then be studied using methods from network science or methods from *structural balance theory* which are used to study relationships between negative and positive edges. Another approach to analyse networks is to apply ideas from *computational topology*, a set of algorithmic methods that characterises topological invariants such as connectedness, loops, or holes in high-dimensional data structures. These methods go beyond pairwise connections. In particular, *persistent homology*, a method that consists of a mathematical formalism to explore the persistence of such structures, has led to promising results on neuronal networks. We analyse task-based fMRI data from schizophrenia patients, controls and siblings of schizophrenia patients using both methods from network science and structural balance theory as well as methods from persistent homology. We also look at the effect of fMRI preprocessing steps that are commonly performed on such data on our results. (Received September 22, 2015)

1116-92-2794 **Erica M Rutter*** (erutter1@asu.edu), **Tracy L Stepien**, **Barrett A Anderies**, **Eric J Kostelich** and **Yang Kuang**. *Experimental and Numerical Results for Glioblastoma Multiforme in Murine Brains.* Preliminary report.
Glioblastoma Multiforme (GBM) is a malignant form of brain cancer which is very difficult to treat for several reasons. Firstly, GBM characteristics include not only large proliferation, but also large migration. Secondly, MR images are often used to determine where the cancer is present in the brain. However, what shows on the MR image is not necessarily the full amount of GBM tumor present.

Identical mice were injected with GL261, a GBM-like cell line and imaged over several time points using MR. Despite these controlled experimental conditions, we observed a large variance in the final tumor sizes of the mice (from 10 mm^3 to 60 mm^3). We formulate several hypotheses to explain this large discrepancy and use a 3D finite difference simple reaction-diffusion model to test these hypotheses. We also experiment with introducing slight complexities into the model, such as stochastic parameterization and density-dependent diffusion, to examine how this affects the results. (Received September 22, 2015)

1116-92-2829 **Sheldon H Lee*** (shlee@viterbo.edu). *A stochastic process model for fish migration.*
In this talk, I will discuss a continuous-time Markov model to describe the migration of fish along a river system. We assume that a river is divided into several regions, and that they are separated by barriers such as dams. We assume that fish may cross such barriers at various rates which may depend on a factors such as the type of dam, the season, and the water temperature. In this talk I will discuss the probability of fish reaching the end of a river system, and how harvesting at a particular pool affects this probability. As an example I will discuss the migration of an invasive species of Asian carp in the Illinois River. (Received September 22, 2015)

1116-92-2843 **Reginald L. McGee*** (mcgee.278@mbi.osu.edu), The Ohio State University, 1735 Neil Avenue, Columbus, OH 43210. *Dynamic immunity: Mathematical models for B cell signaling pathways and chronic lymphocytic leukemia.*

In this talk I will discuss results from my dissertation: "Modeling, analysis, and control of Syk-mediated signaling events for B cells and associated cellular response for B cells." Primarily, I will focus on the mathematical model developed for B cell antigen receptor signaling and on experimental design results for reducing dynamic uncertainty that are applicable to nonlinear models. Additionally, I will discuss connections to my current work on chronic lymphocytic leukemia and new directions. (Received September 22, 2015)

1116-92-2850 **Nikhil S Ladva*** (nsladva@cpp.edu), Brea, CA 92821, and **Rex Woon**, **Jesus Navarro** and **Alex Nguyen**. *Surviving through California's drought.*

Since 2011, California has been experiencing a severe drought. Applying predictive models on California's rainfall, water supply, and water usage, we forecast California's water supply for the next 20 years. Evaluating these predictions based on surivability criteria, we determine the minimum conservation measures needed in order to endure past the drought. (Received September 22, 2015)

1116-92-2931 **Leah Edelstein-Keshet*** (keshet@math.ubc.ca), Dept of Mathematics, UBC, Vancouver, BC V6T 1Z2, Canada. *Using mathematics and computation to address problems in cell biology.*

In this talk, I will highlight research carried out in my group over the past decade, focusing on problems motivated by cell biology. First, I will describe how we created models for cell polarization (determining front and back of a cell) and how we used those models to get insight into crawling motion of cells. I will describe new mathematical methods that we found useful in understanding the systems of PDEs that depict concentrations of regulators inside a cell. I will also discuss how the models were validated against experiments. In the second part of my talk, I will mention a few examples of how simplified models can be used to motivate undergraduate students in a Life-Science calculus class. (Received September 23, 2015)

1116-92-2950 **Nakeya D Williams*** (nakeya.williams@usma.edu), West Point, NY 10698. *Modeling Head-up Tilt via an Optimal Control Approach and a Non-pulsatile Cardiovascular Model.* Preliminary report.

This study considers an optimal control approach to modeling effects of cardiovascular regulation during head-up tilt (HUT). Many patients who suffer from dizziness or light-headedness are often exposed to the HUT test to explore potential deficits within the autonomic control system, which maintains the cardiovascular system at homeostasis. This system is complex and difficult to study in-vivo, thus we propose to use mathematical modeling to achieve a better understanding of the cardiovascular regulation system during HUT. In particular, we show the feasibility of using optimal control to predict changes in vascular resistance and cardiac contractility, quantities that cannot be measured directly, but which are useful to assess the state of the cardiovascular system. A non-pulsatile lumped parameter model is utilized as well as a direct transcription optimal control method to regulate the cardiovascular system. (Received September 23, 2015)

93 ► Systems theory; control

1116-93-721 **Dylan R Poulsen*** (dpoulsen2@washcoll.edu). *Can an Unstable Control System Be Stabilized By Timing Noise?*

We consider the scalar, linear time invariant control system $\dot{x} = Ax+Bu$, where the control u is a sample-and-hold state feedback rule which updates at nonuniform time steps. We show that even if the system becomes unstable when updated with the uniform time step τ, the system may still be stabilized when updated at non-uniform time steps with an average time step $T > \tau$ if $A < 0$. (Received September 11, 2015)

1116-93-1755 **Nina H Amini*** (nina.amini@lss.supelec.fr), 3, Rue Joliot Curie, 91190 Gif-Sur-Yvette, France. *Stability of quantum filters driven by Poisson and Wiener processes in presence of measurement imperfections.*

In this talk, we prove the stability of quantum filters driven by Poisson and Wiener processes which take into account measurement imperfections. Firstly, we apply quantum repeated measurement approach to obtain discrete-time Markov chains approximations of the quantum filter and its estimate. Then, we obtain continuous-time stochastic master equations (SMEs) as the limit of these discrete-time Markov chains. Moreover, the obtained continuous-time SMEs are slightly more general than the ones usually encountered in the literature.

Such SMEs could be of some interest to derive quantum filters taking into account a larger class of incompleteness and errors in measurements and jump detections. Indeed, these filters are designed based on modeling the measurement imperfections by a left stochastic matrix. This work shows the stability of such quantum filtering process but does not necessarily ensure the asymptotic convergence of such quantum filters. (Received September 21, 2015)

1116-93-2205 **Juan Durazo*** (juan.durazo@asu.edu), Tempe, AZ 85281, and **Eric Kostelich** and **Alex Mahalov**. *Ionospheric Weather Forecasting Using a Climatology-Augmented Ensemble Kalman Filter.* Preliminary report.

We asses the performance of an ensemble Kalman filter in forecasting the global distribution of electron density when assimilating globally distributed electron density profiles. The forecast model used is the TIEGCM, which is a 3D non-linear model of the ionosphere on a global grid. Electron density observations are obtained from the COSMIC satellite mission and are assimilated to adjust the forecast once every hour. The data assimilation scheme used is the LETKF, and it incorporates observations within a prescribed radius of each grid point to compute a unique linear combination of the forecast ensembles at each grid point to update the initial conditions for the next forecast. The ensemble of forecasts is augmented with additional climatology-derived forecasts at analysis time to increase the effective rank of the forecast uncertainty estimate and potentially reduce forecast uncertainty in additional directions. We present the benefits of augmenting the ensemble with climatology in estimating global electron density distribution. This validation is done with independent satellite observations and ionosonde measurements of peak electron density in the F2-layer. (Received September 22, 2015)

94 ► Information and communication, circuits

1116-94-732 **Pani Seneviratne*** (padmapani.seneviratne@tamuc.edu). *Automorphism group of binary MacDonald codes.* Preliminary report.

McDonald codes are an important class of maximum minimum distance error-correcting codes that meet the Griesmer bound. Further, these codes belong to the class of two-weight codes. In this work we determine the automorphism group of the binary MacDonald codes. Further we find full error-correcting PD-sets for permutation decoding for these codes (Received September 11, 2015)

1116-94-2211 **Sui Tang*** (sui.tang@vanderbilt.edu). *Exact reconstruction of an evolving signal from incomplete information of its future states.*

Let $f \in \ell^2(I)$ be a signal at time $t = 0$ of a dynamical process controlled by a bounded linear operator A that produces the signals $Af, A^2f, \cdots$ at times $t = 1, 2, \cdots$. Let $Y = \{f(i), Af(i), \cdots, A^{l_i}f(i) : i \in \Omega \subset I\}$ be the spatio-temporal samples taken at various time levels. The problem under consideration is to find necessary and sufficient conditions on A, Ω, l_i in order to recover any $f \in \ell^2(I)$ from the measurements Y. This is the so called Dynamical Sampling Problem in which we seek to recover a signal f by combining coarse samples of f and its futures states $A^l f$. This problem has connection to many areas of mathematics including frames, Banach algebras, and the recently solved Kadison-Singer/Feichtinger Theorm. We will discuss the problem, its extentions, and show some recent results. (Received September 22, 2015)

1116-94-2386 **James Edward Mihalisin*** (jedmdesigns@gmail.com), 2821 Edridge Ct. Unit 202, Raleigh, NC 27612. *Meta-Graphs and Gamification.* Preliminary report.

I define a *graph* to be any utilization of the attributes (size, shape, placement, color, etc.) of geometric primitives (circles, rectangles, etc.) to display data. Roughly speaking, a *meta-graph* is a graph of graphs.

Typically, *gamification* refers to the concept of applying game mechanics and game design techniques to engage and motivate people to achieve goals. This concept is of particular interest to me when those goals involve harnessing human cognitive ability for a greater purpose. For example, the "Fold-It" website from the University of Washington harnesses human intuition to help solve computationally intractable protein folding problems.

In this talk, I will share my progress on an iOS app that employs meta-graphs in an attempt to gamify the statistical analysis of multi-variate data. (Received September 23, 2015)

1116-94-2581 **Kashi N Neupane*** (knneupane@ung.edu), University of North Georiga, Department of Mathematics, Gainseville Campus, Gainseville, GA 30503. *Long-term secure two-round group key establishment from pairings.*

In 2007, Bohli et al. introduced the concept of long-term security as resistance against attacks even if later, after completion of the protocol some security assumptions become invalid, and proposed a three-round long-term secure two-party key establishment protocol. Building on a two-party solution of Bohli et al., we present an authenticated two-round group key establishment protocol which remains secure if either a Computational Bilinear Diffie Hellman problem is hard or a server, who shares a symmetric key with each user, is uncorrupted. (Received September 22, 2015)

1116-94-2664 **Dmitry E Chebukov*** (tche@mi.ras.ru), Moscow, Moscow 119991, Russia. *Collection of the mathematical publications and video records on the All-Russian mathematical portal Math-Net.Ru.*

The main goal of the project is to collect scientific publications in Russian and Soviet mathematics journals and the authors of these publications into a single database and to provide access to full-text articles to broad international mathematical community. Leading Russian mathematics journals have been comprehensively digitized dating back to the first volumes. The database includes papers in Russian, English, French and German. All publications are supplied with English translations of the title, abstract and keywords, and a link to the publication of the English version if any. Reference links to Crossref, MathSciNet, ZentralBlatt Math, Astrophysics data system and ISI Web of Knowledge are provided for every paper. Reference lists free to read and download as well as forward links are supplied. The system provides comprehensive information about the authors of mathematical publications and their institutions. It also includes lists of lectures and presentations on scientific conferences and seminars. Free access to video records of the presentations and lectures is provided. The system offers advanced functionality for editorial needs including manuscript submission and tracking system. (Received September 22, 2015)

1116-94-2901 **Shuyang Ling*** (syling@math.ucdavis.edu), One Shields Ave., Department of Mathematics, University of California Davis, Davis, CA 95616, and **Thomas Strohmer** (strohmer@math.ucdavis.edu), One Shields Ave, Department of Mathematics, University of California Davis, Davis, CA 95616. *Self-calibration and biconvex compressive sensing.*

The design of hardwares with higher precision always comes along with the increasing need of calibration. However, calibration can be expensive and difficult for high-performance sensors and even impossible sometimes. Self-calibration manifest itself as one possible way to resolve this issue. The idea of self-calibration is to equip the sensors or systems with a smart algorithm which can take care of calibration automatically. In this work, we bring self-calibration, biconvex optimization and compressive sensing together. We will introduce a new framework of biconvex compressive sensing with a new method called SparseLift, which can handle a class of self-calibration problems successfully. To be more specific, we consider a concrete model as y = DAx where x is the unknown sparse signal and D is an unknown diagonal matrix which represents the calibration parameters. We will show how this problem can be solved via "Lifting" techniques and SparseLift efficiently and robustly. Theoretic guarantees are derived for exact recovery of D and x simultaneously and the effectiveness and robustness of SparseLift will be illustrated by numerical examples. (Received September 23, 2015)

1116-94-2928 **Joseph D Lakey*** (jlakey@nmsu.edu) and **Jeffrey A Hogan** (jeff.hogan@newcastle.edu.au). *Recent Advances in Duration and Bandwidth Limiting.* Preliminary report.

That the prolate spheroidal wave functions are eigenfunctions of an operator that first limits a function to a finite time interval then bandlimits the resulting function was observed by Slepian and Pollak in 1960. Since 2000 much progress has been made involving numerical analysis using the prolates. Here we will focus on some new results in frame theory. Specifically, certain normalizations of shifted prolates form tight frames for the Paley-Wiener space. A corresponding result applies to what we call bandpass prolates. These are eigenfunctions of time limiting then bandpass limiting. Methods to perform numerical computations with bandpass prolates will be discussed and applications will be outlined. (Received September 23, 2015)

1116-94-2952 **Simon Foucart***, foucart@tamu.edu. *Sparse recovery from saturated measurements.*

In classical Compressive Sensing, one aims at faithfully reconstructing high-dimensional but sparse vectors $\mathbf{x} \in \mathbb{R}^N$ from the knowledge of few measurements of the type $y_i = \langle \mathbf{a}_i, \mathbf{x} \rangle$, $i = 1, \ldots, m$. In one-bit Compressive Sensing, the measurements are quantized to an extreme situation where $y_i = \mathrm{sign}\langle \mathbf{a}_i, \mathbf{x} \rangle$, $i = 1, \ldots, m$. In this talk, we consider an hybrid situation where the linear measurements $\langle \mathbf{a}_i, \mathbf{x} \rangle$ can be conventionally acquired unless their magnitude exceeds a given threshold, in which case they are saturated to this threshold. We present a theory of sparse recovery from such measurements that unites classical and one-bit Compressive Sensing. In particular, we establish a property akin to the restricted isometry property and to the sign product embedding property for random measurements. Under this property, we demonstrate the suitability of recovery algorithms stemming from ℓ_1-minimization and from iterative hard thresholding. (Received September 23, 2015)

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1116-97-104 **Paul N Runnion*** (prunnion@mst.edu) and **Barbara J Wilkins** (bwilkins@mst.edu). *Sometimes a Step Forward Requires a Step Sideways: Early Intervention in Calculus I at Missouri S&T.* Preliminary report.

At Missouri University of Science and Technology, less than 10% of students with a D or F in Calculus I at midterm finished the course with a grade of C or better in recent semesters. To address this major concern, we implemented an early intervention program during the Fall 2015 semester which uses the second half of the semester to improve the overall preparedness of students while reinforcing the calculus they saw during the first half. Preliminary data from the first semester of implementation will be presented, along with future plans. (Received July 24, 2015)

1116-97-292 **Ellina Grigorieva*** (egrigorieva@twu.edu), PO BOX 425262, Denton, TX 76204. *Geometric approach to solving algebraic problems.*

Sometimes it is beneficial to look at an algebraic problem from a geometric point of view. For example, for positive values of x and y, the equation $x^2 + y^2 = a^2$ can be seen as the relationship between sides of a right triangle with hypotenuse a and legs x and y. Using Law of Cosines for a triangle, equation $x^2 + x * y + y^2 = a^2$ also can be considered as a relationship between side of a triangle, a expressed in terms of two other sides, x and y, forming an angle of 120 degrees. In this talk, I will demonstrate how geometric approach can be used to solve many complex algebraic optimization problems and to prove some unusual inequalities. (Received August 22, 2015)

1116-97-383 **Natali Hritonenko*** (nahritonenko@pvamu.edu), P.O. Box 519, Dep pf Mathematics, Prairie View, TX 77446. *Puzzles, warm-ups, and games in teaching Calculus.*

Calculus is considered to be one of the most challenging subject by college students. Their mathematical background should be much better in order to quickly grasp the main concept of Calculus and go on further in its study. Warm-ups at the beginning of class, games to review fundamentals, and puzzles for homework can significantly increase students' understanding of the subject, review the fundamentals, and help them to go through challenges of the subject. Description and examples of warm-ups, games, and puzzles in Calculus class will be presented. The benefits of these activities from students' perspective will also be discussed. (Received August 29, 2015)

1116-97-405 **Steven J Miller*** (sjm1@williams.edu), 18 Hoxsey Street, Williamstown, MA 01267. *Building YouTube University Brick by Brick.*

There are many parts to engaging students. We discuss two aspects: the material chosen, and how to present it. I have twice taught a class on the mathematics of Lego bricks. I use the bricks as a springboard to a lot of great concepts, from combinatorics to game theory to chirality. The final project is to assemble the 3152 piece Superstar Destroyer, as a group, in under 10 minutes; this is a terrific hands-on introduction to Operations Research as they optimizing their construction. It's also one of the few times they supervise a large team and deal with the subsequent issues. In both this and my standard classes I record all my lectures on an iPad, uploading them to YouTube within a few hours of the lecture. The quality of the recording is high, as I use a swivl system which tracks my movement and results in a good recording without the need of hiring a cameraman. There are numerous advantages: (1) students can go back and catch missed lectures or review concepts they missed, (2) students can take the class remotely (this includes former students who have graduated and are considering graduate school, people at other institutions which are not offering a similar course, and also students at my institution who want to also take another course meeting at the same time). (Received August 31, 2015)

1116-97-457 **Emina Alibegovic**, emina@math.utah.edu, and **Hugo Rossi***, rossi@math.utah.edu. *University of Utah Master of Science in Mathematics (Teaching).* Preliminary report.

In 2009-10 two graduate programs for teachers were initiated at the U of U: one that would in addition provide an initial licensure, and the other for cohorts of in-service teachers. Research indicated that M.S. programs neither in mathematics nor mathematics education were serving the profession well, and there was a general call for designing programs in which mathematics and teaching would not be treated as two separate disciplines. On this basis, we conceived of a program grounded in mathematics, guided by the content of CCSS, directed to deepening the candidates' understanding of the mathematical and pedagogical structure that underlies the standards. While the content was broadly on school mathematics, the intellectual demand was clearly at the level of graduate study. The courses grounded the mathematics in the context of teaching, and challenged students' understanding of both mathematics and teaching, as well as that of learners of mathematics. We maintained several purely content courses that provided a perspective of mathematics as a live, developing field of study. We shall discuss the structure of the program as it has evolved over this five year period, and illustrate with specific illustrations from several classes. (Received September 02, 2015)

1116-97-459 **Hugo Rossi***, rossi@math.utah.edu, and **Margarita Cummings**. *The Emergence of Essentiality from Educator-Mathematician interactions in context.* Preliminary report.

Over the past three years, the speakers have led a group of teachers, educators and mathematicians in the creation of materials for a middle school curriculum in mathematics. Although the CCSS provides insights into essential structures and practices, we discovered through this experience, unexpected, but essential ways of viewing structure and practice, and the way they are intertwined. These discoveries came out of the interaction between mathematicians and educators, in particular, the complementarity (and often dissonance) between their perspectives. We will illustrate this through several specific examples taken from the middle school curriculum, in geometry, algebra and data analysis. We do not believe that our experience is unique, and hope to generate a conversation on how partnership in curriculum development can improve outcomes for students, help teachers and parents better understand the mathematics students are learning, and helps mathematicians better understand how children and adolescents learn. (Received September 02, 2015)

1116-97-551 **Thomas Garrity*** (tgarrity@williams.edu), Department of Mathematics and Statistics, Williams, Williamtown, MA 01267. *Etudes of Questions: A New Approach for Writing Mathematics.*

There is a joy in doing math, a joy not present in most texts. Even homework exercises, while needed for understanding, are still exercises. But people throughout the world spend their free time on puzzles. Can we recreate this type of pleasure for learning mathematics?

This past July, Aaron Bertram and I each gave three weeks of lectures for undergraduates at the IAS/Park City Mathematics Institute. While there, we experimented with having each attendee write what we called "études of questions." Each étude was a series of enticing questions, leading to a clear punchline on some topic.

The idea of having people write out questions seemed to really enable students to take ownership of their topic in a way that we haven't seen through standard assignments and presentations. Even better, working through these questions is now enjoyable for others, like a fun puzzle. Somehow the shifting of the expectation from the author trying to show their understanding to the author trying to create an aesthetic experience in potential readers changed the dynamics for writing mathematics.

We will discuss the nature of "études of questions", look at some examples, and discuss how this idea can be used in classes and even in our research. (Received September 06, 2015)

1116-97-567 **Katie R Fowler*** (kfowler@clarkson.edu), 8 Clarkson Avenue, Department of Mathematics, Potsdam, NY 13676. *Integrated Math and Physics with Roller Coaster Design for Middle School Students.*

We present our STEM Education Roller Coaster Engineering Camp and K-12 outreach program designed for 7th-12th graders. We use an integrated math-physics curriculum to teach students about roller coaster design. The program helps build students' basic skills while introducing them to exciting applications of computational science and engineering. We describe the hands-on learning experiences, including a trip to Six Flags for roller coaster research. Throughout our program, we also incorporate professional development for teachers, undergraduate and graduate students to ultimately increase the awareness of STEM college programs and careers. (Received September 07, 2015)

1116-97-581 **Rachel Levy***, Mathematics, Harvey Mudd College, 301 Platt Blvd, Claremont, CA 91711. *Mathematical Modeling in Elementary Grades: Outreach activities from the IMMERSION program.*

This workshop will introduce the mini-symposium, then present a few activities from the IMMERSION Program, a 3 year NSF-funded project conducted at three sites: George Mason University in collaboration with Fairfax County schools, Harvey Mudd College in collaboration with Pomona Unified School District and Montana State University in collaboration with Bozeman Schools. In summer 2015, the program delivered professional development (PD) in mathematical modeling to 24 elementary school teachers at each site. The teachers then developed activities and implemented them in their classrooms as part of teachers study groups. The audience will engage in some of the mathematical modeling activities from the PD and follow up lessons, which could be easily adapted for outreach to elementary school students. (Received September 08, 2015)

1116-97-639 **James J Madden*** (madden@math.lsu.edu), 222 Prescott Hall, Baton Rouge, LA 70803. *An Historical Perspective of Proportion, Ratio and Measurement.*

"Ratio and Proportion" is a classical topic of school mathematics, and the mastery of "proportional reasoning" is said to be a critical step in advancing to algebra. To a modern-day mathematician, "proportional reasoning" is about using equations of the form $y = k\,x$ to model situations in the world. Over the course of history, there have been numerous fundamentally different paradigms for representing situations described by this equation and solving the problems that arise in them. Different paradigms are distinguished by basic assumptions about the kinds of things that the symbols employed refer to. For example, Euclid's ratios were formed not from numbers but from non-numerical things called magnitudes. Galileo presented his reasoning in the Euclidean paradigm as did many other thinkers following him up to Newton, and a Euclidean ontology is still used today in some physical sciences. Different sets of assumptions about meanings lead to different conceptualizations of the modeling process, and an understanding of the alternatives provides some deep insights into the logic of school mathematics. In this talk, I will describe how an historical perspective of ratio and proportion leads to some surprising ideas and proposals for the K-12 curriculum. (Received September 09, 2015)

1116-97-821 **Christina Eubanks-Turner***, 1 LMU Drive, University Hall, Suite 2714, Los Angeles, CA 90045, and **Anna Bargagliotti**. *Loyola Marymount University's Masters of Arts in Teaching Mathematics Program.*

In this presentation we will give details about Loyola Marymount University's MA in Teaching Mathematics program. The Master of Arts in Teaching Mathematics program provides an opportunity for secondary school teachers to broaden their background in mathematical science and to correlate this knowledge with current education practice. We will also discuss elements of recruitment, curriculum design and program structure. (Received September 13, 2015)

1116-97-911 **Noriko Tanaka*** (tanaka-nagoya@y5.dion.ne.jp), Atsuta, Mutsuno, 2-6, 26-303, Nagoya, Aichi 456-0023, Japan. *Making Problem -Asking the Students to Make up Problem- and its Assessment.*

Active learning is good for students to enjoy mathematics. "Making Problem -Asking the Students to Make up Problem-"(one of active learning) helps students to increase interest in maths, as well as they understand the usefulness of mathematics. This method has been approached with two sets of learning setting - students in my classroom and students in mathematical circle. I describe the method of making up the problems and its assessmemt, then I will share examples of my students' actual work to exhibit their engagement and mathematical learning. (Received September 15, 2015)

1116-97-945 **Polina D. Sabinin*** (polina.sabinin@bridgew.edu), 374 Great Road, Unit 12, Acton, MA 01720. *Rewarding commitment and community-building in a college mathematics classroom.* Preliminary report.

Do you give extra credit opportunities in your courses? Why? Why not? What if a small amount of extra credit could help transform your classroom by inspiring students to create a community of learners and to show increased commitment to the class? Motivated by a conversation at JMM2014, I introduced an extra-credit system, which rewarded commitment, communication, and community building. In this presentation I will share the philosophy and logistics of the system. I will also report on a small-scale study of this system, including students' reflections on how it affected their attitude and learning in the course. Finally, I will share the improvements I made as a result of what I learned from the data. (Received September 15, 2015)

1116-97-1141 **Jeanette R Palmiter*** (palmiter@pdx.edu). *Portland State University's Masters of Science in Mathematics for Teachers Program.*

Begun in the 1980s, the Masters of Science in Mathematics for Teachers (MS-MTCH) in the F.M. Mathematics and Statistics Department at Portland State University is designed for mathematics teachers interested in deepening their understanding of mathematics to enrich their teaching. Participants are looking to become qualified to teach dual-credit courses. The eight core courses are Topics in Probability, Statistics, Geometry, Algebra, Analysis, History of Math, Discrete Math, and Computing for Math Teachers.

The philosophy of the MS-MTCH program is to provide exemplary teaching, curriculum, and models based on educational research. Classes are activity-based using collaborative learning with heavy use of technology, visual aids and manipulatives. Three education electives are taught by Math Educators in our School of Education. A unique Intern/Mentorship Program, similar to a student-teaching experience, pairs teachers with university faculty in dual-credit courses such has Pre-Calculus, Calculus, Probability and Statistics, and Discrete Math. The program culminates with a research paper and public presentation. (Received September 17, 2015)

1116-97-1183 **Ziva Deutsch*** (zivad@macam.ac.il) and **Hava Greensfeld** (greensfeld@gmail.com). *Emotional aspects of contending with mathematical challenges: The role of positive emotions.*

Mathematics has been perceived as a discipline centered on intellectuality, with only a minimal role attributed to emotions. Recent studies have found interaction between a variety of emotions and the quality of learning. In the present study, we focused on the characteristics of those who are willing to cope with mathematical challenges and on their emotions. The research was conducted among participants in the Israel International Math Competition for Girls (IIMCG). The IIMCG is a competition of problem-solving in mathematical thinking, and targets female high school students. The study participants were 12 competitors chosen from the 60 top-10 finalists in the IIMCG competitions held to date. Research instruments included an in-depth interview and a self-report instrument measuring interviewees' positive and negative emotions, expressed while coping with a mathematical challenge. The most prominent results indicated the intensity of the positive as opposed to the negative emotions. Among the positive emotions, determination and curiosity stood out and stressed the importance of the motivational aspect. The findings of this study stress the importance of positive emotions, which broaden the thought repertoire and are a key to flourishing. (Received September 17, 2015)

1116-97-1189 **Elgin Johnston*** (ehjohnst@iastate.edu), Department of Mathematics, Iowa State University, Ames, IA 50011, and **Heather Bolles** and **Travis Peters**. *Team Base Learning in a Large Lecture Calculus I Class.* Preliminary report.

In Fall 2015 we taught two large lecture Calculus I classes using a team based learning (TBL) delivery. We will talk about the logistical aspects of administering the course, the challenges in managing a large number of student groups, and the lessons learned during the semester. (Received September 17, 2015)

1116-97-1212 **J. Alfredo Jimenez*** (jaj4@psu.edu), Penn State Hazleton, 76 University Drive, Hazleton, PA 18202. *Integrating Calculus I for Deeper Conceptual Understanding.* Preliminary report.

Two particular new approaches that have been rather successful in my calculus I class: (1) Deeper conceptual understanding. (2) Integration of knowledge. For years I struggled with the problem that the definite integral, The Fundamental Theorem of Calculus, and Applications come late into the semester and students do not have enough time to develop a deep conceptual understanding of these topics. The solution, as often happens, is quite simple: start teaching these concepts early on. This has allowed me to place greater emphasis on the conceptual understanding of the definite integral. In addition, I have seen two positive outcomes: students who have taken calculus in high school are quickly introduced to new concepts and ideas. Students who have not taken calculus, this approach is more challenging, but those who are committed, they do as well as those who have taken calculus.

As a byproduct, I have now given the same treatment to the derivative. While introducing limits and continuity as complementary concepts to the two central concepts of calculus. The result is that I now teach these four concepts in an integrated fashion. The class then turns into an exploration of how these concepts can be applied in different context. (Received September 17, 2015)

1116-97-1472 **Weam M Al-Tameemi*** (weam.altameemi@tamiu.edu), 5201 University Blvd., LBV 313, Laredo, TX 78041, and **Michael R Kidd** and **Ana L Cruz**. *Writing Intensive Courses.* Preliminary report.

College campuses are offering various forms of STEM Writing Intensive or "WIN"- Courses across the curriculum. The reason behind establishing these WIN- courses is to produce graduate and undergraduate students that are more prepared for their future careers. The effectiveness of STEM WIN-Courses is important for STEM fields nationwide because of the increase of job openings versus the decline of STEM graduates. Therefore, to help resolve this problem it is important to closely monitor the success of such courses and improve them when needed. The purpose of this research is to closely monitor the STEM WIN- courses at Texas A & M International University (TAMIU) and examine the success of STEM students in WIN-courses to help increase the completion rate of STEM students in writing across the curriculum classes. (Received September 20, 2015)

1116-97-1511 **John Selden*** (jselden@nmsu.edu), Department of Mathematical Sciences, New Mexico State University, Las Cruces, NM 88003, and **Annie Selden** (aselden@nmsu.edu), Department of Mathematical Sciences, New Mexico State University, Las Cruces, NM 88003. *A Proving Supplement for an Undergraduate Real Analysis Course.*

We will describe an intervention in the form of a voluntary 75-minute per week proving supplement for an undergraduate real analysis course, which we studied and facilitated for three semesters. Both the research and the facilitation were guided by our theoretical perspective (Selden & Selden, in press-a, in press-b). Since no major reorganization of the real analysis course itself was undertaken, we feel such a supplement could be implemented practically by many mathematics departments. We will briefly mention relevant parts of our theoretical perspective, where it came from, and how we came to teach the supplement/intervention. After that, we will describe our teaching actions as facilitators in preparing for, and leading, what we came to call co-construction (McKee, Savic, Selden, & Selden, 2010). After describing a sample supplement session, we will discuss the usefulness, advantages and disadvantages of this kind of supplement/intervention, some evidence that it "worked", who benefited, what sorts of things the participating students learned, and what kinds of questions they asked during the supplement. (Received September 20, 2015)

1116-97-1516 **Katherine Socha*** (ksocha@parkschool.net), Upper School Mathematics Department, Park School of Baltimore, 2425 Old Court Road, Baltimore, MD 21208. *Quantitative Lying: data literacy and applied mathematics.*

What does the per capita consumption of margarine have to do with the divorce rate in the state of Maine? Does drinking whole milk really support marriage in Virginia? And why are potato chips deadly to wheelchair users? Middle school students typically know how coordinate axes are set up, what percentages mean, and that scale and proportion are important; however, it can be difficult linking these 'math class' ideas to understanding and interpreting newspaper articles, blog posts, and television pundit pronouncements about sports and other hot topics. Data literacy forms the foundation for applied mathematics education and an involved, informed citizenship. Using online resources to introduce surprising correlations and cherry-picked data, the Afya School-Park School Middle Grades Partnership helped support data literacy in a public-private school summer academic program. This talk describes our evolving work. (Received September 20, 2015)

1116-97-1592 **Elizabeth (Betsy) G Yanik*** (eyanik@emporia.edu), Department of Mathematics and Economics, 1 Kellogg Circle, Emporia State University, Emporia, KS 66801. *"Energizing Students"- a STEM program targeted toward Hispanic middle school students.*

Emporia State University for the last four years has sponsored a summer STEM program for middles school students centered about the theme of energy. Last summer we collaborated with a nearby technical college and held hands-on activities at both institutions as well as making filed trips to a natural gas plant and a nuclear energy plant. These programs have specifically reached out to Hispanic students in the area. (Received September 20, 2015)

1116-97-1593 **Satyan L Devadoss*** (satyan.devadoss@williams.edu). *Becoming Blue Collar.*

Mathematics has advanced tremendously by embracing abstraction, escaping "the dreary exile of the actual world" (Bertrand Russell). But have we gone too far, devaluing the importance of the physical and the visual? By looking at works of art and design, we consider ways in which different disciplines can open the door to new venues of mathematical research. (Received September 20, 2015)

1116-97-1596 **Jonathan Kane*** (kanej@uww.edu), 2814 Regent Street, Madison, WI 53705-5218. *How to Write Proofs in Analysis.* Preliminary report.

Books that purport to teach students how to write proofs make significant mistakes.

(1) They begin with a large amount of introductory logic instruction that students find tedious and unmotivated.

(2) Books cover too much of the underlying topic such as Analysis or Algebra and lose sight of the topic of proof writing.

(3) Proof writing is taught by example with inadequate explanation of the proof writing process.

After teaching a beginning proofs course a dozen times, I retired and began writing *How to Write Proofs in Analysis*, a text with the following goals.

(1) Only the bare minimum amount of logic is covered at the beginning of the text. Other logic concepts are introduced as needed for the construction of proofs.

(2) A majority of the text is devoted to the techniques of writing the proofs.

(3) For proofs that follow a prescribed format, proof templates are introduced.

(4) Each proof is preceded with a discussion of what the student should be thinking about when approaching the task of writing that proof.

This book is scheduled for publication in the summer of 2016 by Springer. (Received September 20, 2015)

1116-97-1723 **Yvonne Lai*** (yvonnexlai@unl.edu), **W. James Lewis** (jlewis@unl.edu) and **Allan Donsig** (adonsig@unl.edu). *Mathematical knowledge for teaching at the University of Nebraska-Lincoln.* Preliminary report.

The CBMS publication, *The Mathematical Education of Teachers II*, emphasizes teachers' need for continued professional growth in their mathematical knowledge. At the University of Nebraska-Lincoln we have invested heavily in creating graduate courses for mathematics teachers and in offering opportunities for teachers to take graduate courses to deepen their mathematical knowledge for teaching. In this talk we will give an overview of Nebraska's program and take a close look at two of the courses that have been developed. We discuss how mathematical knowledge for teaching has been built up and interpreted in designing these courses. We will compare viewpoints of instructors and teachers on the teaching and learning of mathematical knowledge for teaching. The results presented draw primarily from data from a Noyce program; the analysis is informed by two decades of professional development course offerings through the NebraskaMATH partnership. (Received September 21, 2015)

1116-97-1775 **Susan L. Addington*** (saddingt@csusb.edu). *Essential Mathematical and Cognitive Structures in K-5 Mathematics: Where They Come From and Where They Go.* Preliminary report.

Young children come to school with 5 years of learning about the world, and a set of built-in and learned cognitive structures. In the first six years of school, they must turn these raw materials into formal mathematical understanding. We describe some of the essential mathematical structures underlying elementary mathematics (such as sequences, groups, rings, fields, the real line) and connect them with neurological structures (such as estimating the sizes of quantities and subitizing), as well as with cognitive structures that must be developed for further work in learning and using mathematics (for example, composing and decomposing, reunitizing, and reifying). We briefly touch on research in education and neuroscience that supports these ideas. (Received September 21, 2015)

1116-97-1786 **Glen R Van Brummelen*** (gvb@questu.ca). *Why?*

Math is beautiful. We know that; it's obvious to us. To many of our students math is a bore, a meaningless duty. That's obvious to them. How can we turn a burden into art, a lament into celebration? By asking — both them and ourselves — deep, meaningful questions. Why is the chain rule important, and why does it work? Why do we ask students to spend a semester in real analysis studying strange functions that never arise in the real world? Why are my students sitting in this classroom with me? Why are they studying at all? Once we understand our students, we can support them. Once we give them context, they can learn. Once we explain "why", only then can they truly perform. (Received September 21, 2015)

1116-97-1980 **Girija Sarada Nair-Hart*** (nairhaga@uc.edu), 4200, Clermont College Drive, Batavia, OH 45103. *Online mathematics courses – A discussion of access and success.*

In 2012 over 33.5% of students in the United States were taking at least one online course (Allen & Seaman, 2014). However, 27% of Americans live with a disability and the internet may pose increased obstruction for many of these members of the society (Jaeger, 2012). According to Roberts et.al. (2011), many online courses are not designed with accessibility in mind. Increasingly many students are taking advanced online mathematics courses that are more demanding than online courses in other disciplines. The matter of accessibility may pose additional challenges to online mathematics students with disabilities. While many educators are concerned about the accessibility issues of eLearning, they may not be aware of different techniques to ensure accessibility for all students. I developed Calculus 1, Calculus 2, and Multivariable Calculus courses and have incorporated techniques to increase accessibility for disabilities in those classes. There are a number of things that every instructor can easily incorporate to address the matters of learner accessibility in the courses they teach. During this presentation I will share several of these techniques. (Received September 22, 2015)

1116-97-2096 **Girija Sarada Nair-Hart*** (nairhaga@uc.edu), 4200, Clermont College Drive, Batavia, OH 45103. *Facilitating collaboration in online multivariable calculus course via Google docs.*

Online students often miss the opportunity to learn from peer interaction. However, increasing social presence and student-student interaction can optimize student success and satisfaction in online courses (Anderson, T., 2009). During this presentation I will elaborate on a group project that I successfully implemented in my online multivariable calculus course on the concept of limits. Proper understanding of the concept of limits is fundamental to learning calculus. The manifold and complex concept of limits is first introduced in Calculus 1. Often even high achievers exit the course with an incomplete understanding of this concept. The limit concept gets even more complex when discussed in the context of functions with more than one variable. A group activity on the topic of limits will be useful for students' understanding the concept in multivariable setting. The use of google docs as the technological medium made this group project easy to implement in an online environment. (Received September 22, 2015)

1116-97-2157 **James R. Valles, Jr.*** (jrvalles@pvamu.edu), Department of Mathematics, Prairie View A&M University, P. O. Box 519 – Mailstop 2225, Prairie View, TX 77446-0519. *Engagement, Capacity, and Continuity Theory: What is it and how can I use it?* Preliminary report.

There have been a number of theories posited regarding the success, or lack of success, of students in mathematics courses. The Engagement, Capacity, and Continuity Theory (ECC) attempts to address factors that affect student success in STEM courses when they are considered together, as opposed to previous analysis where they may have been evaluated individually.

Some background on ECC Theory will be discussed as will various attempts (some successful and some not successful) the author has made in his classes to incorporate aspects of this theory into the classroom lecture/presentation. (Received September 21, 2015)

1116-97-2234 **Cody L. Patterson*** (cody.patterson@utsa.edu), Department of Mathematics, One UTSA Circle, San Antonio, TX 78249. *Functions, Rates, and Quantitative Reasoning: From Proportionality to Exponential Growth.*

In their work with functions, middle and high school mathematics classes engage in a considerable amount of cross-representational activity: for example, sketching a graph of a linear function given an formula, or producing a formula for an exponential function given a table of values. However, this work is often disorganized and skill-oriented, focusing on mastering techniques for translating from one representation to another rather than on developing key ideas about functions that emerge from and support such translational activity. In this talk, we explore how work with linear and exponential functions can be structured around the key ideas of initial value and rate of change or growth factor, and how these ideas can be developed through quantitative reasoning. (Received September 22, 2015)

1116-97-2265 **Jennifer Johnson-Leung*** (jenfns@uidaho.edu), **Mark Nielsen** and **David Yopp**. *Training Teachers of Mathematics in Idaho and Beyond.* Preliminary report.

The MAT program at the University of Idaho is primarily a distance education degree aimed at the audience of in-service secondary mathematics teachers. The degree is designed to give teachers an opportunity to enrich their content knowledge in mathematics. Over 15 mathematics and statistics courses are available in streamed video format.

We are further expanding course offerings and developing a middle school endorsement. The mathematics courses are specially designed for prospective middle school teachers. The content is design to teach the specialized content knowledge that teachers will need to support students in learning Common Core mathematics and practices. The new courses are in a live online format with three course numbers allowing us to serve three audiences with one course: undergraduate mathematics education majors, MAT students, and in-service teachers through professional development credits.

I will discuss the successes and challenges of both models as we strive to serve a rural population in a large geographic region. (Received September 22, 2015)

1116-97-2310 **Lesa L Beverly*** (beverlyll@sfasu.edu), PO Box 13040, SFA Station, Nacogdoches, TX 75962-0340. *Stephen F. Austin State University's Graduate Programs for Secondary Teachers.*

In addition to our traditional Master of Science degree in Mathematical Sciences, Stephen F. Austin State University offers two master's degree programs to address the needs of secondary mathematics teachers. The Master of Science in Natural Sciences degree was recently modified to serve as a vehicle for various multidisciplinary programs, including a mathematics/mathematics education program. This program is populated primarily by teachers who are seeking qualification for teaching dual credit courses. Additionally, the Master of Science in School Mathematics Teaching program is fully online and targets career changers and current teachers who want to strengthen and deepen their mathematical knowledge. In this session, we will discuss the lessons learned from the implementation of these programs as well as the logistics involved in teaching full-time teachers. (Received September 22, 2015)

1116-97-2323 **Kristin L. Umland*** (umland@math.unm.edu), Department of Mathematics and Statistics, MSC01 1115, 1 University of New Mexico, Albuquerque, NM 87131. *What Do We Mean by Proportionality?* Preliminary report.

Ratios, rates, proportions, proportional relationships - what do we mean by these terms? There is a surprising amount of disagreement about their meaning and relative importance, and the result is a largely incoherent treatment of proportionality in many school textbooks. In this talk, I will discuss a modern treatment of these ideas by highlighting a key shift in recent approaches to this subject area from studying ratios and proportions to proportional relationships and explaining how this is an important pivot point between elementary school arithmetic and the high school study of functions. I will also discuss the role and nature of definitions in school mathematics (Received September 22, 2015)

1116-97-2372 **Katharine B Sawrey*** (katharine.sawrey@tufts.edu), Department of Education, 12 Upper Campus Rd, Paige Hall, Medford, MA 02155, and **Barbara M Brizuela**. *A Fourth Grade Student's Exploration of Linear Equation Representations in a Function Task.* Preliminary report.

In this presentation, I will share a case study in which I analyze one fourth-grade student's work on an algebraic task called the Function Puzzle. The Function Puzzle is a task intended to elicit a "sense of functions" (Eisenberg, 1992) from students who have not formally been introduced to algebra (such as upper elementary students). The task consists of 16 cards: 4 different functions (constant, ratio, linear with positive slope, linear with negative slope) in 4 different representations (natural language, equation, Cartesian graph, function table). Students create sets of cards with one type of representation in each set, developing their own rationale for why the cards might belong together. I administered the Function Puzzle to 12 fourth-grade students in an individual interview setting. By students' admission, the equations, given in slope-intercept form (i.e., $y = 3x + 4$) and Cartesian graphs were unfamiliar representations. Curiously, several students disregarded the independent variable in reading the equation cards aloud and in assessing the value of the dependent variable. This presentation will share video excerpts connecting this consistent omission to Sfard's theory of mathematics as discourse (2012). (Received September 22, 2015)

1116-97-2499 **Katherine M. Kinnaird*** (kkinnair@macalester.edu), Macalester College, Department of Mathematics, Statistics, and Computer Science, Saint Paul, MN 55105. *TRAIn Method: A new lab model for training undergraduates in STEM fields.* Preliminary report.

Inspired by the transition that undergraduate students make from college to any kind of research position, such as being a graduate student, a member of an R&D department, or a new hire at a start-up, the ***TRAIn method*** seeks to train students to be excellent researchers in any field, by requiring students to (T)ry, (R)ead, (A)sk, and (In)corporate. As conceptualized, the TRAIn method seeks to provide a low risk environment for students to push at the boundaries of their knowledge and practice the skills they will need to conduct original research. The four parts of the TRAIn method can be applied to any field of expertise. This method is crafted for students who are enthusiastic and reflective learners, regardless of students' existing knowledge or skills in the field of choice.

In this talk, we present The Data Science TRAIn Lab (dsTRAIn) that is the first lab of this kind and seeks to expose undergraduate students to Data Science and Machine Learning using the TRAIn method. In just one term, dsTRAIn at Macalester College started six machine learning projects, led paper discussions with two machine learning researchers, and read seminal papers on topics from spectral clustering to topic modeling. (Received September 22, 2015)

1116-97-2562 **Marcel Prevuznak***, marcel.prevuznak@tridenttech.edu. *Increasing Student Engagement in an Introductory/Intermediate Algebra Classroom.*

This presentation will discuss some ideas for increasing student engagement, contextual understanding and appreciation of topics in an introductory or intermediate algebra classroom through the use of props to activate prior knowledge. (Received September 22, 2015)

1116-97-2575 **Joni J Schneider*** (js1824@txstate.edu), 1230 N. LBJ DR. 712, San Marcos, TX 78666. *Talk Math 2 Me: Changing One's Mathematical Identity.* Preliminary report.

An individual's mathematical identity is how one would see one's self in the mathematical community. In this presentation, we will share how a seminar program, Talk Math 2 Me, is affecting undergraduate students' mathematical identity and their view of mathematics culture. Talk Math 2 Me is a weekly seminar that provides students with the opportunity to present research of mathematics, mathematics history, and/or interesting math ideas to an audience of their peers. The seminar is set in a casual environment for students to share how they view mathematics. In addition to affecting their mathematical identity, we will address how this seminar has also been increasing undergraduate students' awareness about how fun and rewarding mathematics research can be. (Received September 22, 2015)

1116-97-2588 **Rachel Cywinski*** (worldvisitor@rocketmail.com), worldvisitor@rocketmail.com, San Antonio, TX. *Can't make it to the bottom rung: Adults afraid of mathematics.*

A two-phase, sequential mixed methods study with a primary 16-week quasi-experimental quantitative study, was conducted among students attending below-college-level courses at a Historically Black College that now has a majority of Hispanic students. Half of the students were in classes in which the instructor discussed mathematics anxiety, and half in classes without this supplemental discussion. Supplemental instruction was derived, with permission of publisher Brooks/Cole, from Richard Smith's "Mastering Mathematics" (1998) and Cynthia Arem's "Conquering Math Anxiety, 2E" (2003). The Revised Mathematics Anxiety Rating Scale (Plake & Parker, 1982) was used with permission of Barbara Plake, for pre-semester and post-semester comparisons for 732 students. Findings indicated that changes in level of mathematics anxiety during the semester may be a confounding variable in studies designed to seek correlations between mathematics anxiety and student achievement in mathematics. Results of the study raise larger questions for public policy regarding the availability of below-college-level courses in mathematics for adult students, and implications of such policies on potential lifetime earnings for those students. (Received September 22, 2015)

1116-97-2675 **George Brock Williams*** (brock.williams@ttu.edu) and **Jerry F. Dwyer** (jerry.dwyer@ttu.edu). *The Master of Mathematics program for in-service teachers at Texas Tech University.*

The program began as a attempt to improve the mathematical content knowledge of rural West Texas teachers. From there the Texas Tech M.A. program has grown into an online teacher training program with national reach. We will describe the program and its participants, the structure and nature of the courses as well as their ultimate impact. We will also briefly discuss our new B.A./M.A. program for beginning teachers. (Received September 22, 2015)

1116-97-2853 **Rachel M Bates*** (rachel.bates@redlandscc.edu), 19112 Meadows Crossing Drive, Edmond, OK 73012. *An Exploration of A Non-Traditional Introductory Statistics Course.*

Calls for comprehensive innovative curriculum and pedagogical changes to mathematics courses and introductory statistics courses have been documented within multiple national reports during the last several decades. In recent years, research studies in statistical education aimed at the teaching of introductory statistics have emerged in the literature (see, e.g., Cobb, 1993, Garfield, 1995, Hoaglin & Moore, 1992, Moore, 1997). The essence of the introductory statistics reform movement promotes statistical literacy and quantitative reasoning rather than calculations, procedures and formulae. Although there is a plethora of research on reform based statistics, there has been little research that describes the characteristics of a problem-based introductory statistics course at the college level or on how students respond to a more conceptually-based introductory statistics course. The purpose of this study is to describe the approaches to learning statistical concepts as the student engaged in problem-based learning activities and to focus on the perceived student learning experiences and emerging statistics understanding as a result of engaging in various problem-based learning activities within the course. (Received September 22, 2015)

1116-97-2858 **James A. Mendoza Epperson*** (epperson@uta.edu), Box 19408, Department of Mathematics, UT-Arlington, Arlington, TX 76019-0408, and **Kathryn Rhoads**. *Graduate Courses in Mathematics for Teachers: The University of Texas at Arlington Master of Arts in Mathematics Program for Secondary Mathematics Teachers.*

The Master of Arts (MA) in Mathematics program in the Department of Mathematics at The University of Texas at Arlington focuses on extending undergraduate mathematics in the area of specialized content for secondary mathematics teaching. The program offers opportunities for inservice teachers to deepen and connect their mathematical knowledge of high school concepts from an advanced standpoint. The courses in the MA program simultaneously integrate rigorous mathematics, effective pedagogy, and mathematics education research on student learning. As such, they incorporate instruction that models research-based teaching techniques and strategies in the context of in-depth mathematical concepts grounded in school mathematics, multiple opportunities for incorporating current mathematics-specific technologies and applications, and high yield problem solving experiences for exploring mathematical connections and applications using high quality curriculum resources in mathematics.

We will highlight the structure of the program, course descriptions, and provide examples of mathematics content and evaluation standards. Support for faculty teaching in the program and external funding sources will also be discussed. (Received September 22, 2015)

1116-97-2891 **James J Madden*** (madden@math.lsu.edu), 222 Prescott Hall, Baton Rouge, LA 70803, and **Frank Neubrander** and **Guillermo Ferreyra**. *The Masters of Natural Sciences Degree Program at Louisiana State University.* Preliminary report.

The Master of Natural Sciences (MNS) degree is administered by the LSU Graduate School in conjunction with the LSU College of Science. According to the graduate bulletin, the program "provides the depth and breadth of study in the sciences that is required of science professionals and school teachers." Since 2007, the LSU Departments of Mathematics, Physics and Biology have cooperation with the LSU Cain Center for STEM Literacy to offer specialized course work for secondary teachers, and over 100 teachers have earned the degree. All candidates produce a thesis that is required to be an "evidence-based contribution to the professional knowledge of STEM teachers." Between 2009 and the present, candidates were supported by an NSF MSP Institute grant. In this talk, we will describe the content of the mathematics track and relate what is known about impacts on the professional practice of teachers. (Received September 22, 2015)

1116-97-2895 **Amanda Ellis Francis*** (amanda@mathematics.byu.edu), 275 TMCB, Department of Mathematics, Brigham Young University, Provo, UT 84602. *Teaching strategies for a first course in linear algebra.*

Linear Algebra is polarizing course. Most students end the semester having been transformed by the magic of linear systems, vectors, and matrices; some for good (full of love for mathematics and wonder at its logic), and some for evil (full of animosity for the tedious complexity of mathematics and venomous hatred towards proofs). What can we do save the mathematical souls of our linear algebra students? In this talk, I will discuss some of the strategies that I have found helpful in convincing undergraduates to appreciate linear algebra, even as they face seemingly insurmountable mathematical and logical obstacles. (Received September 22, 2015)

1116-97-2922 **Zephyrinus C Okonkwo*** (zephyrinus.okonkwo@asurams.edu), Department of Mathematics and Computer Scienc, Albany, GA 31705, and **Anilkumar Devarapu** (anilkumar.devarapu@asurams.edu), Department of Mathematics and CS, Albany, GA 31705. *Using item analysis of assessment instruments to enhance instruction, learning, and student achievement: The case of Numbers and Operations Course.*

Tests, quizzes, class projects, and other forms of evaluation instruments are used for the assessment student learning. It is important therefore that the course objectives and the items on the assessment instruments be aligned seamlessly. Analysis of student performance on evaluation instruments must be used to determine which objectives are being met and how well they are being attained. This presentation focuses on the role of item analysis in improving instruction, assessment, student achievement, learning, and student engagement in Numbers and Operations course (Received September 23, 2015)

1116-97-2968 **William G. McCallum*** (william.mccallum@gmail.com). *From the ark of history to the arc of reasoning.*

School mathematics is a summation of centuries of investigation. What was once the frontier of knowledge is now taught to school children. The challenge of school mathematics education is preserving the knowledge distilled from history without recapitulating that history with all its turns and cul de sacs. In this talk we will describe one arc in school mathematics from fractions in elementary school to functions in high school. (Received September 23, 2015)

Table of Contents for MAA Abstracts of Invited Addresses, Presentations by Teaching Award Winners, SIGMAA Guest Lecturers, and Session Papers

The presenter of each talk is indicated by an asterisk (*) in the abstract.

MAA ABSTRACTS

MAA Invited Addresses, Presentations by Teaching Award Winners, and SIGMAA Guest Lecturers

1116-A0-12 **Alan Schoenfeld***, University of California, Berkeley, Berkeley, CA. *What makes for powerful classrooms—and what can we do, now that we know?*

We now understand the properties of classrooms that produce powerful mathematical thinkers and problem solvers. The evidence comes mostly but not exclusively from K–12. The question for us: What are the implications for the ways we teach post-secondary mathematics? (Received May 07, 2015)

1116-A0-17 **Steven Brams*** (sjb1@nyu.edu). *Fair division.*

Ideas about fair division, including "I cut, you choose," can be traced back to the Bible. But since the discovery 20 years ago of an n-person algorithm for the envy-free division of a heterogeneous divisible good, such as cake or land, interest in fair division has burgeoned. Besides envy-freeness, properties such as equitability, efficiency, and strategy-proofness have been studied, and both existence results and algorithms to implement them will be discussed (some implementations will be shown to be impossible). More recent work on algorithms for the fair allocation of indivisible items, and tradeoffs among properties, will be presented. Applications, including those to dispute resolution, will be discussed. (Received September 17, 2015)

1116-A0-18 **Katherine Crowley*** (katherine.d.crowley@gmail.com). *Mathematics and policy: strategies for effective advocacy.*

One day in the United States Senate, a team of political staffers took a spontaneous break from writing legislation to request combinatorial proofs on demand of their favorite mathematical identities from their mathematician colleague (me). As the barrage of job demands implored us to disperse moments later, our legislative director chided me for sneaking in the final answer by induction. What is the level of understanding of mathematics among those who craft our national policies? What impact does a mathematician have in a seat at the table of debate over our country's most pressing challenges? How can mathematicians inform policy, and how can policy support mathematics? I will discuss the elements of effective advocacy for our discipline. (Received May 08, 2015)

1116-A0-19 **T. Christine Stevens*** (tcs@ams.org). *Singing along with math: The mathematical work of the opera singer Jerome Hines.*

For over forty years, Jerome Hines (1921-2003) sang principal bass roles at the Metropolitan Opera in New York and in opera houses around the world. He was also a math major who retained a lifelong interest in mathematics. During the 1950's Hines published five papers in Mathematics Magazine that were based on work that he had done as a student, and he later produced several lengthy mathematical manuscripts about cardinality and infinite sets. I will discuss some of Hines' mathematical work, as well as the way in which his undergraduate experience at UCLA converted him from a student with no particular liking for mathematics into an aspiring mathematician. I also hope to explore the question of what mathematics meant to Hines and why, in the midst of demanding musical career, he felt it important for him to develop and publish his mathematical ideas. (Received July 29, 2015)

1116-A0-21 **Charles R. Hadlock*** (chadlock@bentley.edu), Bentley University, Waltham, MA. *A Mathematical tour through a collapsing world.*

If you search the word "collapse" on Google News on any given day, you are sure to get thousands of hits, as well as a healthy reminder that we do live in a world where a very wide variety of things are collapsing every day. When assessing the risk of collapse, one.s initial mindset about its source can lead to insufficient attention being paid to alternative sources. That's why financial auditors, accident investigators, and similar professionals follow systematic protocols that attempt to assure that a wide field of issues are addressed, even in the presence of strong evidence pointing in a particular direction. This same mentality is important in more general and less structured treatments of risk and possible collapse, whether to companies, currencies, species, governments, facilities, diseases, societies, or almost anything else. Mathematics provides an ideal framework for capturing the essence of a wide range of common collapse dynamics that permeate many areas of application. After all, we customarily discuss subjects like probabilities, extrema, stability, nonlinearity, games, networks, and others, all of which are closely related to possible collapses. But beyond capturing the concepts, which itself should not be understated as an important contribution to workers from diverse disciplines, we also offer powerful tools for

going deeper to mine important insights, resolve specific uncertainties, and guide future actions. I will expand upon these ideas with examples from the real world and with some mathematical gems that many of us might not ordinarily encounter in our mathematical training or reading. I will also mention how this work grew out of an exhilarating interdisciplinary undergraduate seminar course. (Received May 12, 2015)

1116-A0-50 **Robert Devaney***, Boston University, Boston, MA. *The fractal geometry of the Mandelbrot Set.*

In this lecture we describe several folk theorems concerning the Mandelbrot set. While this set is extremely complicated from a geometric point of view, we will show that, as long as you know how to add and how to count, you can understand this geometry completely. We will encounter many famous mathematical objects in the Mandelbrot set, like the Farey tree and the Fibonacci sequence. And we will find many soon-to-be-famous objects as well, like the "Devaney" sequence. There might even be a joke or two in the talk. (Received June 23, 2015)

1116-A0-2992 **James Tanton***, Mathematical Association of America, Washington, DC 20036. *How to Think Brilliantly and Creatively in Mathematics: A Guide for K-12 Educators and Their Students.*

This lecture is a guide for thinking brilliantly and creatively in mathematics for K-12 educators, their students, and all seeking joyful mathematics doing. How do we model and practice uncluttered thinking and joyous doing in the classroom? Pursue deep understanding over rote practice and memorization? Develop the art of successful flailing? Our complex society demands of its next generation not only mastery of quantitative skills, but also the confidence to ask new questions, explore, wonder, flail, persevere, innovate, and succeed. Let's not only send humans to Mars, let's teach our next generation to solve problems and get those humans back if something goes wrong! In this talk, James Tanton will explore five natural principles of mathematical thinking. We will all have fun seeing how school mathematical content is the vehicle for ingenuity and joy. All are so welcome to attend! (Received October 14, 2015)

1116-A0-2993 **Joan Ferrini-Mundy***, National Science Foundation, North Arlington, Virginia. *Studying mathematics learning and improving mathematics teaching: bu= ilding careers of integrated scholarship and practice.*

I cannot imagine a more exciting time for those who are committed to the improvement of undergraduate mathematics teaching. The research base for informing curricular and instructional practice is solidifying and expanding. There are new approaches and tools for research that emphasize the problems of instructional practice and the importance of design and implementation, and there are new opportunities for collaborations with experts across many domains. Technology to support student learning is widely accessible, and that same technology opens novel ways to study student learning. Attention to "mathematical practice" in the preK-12 arena and the mathematics community's report, *The Mathematical Sciences in 2025*, help shape possibilities for undergraduate mathematics. The Federal government has made the improvement of undergraduate science, technology, engineering, and mathematics education a government-wide priority. The Project NExT community is poised to lead the way to significant change and improvement of mathematics learning experiences for the next generations, while focusing both on what is enduring in undergraduate mathematics teaching and learning and on creating pathways to shape what is needed for tomorrow. (Received October 27, 2015)

Addressing the Needs of Mathematics and Computer Science Majors in Discrete Mathematics Courses

1116-A1-48 **Paul R. Bouthellier*** (`pbouthe@pitt.edu`), 504 East Main Street, University of Pittsburgh-Titusville, Titusville, PA 16354. *How Calculators and Computers Compute.*

Any student who uses a computer or calculator should have a good understanding of how the machine actually computes the results. Such knowledge is necessary to guard against (and deal with) approximation errors, overflows, underflows, wrap-around infinities, and a host of related problems. It also shows that behind every button push is not "magic" but rather some clever mathematics and engineering. In this talk we shall look at methods of calculating elementary functions such as nth roots, sin(x), cos(x), tan(x), ln(x), and exponential functions by methods such as CORDIC, polynomial approximations (such as minimax polynomials) and numerical algorithms. These methods will be illustrated by programs run on calculators and computers. The efficiency of such algorithms and the corresponding programs we use will be discussed. Such a calculational problem illustrates to computer science students the importance of efficient mathematical algorithms and illustrates to mathematics students the need for efficient programs in carrying out mathematical algorithms. (Received June 22, 2015)

1116-A1-281 **D A Dietz*** (dietz@american.edu). *Teaching Discrete Mathematics to novice programmers using python, unit tests, and precompiled code.*

In this talk, I discuss the programming component of a course I developed and used at the University of Pennsylvania to teach Discrete Mathematics to students who had no programming experience but were expected to be concurrently enrolled in an introductory programming course.

It is considered a best practice when programming to use unit testing, but beginners struggle to write the code itself, not to mention good unit tests. However, when the unit tests are provided for them, this flips around entirely, making it much easier for them to succeed in writing good code. I also gave the students "broken" starter functions and pre-compiled code as additional scaffolding so they could experiment with the working code prior to writing it.

I will briefly discuss some of the projects used as well as the benefits and drawbacks I felt this system brought to the overall experience of the students. (Received August 21, 2015)

1116-A1-604 **Jerry Lodder*** (jlodder@nmsu.edu), Mathematical Sciences, Dept. 3MB, Box 30001, New Mexico State University, Las Cruces, NM 88003. *Teaching with historical curricular modules: The Juxtaposition of Prüfer and Borůvka.*

We explore how the discrete structure known as a *tree* evolved from the work of Aurthur Cayley (1821–1895) in displaying the logical branching of partial differentiation to the formulation of an algorithm for finding a minimal spanning tree articulated by Otakar Borůvka (1899–1995). Excerpts from these historical sources along with readings from the work of Heinz Prüfer (1896–1934) form the core of a teaching module for topics in discrete mathematics, graph theory or algorithm design. Briefly, Cayley identifies a pattern in the enumeration of (labeled) trees on n-vertices, although he does not provide a rigorous proof of this result. Prüfer develops a one-to-one correspondence between labeled trees and so-called Prüfer symbols, from which "Cayley's formula" follows. Finally, Borůvka describes an algorithm for finding a minimal spanning tree over the domain of all labeled trees. These papers in juxtaposition provide context, motivation and direction for certain topics in discrete mathematics and graph theory, each at an increasing level of rigor and sophistication. Comments from student questionnaires concerning the benefits of learning from historical sources include "It helps me understand the reason why things were put together like they are." (Received September 08, 2015)

1116-A1-605 **David J. Pengelley*** (davidp@nmsu.edu), Mathematics, 3MB, New Mexico State University, Las Cruces, NM 88003. *Throwing away the textbook: Teaching discrete mathematics from primary historical sources.*

Can our students benefit from studying primary historical sources, as is the norm in the humanities? Could guided student projects based on primary sources even form the entire course material for deep questioning, investigation, resolution, and learning? A long-term team effort has created discrete mathematics courses based entirely on primary source projects for mathematics and computer science majors: Goodbye textbook, hello Euclid, Chrysippus, Archimedes, Pascal, Leibniz, Boole, Frege, Cantor, Dedekind, Russell, Whitehead, Post, von Neumann and others.

Our student projects utilize carefully selected excerpts from primary sources, supplemented with our own unifying writing, to provide stimulating and motivating challenges for students based on the sources. These include modern questions and exercises about proofs and programming, and together cover the material in a standard textbook course in a variety of possible ways.

We will present samples of primary source project materials, including challenges for both mathematics and computer science students, and discuss how students benefit, how their work changes, and what their own views are of learning from primary sources. (Received September 08, 2015)

1116-A1-1184 **Edmund A. Lamagna*** (eal@cs.uri.edu), Department of Computer Science and Statistics, University of Rhode Island, Kingston, RI 02881. *Puzzling Through Discrete Mathematics.*

The presenter teaches an applied, yet mathematically rigorous, course on combinatorial problem solving. Algorithmic thinking is emphasized throughout, and the course provides a solid foundation for a follow-on course in the design and analysis of algorithms. Major topics include sets, logic, probability, proofs by induction and contradiction, the pigeonhole principle, arrangements, selections, distributions, binomial identities, inclusion-exclusion, recurrence relations and recursion, and graphs and trees.

Each class begins with a set of puzzles (typically four) that introduce and begin to stimulate thinking about the subject for the day. Students work on the puzzles in small groups for about one-third the period. When puzzles were introduced, it was thought that less material could be covered, but this would be outweighed by an increase in student interest and participation, and the course would be more fun. Unexpectedly, all the original material can still be covered since students are now better prepared and motivated for the more traditional presentation that follows "puzzle time."

The key to this approach is selecting relevant, intriguing puzzles for each topic. Examples covering a variety of subjects that have been successfully utilized are presented in the talk. (Received September 17, 2015)

1116-A1-1306 **Ruth Vanderpool*** (r.e.vanderpool@gmail.com), School of Interdisciplinary Arts & Sciences, University of Washington Tacoma, 1900 Commerce Street, Tacoma, WA 98401. *Examples of Programming Labs that Apply and Motivate Discrete Math using Sage.*

Three labs developed for a Discrete class housed in a Computer Science department will be presented along with the student responses. All labs were created with the open-source mathematical software SAGE and are available for use and modification. The first lab has students use formal logic to make database inquiries. The second leads students to discover cardinality results as they practice set builder notation and set operations. The third lab uses cipher codes to motivate modular arithmetic and the existence of inverses. (Received September 18, 2015)

1116-A1-1612 **Risto Atanasov*** (ratanasov@email.wcu.edu), Western Carolina University, Dep. of Mathematics and Computer Science, Cullowhee, NC 28723. *Discrete Structures Projects - Addressing the Needs of Three Majors.*

The Discrete Structures course offered at Western Carolina University is a required course for three majors: computer science, mathematics, and mathematics education. The greatest challenge in this class is to provide each group of students with meaningful connections between the material and their major. Even though the syllabus is designed to meet the needs of every one of these three groups, I assign projects in the class that are closely related to students' interests and to other classes required for their major. For example, the students majoring in computer science do projects that relate to searching or sorting algorithms; these projects always have a programing component as well as a component that incorporates proof-writing and mathematical problem-solving skills. The focus of this presentation will be the projects assigned in the course. (Received September 20, 2015)

1116-A1-1889 **William P Abrams*** (abramswp@longwood.edu), Department of Mathematics and Computer Scienc, Longwood University, 201 High Street, Farmville, VA 23909. *Discrete Mathematics for First Year Mathematics and Computer Science Majors.* Preliminary report.

In Fall 2013 the Longwood Department of Mathematics and Computer Science began requiring Discrete Mathematics for all Mathematics and Computer Science majors. This course was designed to be taken during the first year. It was intended to make these students aware that not everything was calculus and give them a course that would be more directed at problem solving and less directed at getting them to the next course. The course was not originally intended to include either proofs or programming. I will talk about additional goals this course acquired and why, the problem with using the textbooks that currently exist with first year students at a small state comprehensive university, and the problem with using proofs and not using proofs. In addition I will mention the topics we chose to include and why and the problems that come with teaching discrete math with no prerequisites to first year majors. I will also talk about the changes I made teaching it my second time and whether reducing the number of topics covered, trying to flip this course a little, and concentrating on getting the students to be able to use and understand definitions gave better results.
(Received September 21, 2015)

1116-A1-2688 **Carl Toews*** (ctoews@pugetsound.edu). *Using Jupyter Notebooks to Bridge the Path from Math to Code.*

There are a number of courses in the undergraduate mathematics curriculum that tend to attract both mathematics and computer science majors. "Discrete mathematics" as a stand-alone course is one, but others include optimization, modeling, and numerical analysis. A common tension in many of these courses is how to strike a balance between theory and computation: for non-mathematics majors, the underlying theory can be prohibitively complex, while for non-computer science majors, the programming overhead can be daunting. This talk reports on a recent series of classes in which open-source Python-based Jupyter Notebooks have been used to help mitigate this tension. The Jupyter Notebook allows executable code and typeset mathematical exposition to be embedded in the same document, tremendously streamlining the passage from exposition to code. Since Jupyter Notebooks also display code output, they make it easy for students to inspect, analyze, and modify their computational results, an essential workflow paradigm for harnessing the computer as an exploratory tool. Preliminary student feedback suggests that the Jupyter Notebook can be a powerful element around which to design classroom activities that appeal to both mathematics and computer science majors. (Received September 22, 2015)

1116-A1-2799 **Tracey McGrail*** (tracey.mcgrail@marist.edu). *"Big O" Captain, My Captain.*
Discrete mathematics is a course in which the topics are chosen by computers scientists but which is often taught by mathematicians. There is often a tension between the disciplines. Some textbooks contain material that the instructors do not want to teach; while others contain material that the students do not find relevant. So it is important to present material in such a way that students want to learn it and instructors want to teach it. One particular topic of concern is Big O notation. Big O notation is used to describe the efficiency of an algorithm. First- and second-year students of discrete mathematics often struggle with this concept, in part because they have not yet completed calculus. In this talk, I will make the case that the functional programming language Haskell provides a way to bridge this gap. On the one hand, Haskell is a nice tool for the students because it is an actual working programming language. On the other hand, Haskell is a nice language for the instructors because it is a pure equational theory. I will present a complete system for measuring run time of algorithms expressed in the programming language Haskell. (Received September 22, 2015)

1116-A1-2837 **Monika Keindl*** (monika.keindl@nau.edu). *Using SAGE to illustrate the proof of Euler's polyhedron formula.* Preliminary report.
We will use the computer algebra system SAGE to illustrate the inner workings of the proof of Euler's formula $v-e+f=2$ and in the process learn many of the impressive features this software package offers. This approach is an appropriate middle ground between the mathematical rigor expected from mathematics majors and the programming skills computer science majors are familiar with. (Received September 22, 2015)

Assessing Student Learning: Alternative Approaches

1116-A5-163 **Mindy Capaldi*** (mindy.capaldi@valpo.edu). *Assessing Pre-Class Assignments in a Flipped Class.*
Flipped courses require students to read or watch videos before coming to class. Such tasks are critical to the success of the course, so they are often followed by short graded quizzes or homework. Making these assignments too high-stakes is risky because students have not had a chance to practice the new material. Making them too low-stakes can result in students deciding they aren't worth the effort. This talk describes a method of grading so that each pre-class assignment is pass/fail and does not individually factor into the final course grade. However, accumulation of enough failing grades gradually lowers a student's letter grade. (Received August 10, 2015)

1116-A5-181 **Amanda Harsy*** (harsyram@lewisu.edu), One University Parkway, Unit #298, Romeoville, IL 60446. *Encouraging a Growth-Mindset Approach to Learning through Oral and Mastery Based Testing.*
In this talk, we will discuss two alternate assessment methods which strive to decrease test anxiety and increase full understanding of mathematical concepts by fostering a growth-mindset approach to learning. In mastery-based testing, students are given problems in which they can only receive full credit on the problem after they demonstrate mastery of the concept being tested. Each test includes similar questions over the same concepts from previous tests which allows students who have not mastered an idea to retest and fully comprehend old concepts. Once a student receives full credit for a question, they need never attempt the question again. This method was used in both upper level analysis courses and Calculus II courses. We will talk about the similarities and differences between implementing MBT in each course. We will also discuss our experiences using oral exams instead of take-home exams in Analysis courses. Both of these assessment methods are designed so that test anxiety decreases since one bad exam grade or getting stuck on a proof will not necessarily tank their overall grade. This talk will discuss the benefits, shortcomings, and challenges of implementing these alternate assessment techniques. (Received August 11, 2015)

1116-A5-189 **Mike Janssen*** (mike.janssen@dordt.edu), Dordt College, 498 4th Ave NE, Sioux Center, IA 51250. *Implementing Specifications Grading in a Linear Algebra course.*

Specifications ("specs") grading is a competency-based grading system proposed by Linda Nilson, which is of increasing recent interest among mathematicians due to perceived weaknesses in traditional course assessment structures. Specs grading promotes increased rigor by assessing student progress toward learning objectives on a pass/fail basis according to clear specifications, with no partial credit awarded. In addition, students have opportunities for revising work to eventually meet the desired objectives. Final grades are earned based on the number of learning objectives a student has met by the end of the semester. Thus, students may choose to work toward a grade goal by selecting the number and level of objectives they wish to pass; this has the added benefit of reducing faculty workload. I will discuss my course design and experiences implementing specifications grading in a first course in linear algebra. We will pay special attention to the types of alternative assessments which work well in a specs grading paradigm, including mastery-based testing and learning modules. (Received September 04, 2015)

1116-A5-217 **Samuel Luke Tunstall*** (luke.tunstall@gmail.com). *Tests or Projects? The Impact of Summative Assessment in Promoting Quantitative Literacy.*

This research stems from efforts to infuse quantitative literacy (QL) in an online version of college algebra. Two sections of an online college algebra course ran in summer 2015. The only distinction between the courses was that one had numeracy-focused projects at the end of each unit, rather than an exam. Using the QLRA (developed by members of the National Numeracy Network) and qualitative methods for the measurement of numeracy, we found that both sections had significant gains in algebra ability, while only students in the numeracy-focused section had significant gains in their affect towards mathematics. In this talk I will discuss the study, as well as the implications of the findings for any general education math course. (Received August 14, 2015)

1116-A5-276 **J. B. Collins*** (jcollins@wtamu.edu). *Mastery-Based Testing in Calculus.* Preliminary report.

Mastery-based testing is an assessment technique that can be briefly summarized: no partial credit is given on problems, but students are allowed multiple attempts to demonstrate mastery on each problem. This type of assessment has benefits both for the teacher and the students. In this talk, the implementation of this assessment method will be discussed for Calculus 1 and 2, as well as variations on the method which can be included. Results from student surveys will be given, and the benefits and challenges for both the teacher and student will be discussed. (Received August 20, 2015)

1116-A5-282 **Filippo Posta*** (filippo.posta@gcu.edu), 3300 W Camelback, CHSS 16-323, Phoenix, AZ 85255, and **Jonah Beaumont**. *e-assessment and learning: the relationship between take-home and proctored assessment.*

There is a paradigm shift on knowledge delivery and learning assessment in Math courses. Technology-based educational systems are now the norm from lower to higher learning Institutions. These systems have obvious advantages: cater to a technology savvy student population, provide immediate feedback to the user, automate most of the grading, and allow for asynchronous assessment. In addition, e-assessment provides educators with a large variety of data that can be used for a more in depth analysis than grading. In this study, we collected data over a period of three semesters from a College Algebra course. We analyzed the relationship between proctored and non-proctored assignments with respect to studying habits and knowledge retention. We focused on the effects of on-line Math apps and Math content to determine best practices that encourage productive learning habits and discourage unproductive ones. This data analysis led to interesting results that have been applied to improve the set-up of the e-assessment platform. Our presentation will showcase the results of our data analysis and a comparison of learning outcomes between the old e-assessment setup versus the one stemmed from the results of the data analysis. (Received August 21, 2015)

1116-A5-289 **Richard P Spindler*** (spindlrp@uwec.edu), Department of Mathematics, HHH 508, University of Wisconsin Eau Claire, 105 Garfield Ave, Eau Claire, WI 54702-4004. *Assessment and Rubrics for a Survey Project in an Elementary Statistics Course.* Preliminary report.

Projects have been used for assessment in elementary statistics courses for a long time. However, there are a variety of ways to guide students in implementing a project and to assess their projects. The primary object of the presentation will be the rubrics used to assess a semester survey project, as well as a description of the project assignment and its purpose with respect to the goals of the course. It will also include how the instructor guides the students in learning soft skills. If time, the presentation will include formative assessment used for the course. (Received August 22, 2015)

1116-A5-396 **William E. Gryc*** (wgryc@muhlenberg.edu), Department of Math and C.S., 2400 Chew St, Allentown, PA 18104. *Journaling to Assess Progress in Undergraduate Research.*

Assessing day-to-day learning while mentoring undergraduate research can be difficult, especially when the research occurs during the academic year. For example, a student may come to a weekly meeting with her mentor saying that she has made little progress since the last meeting, and it can be difficult for the mentor to determine what that means. Is the student working hard but stuck on a difficult problem, or has she just not put in enough time this week? What techniques or approaches has the student tried, and how far has she pushed those techniques? Generally, is this a research problem that the student should be able to handle on her own or does the mentor need to guide the student to an easier problem? One approach to this issue is to have the student keep a journal of her research progress. In this talk we will discuss the implementation of student journaling in an undergraduate research collaboration, how journaling can be used to assess student progress, and an anecdotal report on its effectiveness in the author's student research collaborations. (Received August 30, 2015)

1116-A5-543 **Jacquelyn L Rische*** (rische@hws.edu). *Using a "Proficiency System" to Assess Student Learning in Calculus.* Preliminary report.

For the past two semesters, I have used a "proficiency system" to assess student learning in my Differential Calculus classes. I have determined 45 skills that I want my students to master by the end of the semester. The mastery of these skills is 50% of a student's grade (with the rest of a student's grade determined by homework and exams). Each skill appears on three quizzes in a row, and to master a skill a student needs to solve its quiz questions correctly two times. Once a skill falls off the quizzes, students can still master it by coming to my office for a "retake." The students have a "scoresheet" to keep track of their performance on the skills. Given my students' diverse backgrounds, the system works well for them. They like being able to keep track of their progress on the skills on their scoresheets. They also really appreciate being able to come in and get help on the skills they are struggling with and then retake those skills. In this way, they are able to keep going back to the topics that they did not understand. In this talk I will discuss the implementation and success of this system in my Calculus classes and how it can be implemented in other mathematics classes as well. (Received September 06, 2015)

1116-A5-577 **Soofia Malik*** (smalik2@uwyo.edu), Laramie, WY 82070. *Exploration of College Students' Learning through Writing in a Developmental Mathematics Course.*

This case study research explored if and how the integration of weekly writing assignments in a Developmental Mathematics course affects college students' learning as well as their attitudes toward mathematics. This research also addressed the main factors that college students believe are responsible for their learning and for change in their attitudes toward mathematics due to the integration of weekly writing assignments. The study took place in a community college located in the Western United States. The findings revealed that college students became independent problem solvers and active learners due to the integration of weekly writing assignments. Findings also showed that the incorporation of weekly writing assignments have the potential to improve college students' attitudes toward mathematics. Most importantly, college students were able to figure out their own mistakes and keep record of their progress, and thus became more confident in mathematics in general as a result of doing weekly writing in mathematics. (Received September 07, 2015)

1116-A5-731 **Kristopher J Williams*** (kristopher.williams@doane.edu), 1014 Boswell Ave, Doane College, Crete, NE 68333. *Assessing student understanding in an introduction to proofs course.* Preliminary report.

Assessing student understanding in an introduction to proofs course can be difficult. Students are struggling to understand the structure of proofs, to work with the abstraction of new mathematical structures, and to write so many sentences in a math class! In order to help better understand and measure my students' progress, I have implemented a system that blends specifications based grading, mastery based grading and metacognition. This system sets a high bar for student work, but gives students more choice and encourages deeper understanding of material. In this talk I will present how I adapted this type of assessment to a small, introduction to proofs course at a liberal arts college. I will discuss the motivations for adopting this method, the design changes that occurred to the course, and the effects it has had on the course. (Received September 11, 2015)

1116-A5-770 **Thomas J Clark***, Tom.Clark@dordt.edu. *Specifications Grading in Calculus I: Implementation and Student Responses.* Preliminary report.

"Specifications grading" as described in Linda Nilson's recent book provides a framework by which an emphasis on rigor and student learning can be implemented in a way that students are motivated to succeed and achieve their goals. I have implemented a version of this in my Calculus I course that sets a high standard for demonstrating understanding (mastery) of concepts and procedures in calculus while providing multiple opportunities for success. Formative assessment is a prominent feature inherent in the course pedagogy that elucidates for students exactly what is required for mastery.

I will present the rationale for structuring the course this way, outline (and make available to those interested) the details of implementing specifications grading, and comment on the time demands/savings. Finally I will share student survey data I have gathered including student perceptions of the grading system, assessments, and the effect on developing growth mindset. I'll focus on the Calculus I course, but everything can be easily applied to other courses. (Received September 12, 2015)

1116-A5-790 **Khairul Islam*** (khairul.islam@tamuk.edu), Mathematics Department, Texas A&M University-Kingsville, Kingsville, TX 78363. *Quantitative Reasoning Learning Outcome Assessment.*

Quantitative reasoning (QR) courses are designed by integrating theory and applications necessary to enhance students' critical thinking and problem solving skills. Often, courses such as College Algebra, Calculus I, Mathematical Reasoning, Introductory Statistics, etc. fulfill the purpose of QR courses for the general education program. Specific objectives of QR courses may include analyzing real-life problems, understanding of required models, developing computational skills, interpreting analytical results, identifying predictability and limitations of analytical model, etc. In this presentation, we demonstrate examples and applications relating to QR learning outcome assessment applied in an introductory statistics course. (Received September 13, 2015)

1116-A5-801 **David Clark*** (clarkdav@gvsu.edu). *"You want to take* more *exams?": Standards-Based Grading in Calculus 1.* Preliminary report.

Traditional points-based grading systems can make it difficult to determine what a student has actually learned. They may penalize students who require several attempts before mastering a topic, and don't necessarily encourage useful learning behaviors.

We describe a standards-based grading system, implemented in a freshman Calculus 1 course, that aims to address these issues. In this system, students demonstrate mastery of a set of standards that correspond to major learning objectives. These standards are based in part on the Common Core Standards for Mathematical Practice.

Both this system and its associated classroom structure are intended to encourage reflection, revision, and a focus on eventual mastery and useful learning behaviors. We will compare results with a similar class taught by the same instructor, but without the standards-based grading system. This will include both a quantitative and anecdotal look at final grades, learning outcomes, and student statements about their own learning. (Received September 13, 2015)

1116-A5-912 **Aaron Brakoniecki*** (brak@bu.edu). *Concept Maps as a Way to Assess Form and Quality of Student Understanding of Algebra Concepts.*

In order to understand how students are making sense of the mathematical concepts they are learning, mathematics teachers need an assessment tool that captures this information. A concept map "visually illustrates mathematical connections and describes them in writing" (Baroody & Bartels, 2000). This tool allows students to represent their own understanding of mathematics content, both by visually connecting mathematical concepts that they see as related, and also describing in their own words their understanding of the relationships.

This talk presents the results of an attempt to use concept maps in an algebra content course in a teacher preparation program for beginning secondary teachers. These beginning teachers created concept maps both at the beginning and end of the semester that represented how they understood the relationships among key areas of high school algebra. This presentation shows how these beginning teachers grew and changed in their understanding of algebra through the course, and what that change looks like in concept maps. Additionally, this talk illustrates the affordances and challenges of using this assessment strategy when attempting to understand how individuals understand mathematics content. (Received September 15, 2015)

1116-A5-1038 **Rob Eby***, PO BOX 6030, Bryan, TX 77805. *Have Students write memos (with a word limit but no limit on pictures) for each other to enhance their understanding of mathematical ideas and concepts.*

In an effort to enhance student understanding, encourage collaborative learning, and provide a writing experience, I had students (in groups) prepare a memo to explain a problem or topic. The memos had a hard cap of 200 words, but there could be as many pictures included as the group felt necessary. An example of the problems and topics the students wrote memos on is below. There will be a discussion to follow about the student response and effectiveness of the assignments. Handouts will be provided. In class we worked the following: *You park at the trailhead and begin a 2 hour hike at 0700 Friday morning. On Sunday morning you leave at 0700 and hike 2 hours back to your car. Suppose the trail is 6 miles long. Explain why there must be a point where you were at the same position at the same time along the trail* Explain the difference between that problem and the one below. Would the conclusion we reached in class still apply? Explain. **Rob starts at the trail head at 0700 Friday. 30 minutes in to his trip, he teleports ahead 100 meters, then finishes walking the trail, arriving at 0900. On the return trip that again starts at 0700, again 30 minutes into his trip he teleports ahead 100 meters, then finishes walking the trail, arriving at 0900.** (Received September 16, 2015)

1116-A5-1132 **Jessie Hamm*** (hammj@winthrop.edu). *Oral Assessments in Upper and Lower Level Math Courses.* Preliminary report.

In this talk I will discuss my use of oral exams with honors students in Calculus 1 and biweekly oral presentations in my Number Theory course. In both settings, I will discuss the logistics, along with pros and cons, of using these oral assessments. I will also provide explicit examples of questions given to students and rubrics used to assess their presentations. Lastly, I will discuss the effectiveness of this method and plans for future modifications. (Received September 17, 2015)

1116-A5-1166 **Heather Leah Rosenblatt*** (heather.rosenblatt@wgu.edu). *Balancing the Assessment Challenges of Competency Based Education.*

Western Governors University is an online, competency based university. This means each student is self-paced and receives credit for a course after demonstrating competency without a required number of hours spent on the course. At WGU, such competency assessments are often standard multiple choice assessments with a cut score set at the level of desired skill, having students at different places in a course and having competency the only official requirement create unique assessment challenges. We have found certain key requirements to make this nontraditional model work well. I will give an expository discussion of the methods we employ to balance a student's ability to show competency through self-paced instruction while maintaining the integrity of the assessment. For example, it is crucial to have separation between evaluation and learning/instruction, a reliable way for a student to gauge his/her own prior knowledge areas and readiness to take the assessment, and a concrete process of remediation. (Received September 17, 2015)

1116-A5-1196 **Maarten McKubre-Jordens*** (maarten.jordens@canterbury.ac.nz), School of Mathematics & Statistics, University of Canterbury, Private Bag 4800, Christchurch, Canterbury 8140, New Zealand. *A minimalist assessment method which maximizes student learning and participation.*

In undergraduate mathematics tutorials or problem-solving classes, instructors are often faced with the dilemma: how can we assess student learning in a time-minimal way so that we may concentrate on maximizing engagement and learning? To solve the problem, often the decision is made for students to submit, directly, written work for grading. This is a time-intensive option for the instructor, and is sometimes heart-breaking: in today's learning environment, not all students even bother to read written feedback!

The method that I suggest in this talk gives students immediate feedback, encourages direct engagement, and reduces out-of-class grading time. It has been trialed in two separate second-year classes: one on theoretical computer science, and another on engineering mathematics. Measured upsides include increased conceptual understanding of material and lifting the performance of borderline-case students who are willing to engage. A possible disadvantage is the possible drop-off of students who have problems engaging, though this turned out to be difficult to measure. A surprising outcome was the difference in behavior in response to the method between the computer science students and the engineering students. (Received September 17, 2015)

1116-A5-1324 **Jeffery D Sykes*** (sykesj@obu.edu), Ouachita Baptist University, Arkadelphia, AR 71998. *Presentations, peer reviews, and collegiality points: an attempt to restructure assessment in an abstract algebra course.* Preliminary report.

In this talk, the author will discuss his effort to increase student interaction and feedback in his Abstract Algebra course. The class combines weekly student presentations, weekly written assignments with structured peer reviews implemented through moodle workshop activities, and an evaluation of the students' collegiality. The author will provide details of the implementation, will reflect upon the successes and challenges of the approach, and will identify any changes that need to be made before the course is next offered. (Received September 18, 2015)

1116-A5-1414 **Timothy E. Goldberg*** (timothy.goldberg@gmail.com), Lenoir-Rhyne University, Box 7141, Hickory, NC 28603. *Can we be a little more specific?: My experiences with standards-based grading.* Preliminary report.

For the past couple of years, I have experimented with various amounts of standards-based grading in most of the mathematics classes I teach, ranging from Calculus to Abstract Algebra. This has involved significant adjustment for my students, and has had both positive and negative results, depending on the class, the semester, and even the assignment. In this presentation, I will outline some of the approaches I have used, and discuss their outcomes. (Received September 19, 2015)

1116-A5-1435 **Jalalidin Jaenbai*** (jalalidin.jaenbai@zu.ac.ae), Zayed University, P.O. Box 19282, Dubai, United Arab Emirates. *Measuring Student Learning Outcomes under Interval and Fuzzy Uncertainty.* Preliminary report.

We typically ask several questions to find out about the level that a student has mastered a particular concept. As a result, we produce several, often varying, number values each being a measure of the same achievement. With such multi-valued data we cannot easily proceed to finding "mean" and "standard deviation" for a group of students using traditional statistical methods. In this paper we will show how for the purposes of assessing student learning outcomes, can we estimate and use the statistics using the methods developed in [1].

References: 1. H. T. Nguyen, V. Kreinovich, B. Wu, G. Xiang, Computing Statistics under Interval and Fuzzy Uncertainty. Applications to Computer Science and Engineering. Springer, 2012. (Received September 19, 2015)

1116-A5-1767 **Vincent J. Matsko*** (vjmatsko@usfca.edu). *Innovations in Calculus Assessment.*

Two alternatives to traditional assessment have been successfully introduced into the calculus sequence. The first is a system of grading based not on points, but on whether problems are completely correct, essentially correct, or not correct. The second is a series of assignments where students write and solve their own original mathematics problems. Both have had many years of classroom testing, and have proved successful. Practical details of implementation will be discussed. (Received September 21, 2015)

1116-A5-1874 **Matt Boelkins*** (boelkinm@gvsu.edu), Department of Mathematics, 1 Campus Drive, Allendale, MI 49401. *A Points-Free Capstone Course.* Preliminary report.

In the spirit of what is often called "specifications grading," I organized a recent instantiation of our capstone course, The Nature of Modern Mathematics, so that all assignments were graded on a 3-option scale: not-passing, progressing, passing. No assignment in the course had associated points, and no work received a numerical mark. Students exercised choice regarding a wide variety of assignment options, and each assignment contributed to overall expectations as part of a portfolio of work. In this presentation, I will give an overview of the course structure and assessment scheme, reflect on some lessons learned, and share some student feedback. (Received September 21, 2015)

1116-A5-1913 **Emlee Nicholson*** (nichoe@millsaps.edu), 104 Belle Ct., Madison, MS 39110. *No tests. No, really.*

This talk will address methods of assessment and lessons learned from a semester teaching a skills based course in cryptography. The desired learning outcomes of this course are problem solving and collaboration skills. However, nontraditional assessments employed here can translate to content driven classrooms. The focus of assessment is entirely on the problem solving process. For instance, one artifact I assess is the process report. Students are expected to log their process, including mistakes, failed strategies, and how they realized the strategy had failed as they work on a problem. At the end of the project, students submit a process report. On a typical test, students just erase wrong answers when there may have been some insight to be gained from what they initially tried. With the process report, the assessor gets a better idea of student understanding of content and skill development. (Received September 21, 2015)

1116-A5-1917 **Vicky W Klima*** (klimavw@appstate.edu). *Encouraging Careful Questioning Through Two-Color Problem Sets.* Preliminary report.

As teachers of mathematics we encourage out students to ask good questions and we strive to help our students find and understand answers to these questions. If we find careful questioning important, we should include such ideas in our assessment. In this talk, we discuss two-color problem sets in which students record what they do and what they do not understand about a problem, asking pointed questions about whatever is troubling them. In class, the students discuss their questions and use colored ink to record the answers they find. We will present our assessment strategy for these two-color problem sets, initial student reaction to the problem sets and their assessment, as well as evidence of student growth as students complete the problem sets throughout the semester. (Received September 21, 2015)

1116-A5-1963 **John D. Ross*** (rossjo@southwestern.edu), SU Box 7371, 1001 E. University Avenue, Georgetown, TX 78626. *Incorporating emails and discussions into weekly assessments.*

A recent semester of Calculus 1 was taught using a variation of Specifications Grading. Students were given weekly quizzes to test their understanding of basic concepts or skills, and could earn one of four grades: Mastered (M), Email (E), Discussion (D), and Insufficient (I). Students who did not earn the grade of (M) on the quiz would be given another chance to show mastery of the skill, either by engaging with the instructor through email (E), having a discussion with the instructor (D), or by taking another quiz on the same skill (I). Under this system, students could display knowledge of the material in a variety of ways.

In this talk we'll discuss some advantages and disadvantages of this system, as well as some logistical issues regarding implementation. Special focus will be paid to our implementation and our results of using the two middle tiers (email and discussion) as tools to assess mastery beyond the quiz itself. (Received September 21, 2015)

1116-A5-1986 **Morgan H. Sargent*** (mhsargent@gmail.com), , Canada. *IFF You Already Understand: The roots of elitism and exclusion in mathematical education and what we can do about it.*

Formal mathematical education goes back as far as ancient Egypt. In ancient societies, it was often the priesthood that controlled and developed mathematics and therefore mathematical education. The same tools of control that were employed in the administration of religion were often used in the administration of mathematics. Math was used as a tool of religious control, and only by attaining certain levels of priesthood could one gain access to certain points of knowledge or education. Although we are no longer directly engaged in promoting mathematics as a tool only for the religious elite, it is still broadly perceived as something only a select few can participate in. Our methods of assessment only re-enforce this perception: hierarchical pre-requisites for courses; silent isolation for testing; rewards and punishment based on attention to details; and strict recreations of existing knowledge are just some of the tools that we use. As a result, we have a public that accepts as given ideas of "math-phobia" and "math anxiety." In order to change the public perception of mathematics, we must change mathematical education including, or perhaps especially, how we assess students' capacity and understanding of mathematics. (Received September 21, 2015)

1116-A5-2040 **Girija Sarada Nair-Hart*** (nairhaga@uc.edu), 4200, Clermont College Drive, Batavia, OH 45103. *Aftermath – after traditional math tests.*

Students' pre-existing concept images inhibit proper understanding of mathematics concepts (Piaget, 1971; Tall, 1982; Nair-Hart, 2010). Similarly, erroneous translation between verbal and written mathematics also interferes with the proper conveyance of mathematical truth. Working one-on-one with students helped me realize how the disparity between a spoken answer and a written answer interferes with the communication of knowledge during traditional paper- and-pencil tests. The incorrect answer written on an exam jeopardizes student test score which traditionally serves as evidence of their knowledge of the test material. This could compromise the student's confidence and interest in learning mathematics. I found that the inclusion of an oral component along with written tests can facilitate dialogue between a student and the instructor giving students a chance to explain why a perfectly verbalized answer was written in an incorrect format. During the presentation I will share how an oral exam component incorporated with traditional testing could bridge the barrier between spoken and written mathematics. I will also discuss the potential dilemmas posed by the inclusion of such a non-traditional testing component in a majorly test-driven academic world. (Received September 22, 2015)

1116-A5-2221 **Edwin P Herman*** (eherman@uwsp.edu). *Assessing Student Participation and Presentation of Material.* Preliminary report.

A good assessment tool should do more than merely measure the quality of student work: ideally, it should also encourage the student to perform better in the course. This is true whether the method is a traditional exam or something else, such as presentation of student work or participation in class discussion.

In Fall 2011 I developed a method to assess student presentation and participation, as part of the course grade for Complex Analysis. I wanted a method that rewarded students for engagement but also recognized the quality of the work involved as well as the student's level of mastery with the material. Some of my early ideas were too ambitious, requiring too much bookkeeping on my part. Ultimately, I developed a method that was easy for me to use but still allowed me to learn a surprising amount of information about the strengths and weaknesses of each of my students. I have since used the assessment method with other courses as well.

In my presentation I will explain how I developed the student presentation assessment model and how I have used it in various courses; for illustration I will also compare the participation/presentation grade data with grade data from more traditional assessment methods. Student feedback on the grading method will also be given. (Received September 22, 2015)

1116-A5-2346 **Sarah L. Marsh*** (sarah.marsh@okbu.edu) and **Krista B. Hands**. *Alternative Assessment Approaches in a "Math for Elementary Teachers" Sequence.* Preliminary report.

Although all students benefit from diverse instructional and assessment strategies, prospective elementary teachers seem particularly willing to explore a variety of carefully-chosen methods for creating and measuring understanding. Yet, many "Math for Elementary Teachers" courses do not capitalize on these opportunities to utilize more robust assessment techniques. In this talk, we will explore the two primary unconventional assessment approaches that we have incorporated into our revised "Math for Elementary Teachers" sequence. First, a mastery-based approach to exams strikes an interesting balance among students' understanding, anxieties, and expectations within a college-level mathematics course. Second, student presentations of course content allow students to excel in a hands-on, technology-focused format that emulates their chosen career path. This talk will cover key details of each approach, some pros and cons to these forms of assessment, and reactions from both students and faculty. (Received September 22, 2015)

1116-A5-2419 **Paul E. Seeburger*** (pseeburger@monroecc.edu), Monroe Community College, 1000 E. Henrietta Rd., Rochester, NY 14623. *Student Video Problem Presentations as Review Activities in Differential Equations and Multivariable Calculus.* Preliminary report.

For several years, my online students in multivariable calculus and differential equations have been required to create two or three videos of themselves throughout the semester presenting example problems of various course topics. At first, I feared students would find this task too difficult, but instead, most students claim these assignments are one of their favorite components of the course. Some have even suggested I require students to create more of them during the semester. I will show parts of several student videos and explain why I think this assessment activity is a valuable part of my online courses. (Received September 22, 2015)

1116-A5-2644 **Sean M Laverty*** (slaverty@uco.edu), 100 N University Drive, Box 129, Edmond, OK 73034, and **Brittany E Bannish** (bbannish@uco.edu), 100 N University Drive, Box 129, Edmond, OK 73034. *Weekly writing: a lab-notebook in calculus for non-majors.* Preliminary report.

Motivated by informal experiments with writing prose in mathematics classes, we have implemented a weekly writing assignment in a calculus class for non-majors. We will discuss the factors that led us to incorporate this assignment as a key feature in the design of this class. Then we will share the details of the assignment, strategies for submission and grading, and the student's impressions of a relatively non-traditional assignment. A few samples and anonymous quotes from course evaluations will be shared. We will discuss why this assignment may work better in some classes than in others, and close by sharing advice in the form of changes we have incorporated along the way. (Received September 22, 2015)

1116-A5-2720 **Karen D Morgan*** (kmorgan@njcu.edu), Office of the Provost, 2039 Kennedy Boulevard, Jersey City, NJ 07305. *Using Poetry to Assess Students' Learning of Mathematics.*

Using writing activities to assess students can enhance learning in the affective and cognitive domains. The presenter will discuss how writing poetry inspired by mathematics offers undergraduate students the opportunity to frame mathematical reasoning with arguments grounded in succinctness and clarity of thought processes.

Additionally, the presenter will share how writing poetry inspired by mathematics bolsters students' confidence in doing mathematics and in engaging in mathematical discourse. (Received September 22, 2015)

1116-A5-2788 **Austin Mohr*** (amohr@nebrwesleyan.edu). *Mastery-Based Exams are Self-Evidently Better than Traditional Exams.* Preliminary report.

A mastery-based examination is one in which students receive credit only for completely correct solutions, but they are given many attempts throughout the semester to display mastery. A brash assistant professor claims that this simple shift in perspective results in an assessment technique that is necessarily superior to traditional examination. Increases in student perseverance, growth-orientedness, and depth of understanding are among the many virtues we will observe from our armchairs. Survey data attesting to positive student outcomes at six different institutions will be provided for the staunch empiricists in the audience. (Received September 22, 2015)

Current Trends in Mathematical and Computational Biology

1116-AA-527 **Ami Radunskaya*** (aer04747@pomona.edu), Math Department, Pomona College, 610 N. College Ave., Claremont, CA 91711. *Mathematically informed cancer vaccines.*

Novel treatments for cancer that boost an individual's immune response to cancer are the focus of current clinical trials and laboratory research. One of the challenges in the design of cancer vaccines is blocking the tumor's ability to suppress immune effectiveness while stimulating the immune response. To overcome this challenge, delivery mechanisms are being designed that package several treatments together. The big questions are the timing and size of the dose, and the rate of release of each substance.

In this talk, we develop a mathematical model using differential equations to describe the interactions between antigen presenting cells (stimulated by the vaccine), other immune cells and tumor cells. The model also captures some aspects of the trafficking of cells through the body, as well as the delivery of the vaccine and other agents. This model, along with mathematical tools from control theory and dynamical systems, can be used to suggest answers to the questions posed by clinicians. (Received September 05, 2015)

1116-AA-774 **Suzanne Lenhart*** (lenhart@math.utk.edu), University of Tennessee and NIMBioS, Knoxville, TN 37996. *Canine Distemper Outbreak Modeled in an Animal Shelter.* Preliminary report.

Canine distemper virus is a highly contagious virus that can cause outbreaks, specifically in crowding situations, such as an animal shelter, in which a large number of susceptible dogs are brought together. Introduction of this virus into a shelter can have devastating effects, with the potential to result in shelter canine depopulation. Motivated by recent outbreaks in Tennessee, a mathematical model was constructed to find relevant factors that could assist in preventing or reducing outbreaks. We derived a system of ordinary differential equations that models the spread of this virus through S-E-I-R classes as well as a vaccinated and two different infectious classes. Our model was adapted to represent a local Knoxville shelter. The effect of vaccination on disease spread was investigated. The research was from an REU project at the National Institute for Mathematical and Biological Synthesis. (Received September 12, 2015)

1116-AA-1331 **David Murrugarra*** (murrugarra@uky.edu), Department of Mathematics, University of Kentucky, Lexington, KY 40506. *Discrete Models for the Simulation and Control of Gene Regulatory Networks.*

Understanding how the physiology of organisms arises through the dynamic interaction of the molecular constituents of life is an important goal of molecular systems biology, for which mathematical modeling can be very helpful. Different modeling strategies have been used for this purpose. Dynamic mathematical models can be broadly divided into two classes: continuous, such as systems of differential equations and their stochastic variants and discrete, such as Boolean networks and their generalizations. This talk will focus on the discrete modeling approach, which employs techniques from discrete mathematics, combinatorics, graph theory, and computational algebra. Discrete models play an important role in modeling processes that can be viewed as evolving in discrete time, in which state variables have only finitely many possible states. This talk will present an approach for stochastic simulations of discrete models and algebraic techniques to identify network interventions that can change the dynamics of the network from an undesirable state, such as a disease state, into a more desirable state. (Received September 18, 2015)

1116-AA-2015 **Joseph Felsenstein*** (joe@gs.washington.edu), University of Washington, Department of Genome Sciences, Box 355065, Seattle, WA 98195-5065. *Simplifying computations of likelihoods for a multivariate Ornstein-Uhlenbeck process on an evolutionary tree.* Preliminary report.

When we have an evolutionary tree (a phylogeny) estimated by molecular data, it is of great interest to see how measurable characters, controlled by many genes, change on that tree. We typically do not know how many genes are involved for each character or how they create covariation between the evolution of different characters. The major models now used are Brownian Motion and the Ornstein-Uhlenbeck process. The OU process models natural selection, mutation, and genetic drift. Our interest is in inferring the covariances of change of characters, using data from multiple species that have an evolutionary tree. We will explain how to simplify the computation of likelihoods for the OU process using contrasts between tips on the tree. Contrasts are in wide use for Brownian Motion processes but have not yet been made to work for multivariate OU processes. (Received September 22, 2015)

1116-AA-2890 **Brandilyn Stigler*** (bstigler@smu.edu), 3200 Dyer Street, Dallas, TX 75275. *Reducing Ambiguity in Biological Network Inference via Grobner Bases.*

Predicting mathematical models of biological phenomena from experimental data is sensitive to the amount of data used as input. When there are too few data, the number of possible models that explain the data are too numerous, thereby reducing the probability of selecting biologically relevant models. In the context of systems biology where substantial costs are incurred in laboratory experiments, having an estimate of the amount of data required to infer the network becomes important and aids in minimizing wasted resources.

In this talk, we describe a class of discrete models, called polynomial dynamical systems (PDSs), for gene regulatory networks as well as a method for constructing PDSs from data. We also establish a connection between model ambiguity and existence of multiple Groebner bases, which capture the distinct vector space basis representations associated to the input data. Furthermore we provide criteria for determining whether a set of data uniquely identifies a PDS and a strategy for selecting candidate data points for unique model identification. (Received September 22, 2015)

What Do We Know about University Mathematics Teaching, and How Can It Help Us?

1116-AB-1101 **Chris L Rasmussen*** (chris.rasmussen@sdsu.edu). *Advances in inquiry-oriented instruction at the post-secondary level: Student success and instructor practices.*

In the past decade there has been a considerable growth in research examining college mathematics instruction. This presentation will provide an overview of this research based on a review of over 40 articles published since 2004. Specific findings about the nature and role of lecture-oriented instruction and inquiry-oriented instruction will be presented. For example, an international study of the genre of lecture-oriented instruction in 33 undergraduate classes at 10 universities across six different countries revealed a striking and remarkable similarity in the way in which writing out a mathematical narrative on the board while talking aloud is the same across diverse linguistic and cultural backgrounds. Other studies have examined the nature of inquiry-oriented instruction, which refers to classrooms in which students are actively engaged in doing mathematics and the instructor listens to student ideas, responds to student thinking, and uses student ideas to advance the mathematics. One of the consistent findings is that inquiry-oriented instruction leads to improved student success in comparison to lecture-oriented instruction. Such findings come from small-scale studies of single courses and from meta-analyses of multiple studies. (Received September 17, 2015)

1116-AB-1338 **Ann Ryu Edwards*** (edwards@carnegiefoundation.org), 51 Vista Lane, Stanford, CA 94305. *Carnegie's Community College Pathways: Instruction supporting productive struggle and student persistence in developmental mathematics classrooms.*

The Community College Pathways (CCP) project is a systemic reform effort to improve learning, achievement, and retention outcomes for developmental mathematics students in community colleges nationwide. This presentation focuses on the research underlying the learning frameworks that inform CCP's curriculum and pedagogy and reports on how the CCP instructional system integrates supports for powerful mathematics learning with non-cognitive supports targeting growth mindset, social belonging, and persistence. We will also discuss how the CCP project employs an improvement science research paradigm to drive growth in student and faculty outcomes and continuous learning about effective processes and practices for professional development. (Received September 18, 2015)

1116-AB-1557 **Sean P Larsen*** (slarsen@pdx.edu). *An Ongoing Effort to Create Effective InquiryOriented Abstract Algebra Classrooms.*

The purpose of the Teaching Abstract Algebra for Understanding (TAAFU) project was to begin "scaling-up" an innovation in abstract algebra instruction. The focus of the project was an inquiry-oriented course in group theory. The course is built around three core instructional sequences in which students reinvent fundamental group theory concepts (groups, isomorphism, quotient groups). We collaborated with mathematicians teaching the course in order to understand what they needed to be able to implement the curriculum successfully. We learned that the mathematicians needed knowledge of student thinking (e.g., common alternative or incorrect conceptions) in order to listen productively during class discussions. We learned that the mathematicians needed to do significant mathematical work on the fly when teaching the course (e.g., evaluating unusual conjectures and proofs). We learned that mathematicians had differing perspectives on the nature of the teacher's role in inquiry-oriented instruction, and as a result, they worried about different things when teaching the course. In my presentation, I'll discuss some of these findings in more detail and describe how we are supporting instructors with online materials designed to address needs that were revealed by our research. (Received September 20, 2015)

1116-AB-1650 **Greg Oates*** (g.oates@auckland.ac.nz), Department of Mathematics, Private Bag 92019, Auckland 1142, Auckland, 1023, New Zealand. *The LUMOS Project: What do we really learn in Undergraduate Mathematics?*

The LUMOS Project (Learning in Undergraduate Mathematics Outcomes Spectrum) is a two-year New Zealand study investigating the wider Learning Outcomes of undergraduate mathematics. This national project is jointly funded by Ako Aoteoroa, the National Centre for Tertiary Teaching Excellence, and the Teaching and Learning Research Initiative (TLRI). While we do consider the commonly measured learning outcomes of skills and content knowledge, the main focus of our study is on affective, cognitive and process outcomes such as attitudes and beliefs, mathematical processes, communication, habits and expectations. A large part of the project has been involved in developing instruments by which we might observe these outcomes. I will first briefly describe the three initiatives we introduced as windows for these observations, especially the use of Team-Based Learning (TBL) in advanced mathematics pioneered by our late colleague and principal investigator Judy Paterson. I will then consider some of our results including progress on observing attitudes, the effect of active-technology tasks, an evolving instrument for assessing mathematical communication, and an emerging consideration of mathematicians' habits we have conceptualized as mathematical foresight. (Received September 21, 2015)

1116-AB-2920 **Alon Pinto*** (alonp@berkeley.edu). *The same content, but very different lectures: The decisions collegiate mathematics instructors make and how they shape the mathematics in their classrooms.*

Lectures in courses for math majors typically revolve around definitions, theorems, and proofs, but the lessons students learn about mathematics extend far beyond the scope of the content discussed explicitly. There is extensive literature describing how students pick up practices, language, norms, and values through instruction, regardless of what is explicitly taught. Still, only little is known on how instruction at university shapes the learning of ways of doing and thinking about mathematics. In my research, I explore the mathematics in lectures from the perspectives of both instructors and students. I have found that a significant portion of the mathematics instructors try to convey in lectures remain implicit. Furthermore, I have found that even when discussing the same explicit content, the mathematical ideas that different instructors try to convey, and consequently what students experience, can be radically different. In my presentation, I will discuss examples from lectures of different instructors, describe practices instructors use to decide what mathematical ideas to teach and how, explore the factors that shape these decisions, and discuss their strengths and limitations. I will conclude with some implications for professional development at the collegiate level. (Received September 23, 2015)

Fair Division

1116-AC-372 **William Webb*** (webb@math.wsu.edu), Mathematics Department, Washington State University, Pullman, WA 99164, and **Thomas Hatdock**. *Super Fair Division - How Many Cuts.*

Super fair division (also called strong fair division) requires all players to receive more than their designated fair shares. It is necessary that not all of the players' measures are identical. We look at the question of how many cuts are needed, assuming that the players can make marks to indicate where they would cut before the actual cuts are made. The bounds obtained improve previous bounds. We consider both the cases of where the fair shares are equal or unequal. For two players the minimum number of cuts is 3. For more than two players we give both inductive and non-inductive procedures. For example, the inductive procedure uses $n^2 - n + 1$ cuts for either equal or unequal shares, and the non-inductive procedure uses only $2n + 3$ cuts for equal shares. (Received August 28, 2015)

1116-AC-984 **Steven J. Brams** and **D. Marc Kilgour*** (mkilgour@wlu.ca), Department of Mathematics, Wilfrid Laurier University, Waterloo, ON N2L 3C5, Canada, and **Christian Klamler**. *Maximin Envy-Free Division of Indivisible Items.*

Assume that two players have strict rankings over an even number of indivisible items. We propose algorithms to find allocations of these items that are maximin—maximize the minimum rank of the items that the players receive—and are envy-free and Pareto-optimal, if such allocations exist. We show that neither maximin nor envy-free allocations may satisfy other criteria of fairness, such as Borda maximinality. Although not strategy-proof, the algorithms would be difficult to manipulate unless a player has complete information about its opponent's ranking. We assess the applicability of the algorithms to real-world problems, such as allocating marital property in a divorce or assigning people to committees or projects. (Received September 15, 2015)

1116-AC-1278 **Julius Barbanel*** (barbanej@union.edu), Department of Mathematics, Union College, Schenectady, NY 12308. *Geometric Perspectives on Fair Division.*

We consider the following setting for fair division of a "cake" C: Each of n players has a countably additive, non-atomic, probability measure (defined on some σ-algebra of subsets of the cake) that is used to evaluate the size of pieces of cake (i.e., subsets of C). Two geometric structures that arise naturally in this context are:

(1) The "Individual Pieces Set" or IPS, defined by

$$\text{IPS} = \{\langle m_1(P_1), m_2(P_2), \ldots, m_n(P_n)\rangle : \langle P_1, P_2, \ldots, P_n\rangle \in \mathcal{P}\}$$

where $\mathcal{P}$ is the set of all partitions of C into n measurable subsets, and

(2) The "Radon-Nikodym Set" or RNS, defined by

$$\text{RNS} = \{\langle f_1(a), f_2(a), \ldots, f_n(a)\rangle : a \in C\}$$

where $f_1, f_2, \ldots, f_n$ are the Radon-Nikodym derivatives of $m_1, m_2, \ldots, m_n$, respectively, with respect to the measure $m = m_1 + m_2 + \ldots + m_n$.

These two structures (individually and in relation to each other) provide insight into various fair division properties, such as proportionality, envy-freeness, and efficiency. (Received September 18, 2015)

1116-AC-1944 **David Housman*** (dhousman@goshen.edu), Goshen College, 1700 South Main Street, Goshen, IN 46526. *Solutions for Partially Defined Coalition Games.* Preliminary report.

Cooperative game theory provides methods for fairly dividing the benefits due to collaboration in a joint venture. A coalition game consists of a set of players N and a function w that specifies the savings $w(S)$ that a set of players S can achieve through collaboration. An allocation method is a function ϕ from coalition games to payoff vectors, that is, $\phi_i(N, w)$ is player i's recommended share in the savings. Lloyd Shapley characterized a unique allocation method satisfying four fairness criteria: efficient, equal treatment, subsidy free, and additive. This paper suggests allocation methods for coalition games in which not all of the coalitional worths $w(S)$ are known. One approach is to use fairness properties similar to those used by Shapley to characterize a method. A second approach is to use Shapley's allocation method on a centrally chosen, fully defined coalition game that is consistent with the partially defined game. With both approaches, it turns out that it is crucial to determine the class of games to which the partially defined game belongs. Some illustrative results are described and directions for future research are suggested. (Received September 21, 2015)

1116-AC-2450 **Michael A Jones*** (maj@ams.org), 416 Fourth Street, Ann Arbor, MI 48103, and **Jennifer Wilson** (wilsonj@newschool.edu), Eugene Lang College, New School University, New York, NY 10011. *Dividing Child Support Funds Between Parents.*

We consider the child support problem of how to divide parents' pooled resources based on the time spent by the child with each parent. We define several natural axioms that such an allocation function should satisfy and analyze a class of functions used by the State of Michigan that satisfy these axioms. Although this axiomatic approach does not fully characterize the functions used by the State of Michigan, other functions in this class are of interest. We explain how the additional properties of the allocation function may effect the behavior of the parents, and how this may be used to achieve specific social goals by a state. (Received September 22, 2015)

1116-AC-2716 **Kathryn Nyman*** (knyman@willamette.edu), **Francis Su**, **Yan Zhang**, **Amanda Ruiz** and **Roberto Barrera**. *Envy-free divisions of continuous and discrete cakes.* Preliminary report.

A strong notion of a "fair division" of a cake is an envy-free division; one in which every player believes that their share is at least as good as any other share. We look at several cake-cutting questions in which we seek an envy-free solution, including the division of multiple cakes (in which players' preferences of the piece they receive from one cake depends on the piece they received in the other), and the division of a discrete cake (or "string of beads"). Sperner's Lemma, a combinatorial analogue of the Brouwer Fixed Point Theorem, plays a delightful role in the solution of several of these problems. (Received September 22, 2015)

Bringing the Community into the College Mathematics Classroom

1116-B1-35 **Joanne C Caniglia*** (jcanigl1@kent.edu), Kent State University, 401 White Hall, 150 Terrace Rd., Kent, OH 44242. *Mathematical Modeling in Service of Community or Teaching Without Answers in the Back of the Book.*

By incorporating service-learning within a finite mathematics class, students seek out and solve real world problems. Projects are inspired by some of the challenges faced by non-profit organizations, government agencies, small businesses, or within schools. The addition of a service-learning component can deepen students' mathematical understanding by examining a problem and creating solutions that are both reasonable and implementable. Students also have an incentive to improve their written and oral skills for their final presentations to community members. In this presentation, modeling problems involving graph theory, optimization, probability, and simulations will be described within the context of service-learning projects. Two such examples include finding the expected values of wins/losses for local schools' Family Math Nights and optimizing transportation routes for Meals on Wheels. (Received June 07, 2015)

1116-B1-341 **Ekaterina Yurasovskaya*** (yurasove@seattleu.edu), 901 12th Avenue, Seattle, WA 98122. *Improving algebra skills of university students through participation in academic service-learning.*

Seattle University has a long history and a solid institutional structure for implementing academic service-learning in its courses. For the present study, we developed a Precalculus course with a service-learning component, allowing university students to work in the tutoring labs at a local middle school, an immigrant assistance center, and a community college, and to tutor algebra prerequisites to middle-school students and to adults returning to complete their GED diploma. One of the primary goals of the project was to improve basic algebra skills of the student tutors by explaining foundational material to others 2-3 hours per week over the course of the quarter. Through weekly pedagogical diaries, the student tutors analyzed the source and nature of mathematical successes or misconceptions of their own students. Review of the final exams via a special rubric revealed a significant reduction in the number of fundamental mistakes between the Precalculus section with the service-learning component and the control section of the same course. In our talk, we discuss the collaboration with community partners, the course structure and the key components that enhanced student learning, and academic and non-academic benefits to the participants. (Received August 26, 2015)

1116-B1-1119 **Emma Smith Zbarsky*** (smithzbarskye@wit.edu). *Collaboration with the Boston Children's Museum.*

Senior math majors at Wentworth are required to take a course in exposition to ensure that the students have a solid background in mathematical communication. During the fall of 2014, this course formed itself around a collaboration with the Boston Children's Museum. The museum is currently considering a move to extend

its intended audience from children ages 0-6 to children ages 0-10. In the process, they realized that they have effectively no explicitly mathematical exhibits or activities. Our students came in to work with museum staff to design and implement mathematical activities aimed at young children. I shall discuss some of the topics they chose to cover and how implementation went at the museum. (Received September 17, 2015)

1116-B1-2339 **Andrew J Miller*** (andrew.miller@belmont.edu), Dept. of Mathematics and Computer Science, Belmont University, 1900 Belmont Blvd, Nashville, TN 37212. *Connecting Quantitative Literacy to Financial Literacy in the Community.* Preliminary report.

For several years, I have taught a course on quantitative literacy (QL) in the context of consumer finance. One objective for this course is to connect QL to broader social issues, such as high-cost lending and the financial concerns of low-income households. In order to meet this objective, I have partnered with area organizations, including Habitat for Humanity, the Nashville Financial Empowerment Center, and a local mortgage crisis counseling service. Representatives of these organizations have come to class as guest speakers, and students have completed projects related to these organizations' needs. I will share several examples of these interactions and ways they have enhanced student learning. (Received September 22, 2015)

The Broad Impact of Math Circles

1116-B5-290 **Richard P Spindler*** (spindlrp@uwec.edu), Department of Mathematics, HHH 508, University of Wisconsin - Eau Claire, 105 Garfield Ave, Eau Claire, WI 54702-4004. *A Math Student Circle in rural Wisconsin.* Preliminary report.

Math student circles in rural areas can be more difficult to implement sustainably. In this talk, the presenter will discuss the process used and the grant received to implement a math student circle in rural Wisconsin for the past two years. In addition, he will discuss how each session was conducted as well as the feedback from students and teachers. Finally, if there is time, the presenter will discuss how this math student circle was a product of a math teacher circle. (Received August 22, 2015)

1116-B5-340 **Sloan Evans Despeaux***, Department of Math and CS, Western Carolina University, Cullowhee, NC 28723. *Building a Network: The North Carolina Network of Math Teachers' Circles.* Preliminary report.

In the Fall of 2014, the Smoky Mountain Math Teachers' Circle (SM^2TC) began bringing together math teachers from the 7 westernmost counties of North Carolina. Thanks to a sizable foundation grant, we now have our sights on spreading the MTC gospel east and forming the North Carolina Network of Math Teachers' Circles. This talk will discuss how we sought funding and the steps we are taking to make this Network a reality. (Received August 26, 2015)

1116-B5-783 **Bob Klein*** (kleinr@ohio.edu), Ohio University Department of Mathematics, 321 Morton Hall, Athens, OH 45701, **Rebecca Bycofski** (rb226013@ohio.edu), Ohio University Department of Mathematics, 321 Morton Hall, Athens, OH 45701, and **Henry Fowler** (hhfowler@dinecollege.edu), Diné College Department of Mathematics, 1 Circle Dr, Route 12, Tsaile, AZ 86556. *Mentoring Students and Supporting Teachers: New Programs from the Navajo Nation Math Circles Project.*

The Navajo Nation Math Circle Project, begun in 2012 by Tatiana Shubin (SJSU) and Henry Fowler (Diné College), brings Navajo students and teachers into greater participation in problem solving. Until this, the 3^{rd} year of the program, primary activities consisted of a 2-week student summer camp, teacher workshops, math festivals, and academic-year visits to schools by mathematicians.

Having served over 1000 students and 150 teachers thanks to generous funders and the participation of more than 40 mathematicians from around the U.S., the program is building sustainability and impact by offering one-on-one mentorship to students via curated problem solving discussions with NNMC leaders. Undergraduate mentors worked with summer camp participants, creating a model for the electronically-mediated mentor sessions in the academic year.

To support nascent student math circles, the NNMC is compiling a set of session notes tentatively called "scripts" to guide Navajo teachers through leading math circle activities including the many directions students could take investigations, including directions to be avoided.

This paper briefly reports on how these new efforts are working to sustain and broaden the profound impact of mathematics and problem solving on the Diné. (Received September 12, 2015)

1116-B5-1304 **Amy Wangsness Wehe*** (awehe@fitchburgstate.edu), Mathematics Department, Fitchburg State University, 160 Pearl St, Fitchburg, MA 01420. *The benefits of running a Math Circle with college students for middle school students.*

I have been coordinating a Math Circle at a local middle school since 2009. Since 2011, the activities have been created and run by college students. This talk will describe the two-fold benefits of this Math Circle. First, I will talk about how the middle school students have been impacted. Second, I will share with you comments from the college students on how they have been impacted by the experience. Finally, I will speak about my hope for the future of Math Circles. (Received September 18, 2015)

1116-B5-1346 **Michelle A Manes*** (mmanes@math.hawaii.edu), University of Hawaii Dept. of Mathematics, 2565 McCarthy Mall, Keller 401A, Honolulu, HI 96822. *In Their Own Words: Teachers Reflect on their MTC Experiences.* Preliminary report.

The Math Teachers' Circle of Hawaii (MaTCH) serves an incredibly diverse population of teachers. Each month, more than 50 math teachers from the state join us for mathematical explorations. These include elementary, middle, and high scool teachers, instructors from the community college system, and resource teachers. Our teachers come from public, private, charter, and Hawaiian immersion schools. Teachers from islands other than Oahu meet together and connect with us via Google Hangout, participating in a synchronous "e-table" session.

Before and after each session, participants freewrite about the topic of the day's session. Teachers who opt to receive professional development credit for their participation in MaTCH complete an end-of-year portfolio with additional written reflections and lesson plans. We will share a few mathematics activities that we have used with this diverse population, along with reflections of the impact of MaTCH on these teachers in their own words. (Received September 18, 2015)

1116-B5-1585 **Patrice Waller*** (pparker@vsu.edu) and **Sandra Richardson** (srichardson@vsu.edu). *Developing Mathematics Teachers' Mathematical Problem Solving Through a Math Teachers' Circle Framework.*

In-service mathematics teachers often receive frequent professional development opportunities in developing and enhancing content and pedagogical knowledge. However, mathematical knowledge for teaching encompasses much more, including the advancement and augmentation of problem solving techniques, reasoning, and connections. The Central Virginia Math Teachers' Circle is designed to help teachers deepen their mathematical knowledge for teaching through intensifying their problem solving skills. We will describe the nature of this professional development and how it differs from other professional development programs offered to our population of secondary mathematics teachers. (Received September 20, 2015)

1116-B5-1776 **Kaitlyn Phillipson*** (kaitlyn@math.tamu.edu), Texas A&M-Department of Mathematics, 3368 TAMU, College Station, TX 77843, and **Frank Sottile**, **Alex Sprintson** and **Philip B. Yasskin**. *From 5th to 12th: Discoveries and Challenges of Multi-leveled Math Circles.*

The TAMU Math Circle started in 2011 as an after school club. After one semester, it moved to Texas A&M, and opened to all local schools for grades 5th through 8th. Last year, due to interest from older students in continuing to participate in Math Circle, we expanded to include high school-level students. We are also feeling pressure to let in advanced 4th grade students. TAMU Math Circle's biweekly meetings begin with 30 minutes of unstructured activity, followed by splitting the students into 3 groups (pre-Algebra, Algebra 1 and above, Algebra 2 and above), each participating in a 90-minute directed activity. This talk will discuss the challenges in creating activities appropriate for each group. The Art Gallery Problem will be used as a running example throughout the talk. (Received September 21, 2015)

1116-B5-2666 **Brianna Donaldson*** (brianna@aimath.org). *The Broad Impact of Math Teachers' Circles: Results from the First Decade.*

Since their beginnings in 2006, Math Teachers' Circles have grown to more than 80 sites in 37 states. What impact are these groups having on the estimated 1,500 teachers and 300 mathematicians who participate? We review evidence from the first decade of Math Teachers' Circles and present key results suggesting that participating teachers benefit in a variety of ways. These include increased excitement about mathematics, mathematical knowledge for teaching, use of inquiry-oriented practices in the classroom, and professional engagement. Case studies suggest that for those who are ready, Math Teachers' Circles can serve as a catalyst to change their pedagogical practices or take on professional leadership roles. Many teachers report that Math Teachers' Circles transform how they see mathematics, with potentially important implications for their students. Though less studied, mathematicians also report a positive professional impact of their involvement with the program.

Taken together, the evidence points to broad and lasting effects of Math Teachers' Circles on their participants' mathematical and professional lives. (Received September 22, 2015)

1116-B5-2889 **Brandy S Wiegers*** (wiegersb@cwu.edu), Ellensburg, WA 98926, and **Dominic Klyve** (klyved@cwu.edu), **Allyson Rogan-Klyve** (roganklyve@cwu.edu) and **Janet Shiver** (shiverj@cwu.edu). *Kittitas Valley Math Circle, a program for students and their parents.* Preliminary report.

The Kittitas County Math Circle is designed for fourth, fifth and sixth grades students with their parents. What started similar to other elementary Math Circles across the country has grown to be a more unique program over the year, reacting to the needs and interests of the Kittitas community.

To start, the young students work weekly with a group of undergraduates from the university, led by B. Wiegers and D. Klyve. Each week we play different games (NIM, Toads & Frogs, Triangle Pennies and the 4 Square Problem). While playing, the undergraduates lead the younger students in talking about the patterns and problem solving leading to connections of deeper mathematics. This has deepened the undergraduates' problem solving skills and overall mathematical knowledge.

At the same time the students are playing, we are also running a Circle for parents. This Circle, led by A. Rogan-Klyve and J. Shiver, gives parents a chance to play the same games, and explore ways to use these games as a starting point for more mathematical exploration and play at home. The Circle also allows parents the opportunity to discuss aspects of the recently implemented Common Core Curriculum, which so many parents find to be very different than the math they remember from their own school days. (Received September 22, 2015)

1116-B5-2905 **Alessandra Pantano*** (apantano@uci.edu). *UCI Math CEO: The ripple effect of the UCI Community Educational Outreach.*

The Math Circle at the University of California, Irvine ('Math CEO') has dramatically expanded during the years, and evolved from a small program for a selected group of very talented high school students in the Irvine school district to a far broader mathematical enrichment program for students from a low-performing middle school in a nearby largely Hispanic community. In this talk we will discuss the impact of this program on a variety of constituencies. The pupils have demonstrated increased resilience and determination in tacking mathematical challenges; their parents have developed greater awareness about college opportunities for their children; the volunteers have fostered their passion for giving back to the community; and finally, the key educators have learned valuable skills in promoting inquiry-based learning strategies. (Received September 23, 2015)

1116-B5-2921 **Victoria Kofman** (vk@vikaschool.com), Stella Academy, 1358 Busch Pkw, Buffalo Grove, IL 60089, and **Aleksandra Fedorov*** (aleksandramath@gmail.com), **Ryan Marchenko** (ryanmarchenko2001@gmail.com) and **Ethan Soifer** (soifer03@gmail.com).
Students' perceptions for an impact of Math and Logic enrichment program.

The Math and Logic program concentrates on elevating students' problem-solving skills by teaching working memory load reduction techniques. This talk will uncover the students' views from the program.

Many students say school math is boring, but Math and Logic is fun and challenging. They also claim a few years in the program dramatically changed their lives. This program helps students understand solving problems can take hours or days and involves many approaches. The students also claim that trying to solve a problem over and over again until calculating the correct answer is fun, something they never before experienced. All students say the program helped them improve significantly in their school math. They started to think in a more logical and creative way, which allows them to surpass their classmates in their schools. Many students claim they became more popular for being smarter and able to help their friends with math. In addition, the students believe a deeper understanding of math will allow them to pursue professions of their dreams. The students will discuss some problems that helped them understand how interesting math is and how it inspires them to take part in the math enrichment program. (Received September 23, 2015)

Common Core State Standards for Mathematics Practices and Content: Role of Math Departments in Preparing Math Education Candidates for New Assessments

1116-C1-359 **Greisy Winicki-Landman*** (greisyw@cpp.edu), CA. *Reconsidering the role of a university math department in the local community of teachers.* Preliminary report.

As a result of the adoption of the Common Core Standards, our math department first informally and now formally started to adjust to the changes in content but also aligning to the spirit of the Standards of Math Practice. We play a significant role in the preservice teacher education programs, both at the elementary and the secondary level. In this presentation, we will present some of the changes made to the programs in order to better prepare future teachers. We will mainly focus on the collaboration of some math faculty with the local community, assisting school districts a) making sense of the Common Core Standards, particularly the new contents and the new progressions; b) considering the possible impact on their students; and c) supporting the decision makers about their implementation. (Received August 27, 2015)

1116-C1-423 **Cynthia Oropesa Anhalt*** (canhalt@math.arizona.edu), The University of Arizona, Department of Mathematics, 617 N. Santa Rita Ave., Tucson, AZ 85721, and **Ricardo Cortez** (rcortez@tulane.edu), Tulane University, Mathematics Department, 6823 St. Charles Ave., New Orleans, LA 70118. *Rethinking the Undergraduate Curriculum for Secondary Mathematics Teacher Preparation: Using Mathematical Modeling Modules to Address Common Core Standards.*

The secondary mathematics teacher preparation program at the University of Arizona resides in the Mathematics Department. All students in the program are math majors taking 39 credits of mathematics content, 11 credits of mathematics pedagogy, 14 credits of general education plus a student teaching field practicum. In view of the far-reaching role that mathematical modeling plays in the Common Core, several course syllabi have been revised to place emphasis on building a progression for teaching and assessing the various elements of mathematical modeling and their connection to other Common Core standards. The curriculum revisions have been made through a partnership between mathematicians and mathematics educators. I will describe curriculum development in mathematical modeling through modules that are infused in mathematics pedagogy courses. These modules serve to introduce mathematical modeling content within a pedagogical framework that addresses various content standards and mathematical practices. In order to determine the prospective teachers' understanding of mathematical modeling, we developed an assessment rubric that is appropriate for multiple levels of complexity in mathematical modeling, therefore, useful at the secondary and university level courses. (Received August 31, 2015)

1116-C1-784 **Xiaofen Zhang*** (xiaofen.zhang@indstate.edu). *The Challenges of implementing the Common Core State Standards in Mathematics: A survey analysis.* Preliminary report.

The Common Core State Standards in Math have been implemented in schools across the state of Maryland since 2013. A survey investigating the challenges to implementing CCSS in math was distributed online to all math teachers in the state. The analysis of thousands' responses to the survey indicated the math teachers mainly faced the challenges involving content knowledge, resources, student readiness, and time. They struggled to prepare and implement the lessons incorporating the Common Core ideas due to their lack of deep understanding of the Common Core curriculum. They did not have a fully developed curriculum aligning with CCSS to use in their classes and had very limited access to materials for their students to use in the classroom. Their students did not have the required knowledge and skills to be able to understand the common core materials at their grade levels. The teachers also expressed concerns that they did not have adequate time to prepare for and teach their lessons because of the lack of materials and extra time needed to fill the gaps in student knowledge and skills. In order to successfully implement the CCSS, the issues and challenges mentioned above should be considered and addressed. (Received September 12, 2015)

1116-C1-1172 **Crystal Sue Montana*** (montana7@nmsu.edu), Department of Curriculum & Instruction, College of Education, MSC 3CUR, Las Cruces, NM 88003-8001. *Comparing Warren Colburn's 1825 Text, First Lessons in Arithmetic, with the Common Core State Standards in Mathematics.*

This presentation examines the differences and similarities between parts of two mathematics texts written almost 200 years apart. The comparison emphasizes fractions and how they are represented and applied in the two texts. Selections are from a fourth grade Common Core workbook titled Go Math! (2012) by Dixon, Larson, Leiva, and Adams (based on the Common Core State Standards (CCSS)) and Warren Colburn's 1825 text, First Lessons in Arithmetic. Various tables, which Colburn calls "plates," are included in his book and are meant to be used as tools for solving problems involving operations on whole numbers and fractions. In Go Math!, visual representations are not a tool for solving problems, but are models of fractions that are shown to learners. It seems that the amount of work that students are expected to do is more extensive in Colburn's text. (Received September 17, 2015)

1116-C1-1201 **Mark D Oursland*** (oursland@cwu.edu), Dr. Mark D. Oursland, Mathematics Department, 400 E. University Way, Ellensburg, WA 98926-7424. *Teacher Candidates Discover the Power of CCSS Mathematical Practices.* Preliminary report.

At Central Washington University field-based mathematics methods courses are used to prepare teacher candidates for middle and secondary level mathematics teaching. In the beginning math methods course all candidates are required to design, teach, and assess math lessons aligned with the CCSS-Math. In the next math methods course teacher candidate's design and teach learning progression aligned with a cluster in the CCSS-Math. The learning progression includes benchmark assessments aligned with the Smarter-balanced math content items. The most important and powerful teaching practice is emphasized in the third math methods course, the teacher's candidates design performance assessments modeled from the Smarter-balanced Performance Assessments. Performance assessments require the 3-11 grade students to explain their problem solving and reasoning for real-world math problems. The teacher candidates discover the importance of the CCSS Mathematics Practice when teaching students to think and communicate mathematically. (Received September 17, 2015)

1116-C1-1731 **J D Berg*** (jberg5@fitchburgstate.edu), 160 Pearl Street, Fitchburg, MA 01420. *A report from the field: CCSS, PARCC and higher education.*

The author will report on her activities as a PARCC higher education fellow in Massachusetts during the years of development of the PARCC assessment and the related k-16 alignment policies. The presentation will cover collaborations with elementary and secondary educators, adjustments to mathematics requirements for teacher education programs, and the various policies under consideration in Massachusetts. Collaborations include work with districts to familiarize teachers ways to use test development materials to modify existing lessons diversify the types of mathematical practice students engage with (examples provided). Future collaborations include developing Professional Learning Communities with members from local high schools and the secondary education preparation faculty (model will be outlined). The presenter will also overview the curricular changes the mathematics department at her institution enacted to help prepare future elementary mathematics teachers; including examples of assessments given in these courses to assess students proficiency with both mathematics content and practice. Finally, the presenter will give an update on the several policy shifts under consideration in the state to help smooth student transition from k-12 into higher education. (Received September 21, 2015)

1116-C1-1796 **Tetyana Berezovski*** (tberezov@sju.edu), St. Joseph's University, Department of Mathematics, Belarmin 237, 5600 City Avenue, Philadelphia, PA 19131. *Contextualizing CCSS-M in Geometry Course: Innovative Approach, Effectiveness of Fundamental Changes.* Preliminary report.

Like many departments across the United States, our mathematics department developed and implemented new content courses that prepare our students to work in the CCSS-M environment. In this presentation the alternative to a typical College Geometry course will be discussed. Innovations in course structure and some associated assessment tools will portray the effectiveness of these fundamental changes. The impact on students' learning will conclude the presentation. (Received September 21, 2015)

1116-C1-2141 **Kimberly R Elce***, kelce@csus.edu. *The Cycle: Changing the Culture in K-12 Classrooms.*

With the implementation of the Common Core State Standards in Mathematics, comes a change in the expectations of students as evidenced in the new assessments. To address this change, the culture of the mathematics classroom must shift in a way so that students believe that mathematics is something that they can figure out and not something that they are simply told how to do. Creating this cultural shift in the classroom can be an overwhelming task for teachers. When working with K-12 teachers, we introduce a paradigm called "The Cycle" to help teachers take lessons that are traditionally procedural rules told to the students, and shift the focus so that students figure out the procedure themselves. In this talk we will look at examples of "The Cycle" and reflect on the impact it has had on K-12 teachers. In addition, we will address how we are taking our work with K-12 teachers and implementing it in our undergraduate classes that are largely populated by students planning on pursuing a career in teaching. (Received September 21, 2015)

1116-C1-2398 **Ruthmae Sears*** (ruthmaesears@usf.edu), University of South Florida, 4202 E. Fowler Ave., EDU105, Tampa, FL 33620, and **Fernando Burgos** (fburgos@usf.edu), University of South Florida, 4202 E. Fowler Ave., CMC 342, Tampa, FL 33620. *Collaborative Effort to Address the Common Core State Standards for Mathematics In a Middle School Mathematics Teacher Certification Program.*

We will describe a collaborative effort between the mathematics education and mathematics department to develop a new middle school program that attends to the Common Core State Standards for Mathematics (CCSSM) - Content Standards and Standards for Mathematical Practice. To develop preservice teachers' mathematics knowledge for teaching, faculty from both departments' co-planned syllabi and enacted lessons, as well as co-taught lessons. In addition, to developing preservice teachers' mathematical content knowledge within mathematics courses, preservice teachers took the MyMathTest within their mathematics education courses, to review and remediate mathematical objectives identified on CCSSM Content Standards for Grades 5-9. Our faculty reviewed students' performance on MyMathTest to further refine instructional efforts, and improve the overall quality of the program. Furthermore, instructional activities and assessment measures (such as journaling and Socratic seminars) were used to help preservice teachers cultivate habits of minds identified in CCSSM Standards for Mathematical Practice, foster students' engagement, and encourage active learning. (Received September 22, 2015)

1116-C1-2969 **Betty C Rogers*** (brogers@piedmont.edu), Piedmont College, Central Avenue, Demorest, GA 30535. *How Mathematics Departments and Schools of Education must collaborate to prepare future teachers for the new certification assessments and for successfully teaching Common Core State Standards.*

Mathematics departments are faced with new commitments as more emphasis is being placed on teachers being fully prepared in both mathematics and mathematical pedagogy to teach the Common Core State Standards. Assessments for both teacher candidates and K-12 students have changed radically in recent years. With content tests now prevalent for teacher certification and edTPA – a "multiple-measure assessment system aligned to state and national standards including Common Core State Standards and the Interstate Teacher Assessment and Support Consortium (InTASC)" adopted at different levels by institutions in 35 states and the District of Columbia, the role of mathematics departments in teacher education has become more critical. This presentation focuses on the preparation and collaboration between mathematics and programs for teacher education necessary to meet these new requirements. The presenter who holds dual appointment as Professor of Mathematics in the School of Arts and Sciences, and Professor of Education in the School of Education brings a unique prospective to the role that each department must play in the development of future teachers who are ready to teach school mathematics. (Received September 23, 2015)

Contemplative Pedagogy and Mathematics

1116-C5-93 **John W Watson*** (jwwatson@atu.edu), Tomlinson 126H, 1507 N. Boulder Ave., Russellville, AR 72801. *Journaling in a freshman general education math course for non-STEM majors.*

During the spring and summer of 2015 I have been researching open resources to use in teaching a freshman level general education mathematics course for non-STEM majors. In the fall 2015 course, I plan to have each student keep a journal regarding their attitude about and feelings towards mathematics. One of my goals is for students to gain an appreciation for mathematics and its effect on our everyday life. Using these open resources I hope to address the "second challenge" that our President Francis Edward Su wrote about in the April/May 2015 issue of MAA Focus regarding "how we change the public conversation about who can do mathematics" which is tied to "the public view of mathematics". (Received July 21, 2015)

1116-C5-932 **Robert Howard London*** (rlondon@csusb.edu). *A curriculum of nonroutine problems: A contemplative approach to teaching the process of problem solving.*

This presentation explores the integration of contemplative approaches in a curriculum of nonroutine problems. The curriculum focuses on the process of problem solving, especially problems that require a transformation of understanding to resolve. The curriculum has been field-tested in a variety of traditional mathematical content courses (as well as a semester mathematics course in problem solving) involving 8 to 15 problems per course, each involving one to two weeks work, mostly outside of regular class time. Only a few of the problems are directly related to the mathematical content of the course and approximately 40% of the problems involve content not traditionally considered mathematical (e.g., individually defined personally significant problems), supporting transfer of the approach to a variety of fields, both mathematical and non-mathematical. Field-testing indicates that the curriculum can be integrated into a traditional content mathematics course and effectively improve students' problem solving ability as well as have a positive effect on the learning of the mathematical content of the course. This presentation will include a contemplative experiential component to facilitate an understanding of the approach. (Received September 15, 2015)

1116-C5-935 **Katherine G Johnson*** (katherine.johnson@metrostate.edu), 700 East Seventh Street, St Paul, MN 55106-5000. *Inclusion of Write to Learn Activities in an Elementary Statistics Course: Are they beneficial for non-traditional students?*

Research on writing in statistics courses has shown writing is an effective tool for student's learning. A study was carried out to determine if including write to learn activities in a statistics course would benefit nontraditional students and to obtain feedback on students' perceptions of the write to learn activities. The objectives were to determine if the inclusion of writing activities improved students' ability to set up accurate hypotheses; carry out a hypothesis test; and interpret in context the results of a hypothesis test. Also, to determine if students' perceptions of their learning were impacted by the write to learn activities; and if students' perceptions of their level of statistics anxiety were affected by the write to learn activities.

The study shows an increase in the proportion of students who correctly calculate the z-statistic, and an increase in the proportion of students who interpret the results of a hypothesis test in context. The results also show the majority of students had positive impressions of the writing activities, claiming that the writing exercises were helpful in their learning. In addition, students' anxiety levels were reduced from the beginning of the course. (Received September 15, 2015)

1116-C5-1689 **Catherine A. Gorini*** (cgorini@mum.edu). *Geometry for the Artist: An Interdisciplinary Course Based on Consciousness.*

At Maharishi University of Management, students and faculty practice the Transcendental Meditation technique. This practice gives students both experience and knowledge of consciousness that serve as an interdisciplinary basis for the curriculum. In Geometry for the Artist, a course that satisfies the mathematics distribution for students in the arts, we use principles based on the nature of consciousness and the process of meditation, creating a link between mathematical topics such as symmetry, perspective, dynamical systems, non-Euclidean geometry, and topology on the one hand and the subjective experiences inspired by the visual arts on the other hand. (Received September 21, 2015)

1116-C5-1802 **M. Reba*** (mreba@clemson.edu), Department of Mathematical Sciences, O-110 Martin Hall, Box 34097, Clemson, SC 29634, and **M. Burr**. *Problem-Solving, Self-Reflection, and Communication.*

Presented with the challenge of designing a freshman/sophomore level course with a critical-thinking emphasis, we created a special section of our existing Liberal Arts Mathematics course, and this section has been offered every semester since Fall 2014. We use a new text that focuses on solving puzzles and practical problems while introducing recurring mathematical representations and strategies. We incorporate contemplative practices, interpreted as self-reflection on the process of solving problems, to encourage students to experience mathematical thinking. Several times throughout the semester, students are assigned questions about a specific problem, asking them to think about what they know and don't know, what a solution would look like, what strategy is applicable, what representations are useful and why, etc. They are asked to type and submit concise answers to these questions. As a result, by the end of the semester, many students improve their ability to communicate, exhibit a self-awareness when engaging with the material, and better understand the role of creativity in mathematical problem-solving. (Received September 21, 2015)

1116-C5-2170 **John Mitchell*** (jmitchell@clark.edu), Mathematics Department, Clark College, 1933 Fort Vancouver Way, Vancouver, WA 98663. *The Mindfulness Infused Mathematics Class.*

In academic settings, mindfulness skills courses such as "Koru Mindfulness" have been widely adopted to help students reduce stress, enhance focus, and connect their studies with their values during a critical time in their emerging adulthood. The author is in the Koru teacher training program, runs mindfulness courses and workshops for students and staff, and has witnessed the transformative effect mindfulness training can have.

Most students do not have the resources, interest, or time to take a mindfulness course of their own volition. Incorporating mindfulness skills directly into the classroom has strong potential benefits, while requiring careful attention to pedagogy: mindfulness skills need to be carefully selected, condensed, and staged.

A *mindfulness infused* approach will be presented, and detailed for a freshman calculus class. The mindfulness infused course uses short experiential practices to introduce mindfulness at the outset; links mindfulness explicitly

and continually to the challenges students face during the course (e.g. developing good study habits or facing test anxiety); and encourages them to uncover mindfulness skills they already have. Future work will further assess and develop this rich framework for enhancing student learning. (Received September 22, 2015)

1116-C5-2286 **Leah Childers*** (lchilders@benedictine.edu), Atchison, KS 66002. *Creating dialogue to address attitudes towards math in pre-service elementary teachers.* Preliminary report.

In this talk we will discuss strategies to help students acknowledge their preconceptions and attitudes towards mathematics and how those could impact their future students. In particular we will discuss how journal topics and participation self-assessments create an environment for students to objectively examine their attitudes. (Received September 22, 2015)

1116-C5-2308 **Justin Brody***, justin.brody@goucher.edu. *Contemplating Infinity.*

I will discuss some of my experiences in teaching a first year seminar which used contemplative techniques to explore the mathematical infinite. In this course students were taught basic calm-abiding (shamatha) meditation and asked to develop a daily meditation practice. They were also taught techniques of analytical meditation, which they used to contemplate Cantor's Theorem, Goedel's Theorem, and Zeno's Paradoxes. (Received September 22, 2015)

1116-C5-2377 **Shannon Schumann*** (shannon.schumann@gcu.edu), CHSS - Bldg 16, 3300 W Camelback Rd, Phoenix, AZ 85017. *Preservice Teachers' Attitudes toward Faith and Mindfulness as an Intervention for Math Anxiety.* Preliminary report.

The attitudes of preservice elementary mathematics teachers toward faith and mindfulness as possible intervention toward math anxiety are examined in this qualitative study. Students enrolled in an elementary education mathematics course at a faith-based University were trained in a mindful breathing exercise. Students participated in a short exercise combining mindful breathing and/or prayer followed by a brief writing exercise. Students also answered online discussion questions about their attitudes toward faith, teaching, math anxiety and their experiences with the exercise. Responses to all written work is being transcribed for salient themes. (Received September 22, 2015)

1116-C5-2487 **M. Anne Dow*** (adow@mum.edu), Maharishi University of Management, 1000 N. 4th St., MR 715, Fairfield, IA 52557. *Consciousness-Based Education: Using Transcendental Meditation to Enhance Student Learning in Mathematics Classes.*

When I first visited Maharishi University of Management, after more than ten years teaching mathematics at a university in Australia, I was struck by the liveliness of the math students. They were awake, alert, happy, interested in what I had to say, and engaged in lively discussions about the math. In this talk, I will explain why the practice of Maharishi Mahesh Yogi's Transcendental Meditation technique by both students and faculty should have this result, making the teaching and learning of mathematics more effective and enjoyable. I will explain how it works and give an overview of research into those effects of Transcendental Meditation that are relevant to doing, teaching, and learning mathematics. (Received September 22, 2015)

1116-C5-2641 **Blake A. Mandell*** (blake_mandell@brown.edu). *Elementary mathematics starts with the body: Abstract notions become embodied.*

Descartes defined 'intuition' as "the conception of an attentive mind, so clear, so distinct, and so effortless." For children of the lower elementary years, normal attention spans range from the child's age in minutes up to a half hour when the child is properly engaged. A centering mind-body exercise combined with the joining of physical experience with the intellect changes the learning of mathematics from a purely cognitive activity to an embodied one. Thus, the use of the body helps to foster cognitive clarity that leads to mathematical intuition about numbers, arithmetic, and algebraic symbols in young students. This talk will review my past experience of utilizing contemplative pedagogy to teach elementary mathematics and will outline an approach to integrate contemplative pedagogy into the college classroom. (Received September 22, 2015)

1116-C5-2685 **Joshua Holden*** (holden@rose-hulman.edu), Department of Mathematics, Rose-Hulman Institute of Technology, 5500 Wabash Ave., Terre Haute, IN 47803. *Reflective activities in Calculus: Using short writing exercises to improve metacognition and self-assessment.* Preliminary report.

Incoming freshman often enter the Calculus sequence without the academic maturity needed to succeed in their required mathematics classes. These students have often succeeded in high school mathematics despite a lack of study skills and disciplined planning. Without these skills, they often find themselves adrift in college. I have been attempting to use exercises such as "wrappers" and self-assessment inventories to lead them to their own realization of how important it is to master these "meta-skills". Once they understand this importance, they will be more receptive to our efforts to teach them study skills and planning. For some students this will improve their grades immediately. Other students may need more instruction in study skills but will be more likely to follow through. Finally, some students may be able to get by for a time on their high-school skills, but will use these lessons later in their college career. Very few students can be successful in college without discipline and study skills so encouraging these skills should improve both students' satisfaction and their grades. (Received September 22, 2015)

1116-C5-2703 **Jacqueline A Jensen-Vallin*** (jacqueline.jensen@lamar.edu), Lamar University, Department of Mathematics, Box 10047, Beaumont, TX 77710. *Weekly Reflection Assignments in Mathematics Major Courses.* Preliminary report.

Annalisa Crannell's inspiring talk at JMM 2015 led me to have Calculus II students write weekly summary and reflection papers during the Spring 2015 semester. In addition to summarizing the previous week's content, students were encouraged to ask questions and reflect on how they understood the material. The positive results of these papers encouraged me to continue this assignment with Modern Algebra students in Fall 2015. We will discuss how these summaries evolved over the semester for each group and students' reactions to these assignments. Particular prompts will also be suggested for students' guided reflection. (Received September 22, 2015)

1116-C5-2765 **Josh Thompson*** (joshthom@nmu.edu), Math Department, Northern Michigan University, Marquette, MI 49855. *Do in-class mindfulness activities increase student performance?* Preliminary report.

Years ago I opened my Differential Equations class with a mindfulness activity to begin the day. Motivated by my own experiences with my personal practice I led my students through a short series of guided stretches and attentive breathing. Though no one was hurt in the process, I did feel quite awkward and I have never repeated the activity. More recently, motivated by increasing evidence of the positive effects of such activities (eg Ramsburg & Youmans, 2014), I once again incorporated contemplative practices into my teaching.

In this quasi-experimental case study, I compare student performance across two sections of a semester-long college algebra course. In one section I incorporated mindfulness activities such as 1-2 minute guided meditation and breathing exercises. The other section was treated as a control group. In this presentation I discuss the facilitation of the activities and the results of the study. (Received September 22, 2015)

1116-C5-2805 **Robbie Pinter***, Department of English, Belmont University, Nashville, TN 37212, and **Mike Pinter**, Dept of Mathematics and Computer Science, Belmont University, Nashville, TN 37212. *Mindfulness Across the Curriculum: From Freshmen to Seniors.*

Providing structures and opportunities for our students to develop "slowing down" as a habit of mind offers them enriched learning opportunities. In the primary part of the presentation, Robbie (Professor of English) will use her training in contemplative pedagogies to describe several specific strategies that can be used with students in the classroom and outside of class to help them constructively slow down. Robbie and Mike (Professor of Mathematics) will share a variety of ways they have employed contemplative elements in their courses, including writing courses, mathematics courses, a first-year seminar course and a capstone course. (Received September 22, 2015)

The Contributions of Minorities to Mathematics Throughout History

1116-D1-98 **Emelie A Kenney*** (kenney@siena.edu), Department of Mathematics, Siena College, Loudonville, NY 12211. *Polish Women in Mathematics During the Nazi Occupation.* Preliminary report.

Rasiowa, Krygowska, Hosiasson-Lindenbaum, Szmydt–these names may be unfamiliar to many of us. Each name, however, represents a person who contributed to mathematics, mathematics education, or both, and did so under seemingly impossible conditions. Who were they? First, we describe what is called The Flying University, which began operating without the knowledge of forces occupying Poland around the turn of the 20th century in order to provide educational opportunities to women and the poor (A later version operated around the late 1970s during the period of Soviet domination of Poland.). The second incarnation of organized clandestine education arose within the vast underground resistance, the largest and most sophisticated in Europe, in Nazi-occupied Poland during World War II. In this dangerous environment, many mathematicians–male and female–studied, taught courses, gave exams, or prepared their students or themselves for university degrees at all levels, all in secret, all under threat of concentration camps or death if caught. In this context, we discuss a number of women who, through their daring efforts during and immediately following the war, contributed to mathematics, mathematics education, and the re-emergence of mathematical life in Poland. (Received July 22, 2015)

1116-D1-265 **Charles P. Funkhouser*** (cfunkhouser@fullerton.edu), **Miles R. Pfahl** and **Harriet C. Edwards**. *Discovering Undergraduate Mathematics in Native American Culture.*

This project has developed and researched mathematics materials based in the culture and mathematics of Native American Peoples. Mathematics topics include the history of mathematics, probability and statistics, number theory, transformational geometry, calculus, and preservice elementary and secondary education-related content. These materials generated–both paper and electronic–are classroom ready for integration into undergraduate courses, and are developed and piloted in consultation with Tribes in the Rocky Mountains, the Plains, the Pacific Northwest, and the Southwest. This work is an NSF DUE TUES Type 2 funded project. (Received August 19, 2015)

1116-D1-488 **Robert L Brabenec*** (robert.brabenec@wheaton.edu). *Sonya Kovalevsky: The Rest of the Story.*

The standard story of the life of Sonya Kovalevsky is that she learned mathematics from calculus notes used as wallpaper in her childhood room, entered a nihilistic marriage to escape from Russia where women could not attend university, was tutored by Karl Weierstrass at his home in Berlin, and was given a teaching position in Sweden. The complete story is much richer including such things as: (1) extensive travel throughout Europe and acquaintance with many notable figures, including a lifetime friendship with Fyodor Dostoyevsky; (2) tireless efforts for the equal rights of women in social and scientific circles; (3) winning a coveted prize from the French Academy of Science and serving as editor of the *Acta Mathematica* journal; and (4) being a respected colleague of mathematicians as Mittag-Leffler, Hermite and Poincare, as well as a disseminator of Weierstrass's analysis results. Details of her personal struggles to find her place in a world reluctant to recognize her abilities add color to the story of this remarkable woman. At the time of her death at age 41, she had a 13 year old daughter, hope of a second marriage, and anticipation of a fulfilling career at the University of Stockholm. (Received September 03, 2015)

1116-D1-663 **Sarah J Greenwald*** (greenwaldsj@appstate.edu), Department of Mathematics, 326 Walker Hall, 121 Bodenheimer Drive, Boone, NC 28697. *Incorporating the Contributions of Women and Minorities into Classrooms: David Blackwell, Evelyn Boyd Granville and Mary Gray.* Preliminary report.

Stories of mathematicians and statisticians and their contributions can help students connect to mathematics and inspire them. We'll discuss how to incorporate these into a variety of classes including linear algebra, senior capstone, and general education courses. We'll examine the benefits and challenges in addition to student responses as we look at examples related to David Blackwell, Evelyn Boyd Granville and Mary Gray. Interviews abound in the existing literature, and I've also personally communicated with each of these inspiring individuals (David Blackwell is deceased but I communicated with him in the early 2000s). For more information, see http://cs.appstate.edu/∼sjg/history/wmm.html (Received September 10, 2015)

1116-D1-1078 **Satish C. Bhatnagar*** (bhatnaga@unlv.nevada.edu). *THE MAKING OF BENJAMIN BANNEKER.*

At the outset, this paper is by one minority on another minority. History encompasses chronological study of people, places, principles etc. As a corollary, the history of mathematics ought to cover any topic having mathematical touch. It is claimed that Benjamin Banneker (1731-1806) is the first 'applied mathematician' of Afro-American ethnicity. Under the hypothesis that the value of an historical event of lies in its connection with the present, this paper briefly touches upon seven questions related with the life of Benjamin Banneker. Some are left open, some partially answered, and some stoutly laid out. In the realm of history of mathematics, there is no one right answer. It is this characteristic that sets it apart from the world of hardcore mathematics.

1. Pre-USA of Banneker's times 2. Banneker's education 3. Banneker's wife and children 4. The development of Banneker's life 5. Banneker's mathematical legacy 6. Did Banneker meet Benjamin Franklin (1706-1790)? 7. Banneker's non-mathematical legacy (Received September 20, 2015)

1116-D1-1287 **Jill R. Duke*** (jrduke@nmsu.edu). *"Arithmetic Simplified" (1832): The Story Behind Catharine Beecher's Most Unrecognized Work.*

A personal tragedy in the life of Catharine E. Beecher (1800-1878) inspired an intellectual awareness resulting in her becoming a prominent advocate and reformer of women's education. Despite early American opinion that formal education of females was impractical and uneconomical, she petitioned for funds and in 1823, 1833 and 1850 opened schools for girls that taught advanced topics such as mathematics. A 19th century American writer, Catharine authored numerous books and articles addressing topics of her era including suffrage and the role of women in society as mothers and educators. She also developed her own course material and published textbooks. One of her earliest but least recognized works is a math textbook titled "Arithmetic Simplified."

This presentation begins with an introduction of Catharine Beecher's accomplishments as an educator and writer followed by an exploration of her educational background to discover what mathematics she learned as well as where and from whom she learned it. In conclusion, Catharine's motivation to write a mathematics textbook and her philosophy of education are discussed. (Received September 18, 2015)

Conversations with the Partner Disciplines: Collaborations to Improve the Mathematics Curriculum

1116-D5-241 **David White*** (david.white@denison.edu), P.O. Box 810, Granville, OH 43023. *An Application-First Approach to Statistics.*

Interdisciplinary is central to the mission of most liberal arts colleges. In addition, studies have shown that student interest and retention (especially for under-represented groups and especially in introductory courses) improve when students see the connection to their other classes and interests. I'll present an approach to statistics that introduces new material first via the real-world problem that motivates the mathematics. I'll share labs and semester-long projects I designed based on data sets from and discussions with colleagues in 11 departments. Together with guest lectures, this approach prepares students to analyze data from numerous settings, to succeed in quantitative electives in other departments, and to conduct interdisciplinary senior research.

The connections this fostered in other departments helped lay the ground-work for a new Data Analytics major, for interdisciplinary collaborations, and for improved pedagogical synergy. I'll discuss which data sets worked especially well for introducing mathematical content, how to balance the mathematics and the projects so students are not overwhelmed, and ongoing work to create different introductory statistics sections with domain-specific applications. (Received August 17, 2015)

1116-D5-448 **Julie C. Beier*** (beierju@earlham.edu), 801 National Road West, #138, Richmond, IN 47374. *Social Justice – It's not only statistics!*

What do food, the civil rights movement, and human trafficking have in common? Mathematics of course! Often the connections between social justice and mathematics are limited to statistics or economics. In this talk, I present a different kind of intentionally interdisciplinary first-year seminar course, titled *Social Justice: Adding a Mathematical Dimension*. This course includes regular reading and writing, as well as labs and activities to better understand the issues at hand. Additionally, I will briefly discuss co-mentoring in planning, how the change in viewpoint impacted the discussions on our campus, and how the experience led to two new interdisciplinary courses. (Received September 02, 2015)

1116-D5-519 **Holly Hirst*** (hirsthp@appstate.edu), **Mark Ginn** and **Katrina Palmer**. *Revising General Education Math Courses with Client Discipline Input.*

Periodically, courses approved for our University's quantitative literacy (QL) requirement in the general education program must be re-certified. The Math Sciences Department took advantage of this process to revise the three courses non-technical majors typically take: an application-based "liberal arts" course, a college algebra course, and a precalculus course. Many client disciplines had found that the college algebra course did not meet their needs and were requiring precalculus, even though their students did not need to take calculus. This led to a precalculus that did not prepare students for calculus or for the needs of the client disciplines.

Client disciplines across the university were asked to describe needs of their majors, which led us to a significant revision to the college algebra course, allowing the precalculus course to be specifically designed to prepare students for calculus. The conversations also yielded problems to be incorporated into the college algebra course from nutrition, exercise science, and building science, as well as from general education courses in chemistry, geology, and physics.

This presentation will provide outlines of the three redesigned courses, and share examples of input from the client disciplines. (Received September 05, 2015)

1116-D5-905 **Suzanne Ingrid Doree*** (doree@augsburg.edu). *Just Enough Algebra to Prepare Students for Quantitative Courses Across the Disciplines – a New Approach to Developmental Algebra.*

What algebra do students need to know to succeed in college, to understand their everyday life, and to become effective participants in today's society? For the past 20 years at Augsburg College we have taught a successful developmental algebra course that helps students learn Just Enough Algebra. Conversations with our partner disciplines have been critical to our course design and renewal, with special attention to economics, business, the sciences, and quantitative reasoning courses in mathematics/statistics. Content choices at Augsburg echo national findings from the Curriculum Foundations Project: Voices of the Partner Disciplines – students need to experience the power of an algebraic model, but just as importantly they need to develop stronger number sense, numerical and graphical methods, and effective use of technology. In this talk I will briefly describe (1) the process we used to develop the course and (2) the content choices we made. I will also share one secret to our success (3) the ability to "fast-forward" to important content students will need in subsequent coursework including (a) introducing systems of linear equations effectively in one class period and (b) teaching how to solve exponential equations exactly without knowing the rules for logarithms. (Received September 15, 2015)

1116-D5-1312 **Carrie Diaz Eaton*** (ceaton@unity.edu) and **Hannah Callender** (callende@up.edu). *Designing Calculus for and with Biologists.*

This is a tale of two undergraduate colleges in which biology programs were revising majors and eliminating calculus as a requirement, because it did not serve their students. For one college, University of Portland, most majors were pre-med, but not all. For another college, Unity College, the constituents were a variety of non-pre-health life science majors. In this presentation, we discuss how we developed calculus courses for these disciplines, what conversations we had, and what tools we used. We compare and contrast these solutions, but student performance was comparable to traditional calculus sections and in both cases, majors have re-added or are exploring the re-addition of calculus to their major requirements. (Received September 18, 2015)

1116-D5-1444 **Tevian Dray*** (tevian@math.oregonstate.edu), Department of Mathematics, Oregon State University, Corvallis, OR 97331, and **Corinne A. Manogue** (corinne@physics.oregonstate.edu), Department of Physics, Oregon State University, Corvallis, OR 97331. *Reimagining Second-Year Calculus: The Vector Calculus Bridge Project.*

In 1997, the Department of Physics at Oregon State University completely redesigned their upper-division major. With ongoing funding from NSF, they developed 18 new courses, reorganizing the curriculum around mathematical themes such as spherical symmetry. In 2000, a closely related project, the Vector Calculus Bridge Project, began to address the gap between the ways mathematicians typically teach vector calculus, and the ways in which other scientists typically use it. With funding from NSF, a series of small group activities were designed to emphasize geometric reasoning, and a novel, online textbook was written to accompany them. These projects merged in 2006, and since 2013 significant effort has been devoted to developing similar materials for all of multivariable calculus.

This talk summarizes the history of the Bridge Project, its successes and failures, and what we've learned along the way. One of the unanticipated successes: The creation of a learning community that has met monthly for 18 years to discuss curriculum and student learning (mostly in physics)! (Received September 19, 2015)

1116-D5-1822 **Steven LeMay*** (steven.lemay@uconn.edu), **Megan Brown**, **Grace Wright** and **Fabiana Cardetti**. *Collaboration Across Disciplines Exploring Mathematical Tasks focused on Argumentation.*

In this presentation, we will discuss the results of a study motivated by the current emphasis on argumentation in the new Common Core State Standards for Mathematics and its implications for the college mathematics curriculum. Our study focused on the analysis of mathematical tasks addressing the third Standard for Mathematical Practice that highlights argumentation as an expertise all students should develop. In this study we merged our expertise from mathematics and education to analyze 157 tasks from 40 schoolteachers participating in a professional development program focused on mathematical argumentation. We analyzed the effects of argumentation on the cognitive demand levels of the tasks, as well as how argumentation detracts or contributes to the mathematical content in the tasks. In addition, five different themes emerged from our analysis with regards to the interplay of argumentation and mathematical concepts. While our study was focused on school mathematics, this interdisciplinary collaboration helped us better understand the implications that the new standards will have in the curriculum at the college level especially in relation to argumentation. (Received September 21, 2015)

1116-D5-2320 **Chris Oehrlein*** (cdoehrlein@gmail.com). *Teaching Non-Calculus-Based Physics: One Semester of Thoughts and Observations.* Preliminary report.

One week before the semester began, I needed to substitute a class in my workload because of some other changes that had been made to the schedule. Choosing not to teach another section of College Algebra, I opted for an opportunity provided by my dean: teach the section of College Physics that was still open (and for which no suitable adjunct had been found). Most math departments interact with physics departments at the calculus level and higher. This was an opportunity to observe how students think about, do and apply the general education math they have learned. What lessons could there be for me as a math teacher and for us as the mathematics education community? (Received September 22, 2015)

1116-D5-2507 **Anneke Bart*** (barta@slu.edu), 220 N. Grand Blvd, St Louis, MO 63103, and **Mike May**. *Survey of Calculus with Excel.* Preliminary report.

At Saint Louis University we offer Survey of Calculus with Excel. This course has been revised in recent years. The research basis for the revision of this course was a survey of the faculty in our Business school, giving results similar to those found by the CRAFTY report, with verification from similar studies done at other schools. The topics covered are the same, but more weight is now given to multivariable calculus, and Excel is used as the computational tool in the classroom. The use of Excel is incorporated very early in the course so that we can use several applications to explore concepts in mathematics. Linear equations are reviewed for instance using supply and demand problems as the basis; the Cobb-Douglass equation is used to motivate the study of rates of change and multivariable functions; marginal cost, revenue and profit are used to motivate explorations in differential calculus.

Collaborations between mathematics faculty and business faculty include guest lectures by business faculty and careful use of examples students will see in classes in both colleges. Discussions have been held to look at modifications to business courses to reinforce the changes made in the mathematics courses. (Received September 22, 2015)

1116-D5-2780 **Susan A. Ruff***, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Building E17-404, Cambridge, MA 02139. *What can mathematics-across-the-disciplines learn from writing-across-the-disciplines?*

At MIT, the math department has recently collaborated with Writing, Rhetoric, and Professional Communication (WRAP), MIT's writing-across-the-disciplines program, to renew Principles of Discrete Applied Mathematics, an introductory subject taken by sophomores and juniors. Our interdisciplinary goal is to teach students to communicate effectively as mathematicians: that is, to craft mathematical arguments not only to convince but also to communicate effectively to the target audience. The first part of the presentation will summarize this successful collaboration and the resulting interdisciplinary pedagogy. The collaboration is part of a broader collaboration of WRAP with disciplines across the institute; the second part of the presentation will focus on WRAP's strategies of interdisciplinary collaboration that may be relevant to mathematics across the disciplines, including a research tool for visualizing interdisciplinary pedagogy. (Received September 22, 2015)

The Development and Adoption of Open Educational Resources for Teaching and Learning

1116-E1-95 **John W Watson*** (jwwatson@atu.edu), Tomlinson 126H, 1507 N. Boulder Ave., Russellville, AR 72801. *Using open resources to teach a freshman general education course for non-STEM majors.*

During the spring and summer of 2015 I have been researching open resources to use in teaching a freshman level general education mathematics course for non-STEM majors. This presentation is a report on the resources used in teaching the class, in lieu of a textbook, during the Fall 2015 semester, their effect on student attitudes, and their effectiveness in promoting student learning. (Received July 21, 2015)

1116-E1-338 **Kimberly Jordan Burch*** (kjburch@iup.edu). *Voting with Plickers - No Device Required!* Preliminary report.

Plickers is a free classroom voting system that enables the collection of real-time formative assessment data without the need for specialized hardware. The students vote using cards downloaded and printed from the website, while the instructor records their answers using the camera on a Wi-Fi-enabled device. This device works interactively with the intructor's online Plickers account, displaying the chosen question via the computer projector. Students can validate if their answers were accepted and can view a graph of the class polling results. The investigator will present findings using Plickers both on Apple devices (IPad Air and IPod) and Android devices (Samsung Galaxy S6 and Galaxy 4 tablet). Results of a student survey assessing the Plickers will also be shared. (Received August 26, 2015)

1116-E1-1060 **D Scott Dillery*** (dillerys@lindsey.edu), Mathematics, Lindsey Wilson College, 210 Lindsey Wilson Street, Columbia, KY 42728. *Using SageCell for Engaging Students.*

SageMathCell is a web interface for the free open-source athematics software system SageMath that may be embedded in any webpage and utilized by most any device. This talk highlights four features that have been extremely useful to engage students in introductory statistics and in calculus 2. The features are the interact capability for exploring the effect of parameters in various problems, the ability to link cells for online practice, the ability to generate essentially endless examples for exposition, inquiry and practice, and the ability to use it as a platform for programming skills. Examples in the talk will include histograms used to explore probability and the normal distribution, interactions with Bayes' formula and diagnostic testing, and parameterized curves made of cubic splines used to connect the dots. (Received September 16, 2015)

1116-E1-1081 **Robert A Beezer*** (beezer@ups.edu), Department of Mathematics, #1043, University of Puget Sound, Tacoma, WA 98416-1043. *A WeBWorK-MathBook XML Bridge.*

We will describe the development and enhancement of two open source projects for teaching and learning mathematics through the integration of one within the other. WeBWorK is an established open source program for online, interactive, and automatically graded homework problems. MathBook XML is a new authoring language that allows a mathematics textbook to be rendered from a single source document into many different output formats. This project enables authors to easily create new WeBWorK problems within their MathBook XML source, making it possible for tighter integration of the problem content with the remainder of the text. It also allows authors to reuse existing WeBWorK problems (such as from the Open Problem Library) within their text.

For HTML output, the problems are interactive in the usual way, while for PDF output a static version of the problem is created.

We will will demonstrate these new capabilities and discuss the design decisions and challenges that occurred in this project. The result could be used in textbooks designed for audiences at high schools, community colleges or undergraduate courses across the sciences, engineering and mathematics. (Received September 16, 2015)

1116-E1-1136 **Michael E Gage*** (gage@math.rochester.edu), Department of Mathematics, University of Rochester, Rochester, NY 14627. *Case study of interoperability and reuse: WeBWorK, HTML and Moodle.* Preliminary report.

WeBWorK, used alone, presents interactive mathematics homework exercises in a manner suitable for "end of section" review. Its analysis of students' mathematical answers is second to none.

WeBWorK questions become even more powerful when they are used with other systems.

I'll illustrate how one can spice up a web page of mathematics exposition by embedding one or more active WeBWorK questions. One easy snippet of HTML code provides interactive examples in the middle of the text.

The same WeBWorK webservice makes it possible to add the mathematical smarts of WeBWorK to the Moodle quiz module. Moodle provides all of the features of an LMS and WeBWorK adds high quality processing of mathematics questions to the Moodle quizzes.

These examples show how interoperability between open source systems makes a sum more useful than its parts and how a single WeBWorK question can be repurposed as an example, as a homework problem and as a quiz question. Reuse saves instructor and author time. Interoperability allows for fewer compromises, better instructional materials, and cuts down on unnecessary reinvention.

I will give references to detailed instructions for combining WeBWorK with Moodle, Sage, GeoGebra and MathBook XML for use with your own students. (Received September 17, 2015)

1116-E1-1241 **Marcela Chiorescu*** (marcela.chiorescu@gcsu.edu), Georgia College, Milledgeville, GA. *Exploring Affordable Learning Resources for College Algebra.* Preliminary report.

It is been estimated that the average student spends around $1,200 on books and supplies every year (The College Board, Annual Survey of Colleges). Affordability has become more and more of a challenge for students, especially for the cost of textbooks. In Spring 2015, with the support of an Affordable Learning Georgia Textbook Transformation Grant from University System of Georgia and in collaboration with one of Georgia College's librarians I put together "low-cost-to-students" resources for College Algebra. This presentation focuses on discussing my experience with adopting such materials. (Received September 18, 2015)

1116-E1-1434 **Robert Jacobson*** (rjacobson@rwu.edu), 3 Bayview Ave, APT 1w, Bristol, RI 02809. *Bridging the Closed and Open: How FoxySheep Can Benefit Both Proprietary and Open Technologies for Teaching and Research.*

The proprietary computer algebra system Mathematica is a favorite among many teachers and researchers. Its polished interface and powerful library make it easy for undergraduates and researchers to use. However, its proprietary nature presents difficulties in terms of cost, peer review, reproducibility, etc. Meanwhile, excellent open alternatives exist but have incompatible syntax. FoxySheep is a parser for Mathematica-like syntax that facilitates communication between open mathematical software and Mathematica as well as using Mathematica-like code with open software without requiring proprietary software. (Received September 19, 2015)

1116-E1-1437 **Sue R. VanHattum*** (svanhattum@contracosta.edu), 5121 Solano Ave., Richmond, CA 94805. *Remixing OER to Share the Beauty & Power of Calculus.*

Have you seen your students disengage from your calculus class in the first weeks as they struggle with the technical topic of limits? They don't see the point, get mired in the algebra, and can become alienated. I'll share why I save limits for later, and how I start out with an exciting and historical approach using slope and velocity.

But perhaps your textbook, like mine, follows a traditional sequence? I'll also share how I used parts of two Open Educational Resources (OER), one by Matt Boelkins and one by Dale Hoffman, along with a few pages I created, to make a coursepack for my first unit. [Link to modifiable materials provided at talk, or by email.] Their materials gave my students the support they needed in our excursions off the traditional textbook's beaten path.

I'll help you see why there's a better order to the topics. (It's not just the limits.) And I'll show you one way to make calculus fun for yourself and your students.

Use the experiences I share in my talk as inspiration to help you get started remixing OER to develop your own approach and materials. Using these materials in a coursepack alongside the required text may also be a way to show your reluctant department that they don't need those $200-plus conventional textbooks. (Received September 19, 2015)

1116-E1-1806 **M. Reba*** (mreba@clemson.edu), Department of Mathematical Sciences, O-110 Martin Hall, Box 34097, Clemson, SC 29634, and **Allen Guest** and **M. Burr**. *Interactive Instructional Apps for Specific Calculus Concepts.*

Mathematics and Computer Science faculty and students have developed instructional apps for beginning calculus that resulted from two NSF grants. We discuss three completed apps (TouchCalc, CoreCalc, and EpiCalc), as well as some that are under development. TouchCalc is an interactive app intended to help students understand the graphical relationship between functions and their derivatives. CoreCalc is based on an analysis of common-errors made by students in Calculus I and offers questions in categories such as limits, derivatives, and optimization, including solutions and reference screens. EpiCalc, resulting from student input in a Creative Inquiry course, shows how calculus has been applied to modeling diseases in Epidemiology. Our discussion will include a demo of the apps, as well as results from limited classroom use. We will include anecdotal feedback from students, and describe initial and future plans to study app effectiveness when testing specific concepts. (Received September 21, 2015)

1116-E1-1818 **Alina N Duca*** (anduca@ncsu.edu), **Hatice Ozturk** (hoo@ncsu.edu), **Dianne Raubenheimer** (raubenhe@meredith.edu), **Joel Trussell** (hjt@ncsu.edu) and **Geoff Goehle** (grgoehle@email.wcu.edu). *JITAR online modules to improve math preparation of engineering students.* Preliminary report.

Engineering educators face the challenge of having to teach students with a diverse mathematical skill levels while needing to quickly bring all students up to the same mathematical mastery level at appropriate points during a semester. To address this problem, a team of mathematics and engineering instructors designed a teaching e-tool Just-In-Time Assessment and Review (JITAR). It is delivered as an on-line system consisting of a series of individualized mathematics modules inserted within engineering courses at strategic points in the semester. JITAR assesses the mathematical competency level of the individual student and provides formative individualized learning opportunities in time for the students to be successful in applying the necessary mathematics to the new engineering course material. The open source on-line homework system WeBWorK was chosen for the delivery of these modules. The structure of the modules relies heavily on the fact that the assessment and review content needs to be generated based on individual student's performance. Within WeBWorK a new type of assignment was created to support the desired presentation and flow of the module integrating assessment and e-learning assistance by offering a customized learning path to students. (Received September 21, 2015)

1116-E1-1840 **Cheryl J. McAllister*** (cjmcallister@semo.edu), Southeast Missouri State University, Math Department, MS6700, Cape Girardeau, MO 63701, and **Craig W. Roberts** (croberts@semo.edu), Southeast Missouri State University, Math Department, MS6700, Cape Girardeau, MO 63701. *Recycling the Book: Adventures (and Misadventures) in Transforming an Undergraduate History of Math Class Using OER.* Preliminary report.

The presenters will discuss their experiences with converting and reorganizing a History of Mathematics class from dependence on a single, traditional text to a course utilizing OER. The planning and testing of one unit for the class will happen during the Fall 2015 semester and full implementation to the OER format will occur in the Spring 2016 semester. The History of Mathematics course is taken by a variety of math majors, education majors, and any interested student who has had at least a course in Applied Calculus. The course is taught using distance learning technology with the instructor and some students in one classroom and students from (up to three) additional campuses joining the class via closed circuit television. The goals for this revision of the class include providing learners with a wide variety of multimedia resources for learning content, an opportunity for students to have virtual access to primary sources, encouraging students to interact with a variety of classical texts and resources, and enriching and enhancing the discussion that takes place during class meetings. (Received September 21, 2015)

1116-E1-1923 **Geoff R Goehle*** (grgoehle@email.wcu.edu), Stillwell 426, Western Carolina University, Cullowhee, NC 28723. *Adaptive Just-In-Time WeBWorK Assignments.*

This talk describes the "Just-In-Time" assignment type for the online open source homework platform WeBWorK. This new assignment type allows instructors to add dynamic review elements to homework assignments. Individual homework problems can be augmented with sub-problems designed to deliver review content or give students additional practice. These sub-problems are only presented to students if they are unsuccessful in completing the original problem. This allows instructors to create homework sets which adapt to students needs by presenting extra material only for those topics with which the student needs help. This assignment type was developed as part of the the NSF grant *Bridging Mathematics Contents to Engineering Contexts; Just-In-Time Assessment and Review Modules*. (Received September 21, 2015)

1116-E1-2252 **Mark J. Morabito***, mmorabito1@framingham.edu. *Tailoring the Text: Creating a Quality Open Educational Resource for College Algebra.*

In an effort to meet the academic and financial needs of college students in their core mathematics requirements, this talk will discuss the progress and results of a recent collaboration of instructors at both the high school and collegiate levels to create a high quality, low or no-cost textbook and accompanying enhancements for a traditional College Algebra course. Primarily, the presenter will detail the harvesting of course content from two pre-existing Open Educational Resources (OER), customization and supplementation of original content during the creative process, as well as the Creative Commons license selection. The presenter will also discuss pairing the text with the MyOpenMath free online homework website, as well as future plans and initial student impressions and findings related to the effectiveness of the text. Ultimately this presentation will provide a first-hand account for those individuals who may be interested in creating their own OER or simply wish to know more about adopting and customizing resources that already exist. (Received September 22, 2015)

1116-E1-2337 **Oscar Levin*** (oscar.levin@unco.edu), School of Mathematical Sciences, University of Northern Colorado, Greeley, CO 80639. *"Finishing" an open textbook.*

Writing a free, open source textbook might seem like a lot of work with little or no reward. Alternatively, you might think that since you are teaching the course anyway, it is worthwhile and not too much additional work to develop course notes and practice problems which you could later simply release as an open text. In this talk I will argue that the truth is somewhere between these two extremes. I will share my experience spending a summer transforming a set of lecture notes into a reasonably "finished" open textbook on discrete mathematics. (Received September 22, 2015)

1116-E1-2423 **Paul E. Seeburger*** (pseeburger@monroecc.edu), Monroe Community College, 1000 E. Henrietta Rd., Rochester, NY 14617. *Teaching Online Differential Equations Using OER Textbooks and WeBWorK (an OER Homework Platform).* Preliminary report.

The presenter will share his experience teaching an online differential equations course using a set of three freely available OER textbooks along with WeBWorK homework sets. He will discuss how well the topics aligned between the books and the course objectives, what extra work he needed to do to help his students navigate these three books, and what the students thought about using these OER resources in the course. As time allows, several freely available visualization tools used in the course will also be shared. (Received September 22, 2015)

1116-E1-2604 **Edwin P Herman*** (eherman@uwsp.edu). *Free, peer-reviewed, open-source Calculus textbook by OpenStax.*

OpenStax is a nonprofit organization committed to improving student access to quality learning materials. An initiative of Rice University and made possible through the generous support of philanthropic foundations, OpenStax provides free textbooks developed and peer-reviewed by educators to ensure they are readable, accurate and meet the scope and sequence requirements of most introductory college courses. Since its inception in 2012, OpenStax has saved over 540,000 students $53 million. OpenStax has published 17 titles to date, including Chemistry, College Physics, and Precalculus.

Calculus, an upcoming text by OpenStax, is suitable for most calculus courses whether an instructor uses an early or late transcendental approach. More than twenty mathematicians worked as authors and reviewers to create this textbook over a two-year period. As a calculus instructor and the book's content lead, I will describe the textbook and its features (including reader "checkpoints" and a variety of student projects) and ways an instructor can customize the book to suit their own course needs. Additionally, I will give reviewer feedback regarding key chapters from the book so that instructors can better decide if it suits the needs of their school's calculus sequence. (Received September 22, 2015)

1116-E1-2636 **Stephen Wang*** (sswang@rice.edu), Department of Mathematics MS-136, Rice University, Houston, TX 77005. *Doubly Active Learning: Flipping Calculus using the edX Platform.* Preliminary report.

The author will present a preliminary report on the results of an experimental Fall 2015 section of Calculus I at Rice University. Before each class, students were provided with an online learning sequence on a server running the edX platform consisting of a series of questions, text blocks, and short videos. These sequences required students to actively participate in the discovery of new material; students would review previously learned ideas, draw on real-world intuition, and make logical deductions in order to make connections to the new topic. In-class activities then allowed them to discuss the material in groups, apply it to problems, and explore deeper aspects of calculus. (Received September 22, 2015)

1116-E1-2650 **Mary R Parker*** (mparker@austincc.edu) and **Hunter Ellinger** (hunter@ellinger.org). *Lessons from a teacher-developer collaboration on a set of open-source educational web apps.* Preliminary report.

Differences in perspective between teachers and developers can impede efforts to make full use of the expanded opportunities for free instructional apps, even when both parties have a deep understanding of the mathematics involved. A mathematics professor and a software developer, each with decades of experience in their respective fields, report on how they overcame these difficulties when developing a set of open-source web apps. These specific apps enhance statistics instruction, but the lessons learned apply broadly to the development of educational apps. http://visualize.tlok.org/ (Received September 22, 2015)

Experiences and Innovations in Teaching Probability Theory

1116-E5-24 **Jeremiah D Bartz*** (jbartz@fmarion.edu), Francis Marion University, Department of Mathematics, PO Box 100547, Florence, SC 29502. *Using dice games to teach probability.* Preliminary report.

Learning probability theory is often challenging for non-math majors. In this talk, we examine how using dice games such as Farkle as classroom activities engages students and facilitates learning probability concepts. Classroom experiences will be discussed. (Received May 31, 2015)

1116-E5-47 **Paul R. Bouthellier*** (pbouthe@pitt.edu), 504 East Main Street, University of Pittsburgh-Titusville, Titusville, PA 16354. *Statistical Simulations of Lottery Tickets.*

In our statistics classes we can illustrate some of the basic rules of probability by deriving the chances of winning various amounts on a given lottery ticket. These probabilities are then used to derive the expected value of the ticket. However, it is far more interesting to allow students to design their own lottery tickets. The students have to decide what is considered winning, calculate the probabilities of winning and how much the prizes should be to make sure the lottery ticket will return a certain percent profit to the state with a probability of near 1. Simulations then need to be run to estimate the mean and standard deviation of such tickets given a finite number, say 10,000, are sold a week in order to show the tickets perform as expected. Such simulations need to be run a large number of times to ensure consistent results. Java programs and interactive web pages will be used to simulate our results with a lottery ticket called "Poker Kings" which simulates a scratch-off ticket. A person selects 5 out of 52 possible "cards" and wins a given amount if they get certain poker hands. Allowing students to design their own lottery tickets (and games) gives students an unlimited number of possible, and practical, real-world examples. (Received June 22, 2015)

1116-E5-100 **Gerardo Emmanuele Serrano*** (geprcm688@gmail.com), Street 144, Bo. Coabey, Jayuya, Puerto Rico, Jayuya, PR 00664. *Improving the pyrenees probability tutor to enable comparison of pedagogical interventions.*

The Pyrenees Tutor is an interactive intelligent software tutor for students to solve math probability problems, and the researchers are testing the impact of different tutor pedagogies on learning. The five different pedagogical conditions are: Worked Example, Worked Example/Problem Solving, Faded Worked Example, Problem Solving and All. Pyrenees has four different parts. First it has a textbook on the basics of solving probability problems, then a pre-test to get data about how much each student knows, then an interactive part where the conditions differ as above, and finally a post-test. The system was deployed in a discrete math course in Spring 2015, but there were several bugs in the system that prevented students from completing all four parts. The purpose of this research project is to improve the usability of the tutor by testing and documenting all conditions of the tutor using the "Github" Pyrenees project repository for bug reports and issue tracking. The bugs can include trivial things like a missing word, or an incorrectly-spelled word, or it can be something more important like logic errors. Once these bugs are repaired, future researchers on the project will be able to investigate the impact of the different pedagogies on changes between the pre and post test. (Received July 22, 2015)

1116-E5-992 **Ryan Gantner*** (rgantner@sjfc.edu). *Probability projects with multiple motives.*

At many institutions, the size of the student population limits the diversity of course offerings. For such institutions, one often finds that each course must contribute to multiple programmatic learning goals. In this presentation, we'll describe a course which has the three-pronged charge of enhancing theoretical understanding and computational fluency in probability, establishing a foundation in computer programming, and instilling broad reaching paradigms for mathematical modeling. Because the college does not send many students to graduate schools upon graduation, particular attention is paid to aspects that are desirable to their future employers. In an attempt to bring together all of these facets of the course, a collection of projects were developed. Here, we'll examine one of these projects in detail to see how well it allows the students to achieve the various goals of the course. (Received September 15, 2015)

1116-E5-1370 **Edward Early*** (edwarde@stedwards.edu), 3001 S Congress Ave, Austin, TX 78704. *Guessing your way through a probability test.*

The final exam for a probability class consists only of four true-false problems. Unfortunately, the questions are completely illegible. What do you do? Does it help if you know how many of the answers are supposed to be true? Does it make a difference what grade you have going into the exam? This one scenario provides a surprising number of examples for an introductory probability class. (Received September 19, 2015)

1116-E5-1510 **Joe P. Chen*** (joe.p.chen@uconn.edu), Department of Mathematics, University of Connecticut, Storrs, CT 06269, and **Thomas W. Roby** (tom.roby@uconn.edu), Department of Mathematics, University of Connecticut, Storrs, CT 06269. *Using cultural references and flipped classrooms in teaching undergraduate probability.*

Undergraduate probability has become an increasingly popular course at UConn, with hundreds of students majoring in math, actuarial science, other sciences, and engineering, taking the course every semester. To offer students an experience that is both fun and rigorous, we 1) highlight connections to engaging real-life examples, and 2) focus much classroom instructional time on problem solving.

In this talk we will present our progress on these two fronts.

On point 1, the first author has been creating novel homework and exam problems for probability students over the past two years. Certain difficult-to-understand topics can be explained using accessible, low-tech methods: for example, the (compound) Poisson process as a drinking game; illustrating marginal and conditional distributions using Play-Doh and a plastic knife; or the use of the central limit theorem in UConn basketball.

On point 2, both authors have begun to implement flipped classrooms in our probability classes since Fall 2015. We will present sample video lectures using the recently-developed technology of Lightboard, and explain how the use of video lectures affects the types of activities done in class. Students' feedback has been crucial in our continued fine-tuning of the flipped classroom experience. (Received September 20, 2015)

1116-E5-2511 **Mark Daniel Ward*** (mdw@purdue.edu), Mark Daniel Ward, Department of Statistics, Purdue University, West Lafayette, IN 47905. *Probability in an Active Learning Environment.*

The speaker will discuss his experiences teaching probability theory to undergraduate students in an active learning environment. Half of the students in his courses are also in a living learning community that blends the academic, research, residential, and professional development aspects of the college experience. The speaker will share his materials from this experience, including notes, videos, practice problems, assignments, etc. A key goal is to enable colleagues to start their own active learning environments in probability. (Received September 22, 2015)

1116-E5-2512 **Jonathon Peterson*** (peterson@purdue.edu), 150 N University St, West Lafayette, IN 47907. *Developing an undergraduate stochastic processes course.*

Undergraduate students often learn the basics of probability theory, including the central limit theorem and the law of large numbers, in a one semester probability course. However, these courses often do not have time to cover in depth many stochastic processes which are extremely useful in probabilistic modeling. A natural addition to the undergraduate math curriculum is a second course in probability covering Markov chains and Poisson processes. This talk will report on lessons learned in offering such a course for the first time to undergraduates at Purdue University. (Received September 22, 2015)

1116-E5-2625 **Matt Roscoe*** (matt.roscoe@umontana.edu) and **David Patterson** (dapatterson@mso.umt.edu). *Using R Simulation to Encourage Creativity in an Introductory Probability Course.*

Mathematicians commonly engage in processes that can be described as creative and investigative. Unfortunately, many students do not experience mathematics as such in their coursework. In this session we will describe how instruction in R, a freeware statistical platform, has supported mathematical learning in an introductory probability course by creating opportunities for conventional and non-conventional student activity. Students employ R simulations in the course in conventional ways: using R to verify, estimate and generate probability solutions where analytical methods sometimes fail. Students also employ R simulations in the course in non-conventional ways: investigating probabilistic settings, creating and analyzing probabilistic scenarios, and front-loading analytical methodology with target probabilities. Web resources and examples of student work will be shared. A cost-benefit analysis of instruction in R will also be addressed. (Received September 22, 2015)

1116-E5-2738 **David P Ely*** (ely.65@osu.edu). *A Study in Using Computer Programming to Simulate Classic Probability Problems.* Preliminary report.

Teaching traditional probability theory results in most students unable to apply the theory to classic probability problems with any confidence. So was the conclusion of a study conducted in 2015 at a large Pacific Northwest university. After completing a term on introductory probability theory using Minitab, secondary mathematics teachers struggled to solve classic probability problems. Yet, when presented with a second term showing ways to simulate probabilities and verify models using computer programming, the teachers excelled. Simulation packages inside of software such as Minitab, Tinkerplots and calculators are limited; yet, teachers programming their own simulations in C were not. This new "as-needed" pedagogy on blending introductory computer programming with introductory probability theory was found to be highly effective. (Received September 22, 2015)

1116-E5-2764 **Jesse W Johnson*** (jwjohnson@westfield.ma.edu), Westfield State University, Department of Mathematics, 577 Western Ave., Westfield, MA 01086. *Teaching to the Actuarial Exams: One of the Few Times Teaching to an Exam is Okay.* Preliminary report.

I will share my experiences in the creation and teaching of two courses at my home institution that cover the material on the actuarial exams Probability P/1 and Financial Mathematics FM/2. By continually putting the students in an exam-like setting, these courses serve a dual purpose of teaching the material and building problem-solving skills. The results have been overwhelmingly positive. I will focus of the strengths and the drawbacks of this style of teaching, and I will share some of the personal successes of some of our students. (Received September 22, 2015)

Graduate Students Teach Too: Ideas and Best Practices

1116-F1-59 **Robert Lee Nichols*** (rnichols@fgcu.edu), 10501 FGCU Boulevard South, Fort Myers, FL 33965-6565. *Training and Evaluation of Graduate Teaching Assistants: Role of a Faculty Assistant Coordinator.* Preliminary report.

The department grew to a point where it needed to re-evaluate the current structure of the coordination of the Undergraduate Instructional Assistants (UIA), Graduate Instructional Assistants (GIA), and Graduate Teaching Assistants (GTA). The scope of responsibilities of the Faculty Assistant Coordinator (FAC) include: scheduling Instructional Assistants, working with the Graduate Faculty Coordinator to hire and manage new GTAs, creating payroll information for the payroll specialist and maintaining all records, acting as a mentor for GTAs, training all GTAs, conducting training sessions in pedagogy and instructional technology, coordinating the assignment of faculty mentors and facilitate teaching cells among GTAs for peer review of teaching, and coordinating the review and evaluation of GTAs with the Graduate Faculty Coordinator. Through the development of the position of FAC a more streamlined process was achieved. The supervision and development of UIAs, GIAs, and GTAs by a FAC improved the level of instruction in many of the fundamental courses of mathematics given to undergraduate students through the department. (Received July 08, 2015)

1116-F1-172 **Mary E Pilgrim*** (pilgrim@math.colostate.edu) and **Jessica Gehrtz** (gehrtz@math.colostate.edu). *Training Graduate Teaching Assistants to Use Evidence-Based Practices.*

Evidence-based research in education supports the use of classroom methods that encourage student engagement in learning. Regrettably, mathematics courses are often taught in traditional, non-engaging, teacher-centered ways. At our institution GTAs serve as the primary instructor of foundational mathematics courses, such as Calculus. However, GTAs often receive little to no training in the use of evidence-based pedagogy and creation of an active classroom. Literature points out that teachers often teach in a style that is reflective of their own learning experiences, so when the learning experiences of a GTA do not reflect best practices it cannot be expected that they will have the capability to implement such strategies in an effective and meaningful way.

To address this problem, we have designed a model that incorporates evidence-based practices into (1) a pre-fall semester training workshop and (2) ongoing semester training activities. The framework of our model incorporates best practices outlined in Mathematics Education literature while balancing the time constraints that GTAs often have. We will describe our training model as well as the fall 2015 pilot with Calculus I GTAs. We will also discuss revisions, modifications for other courses, and future implementations. (Received August 11, 2015)

1116-F1-392 **Tracy Weyand*** (tracy_weyand@baylor.edu). *A GREAT Idea.*

I began the GREAT (Graduate students Reaching for Excellence in Academics and Teaching) Program at Texas A&M University in 2012 (when I was a graduate student there) to provide other GTAs with relevant information and resources in a time efficient manner. It was the first GTA training program the mathematics department ever had. The material came directly from GTAs' questions, complaints, and suggestions. One goal of the GREAT Program was to provide information, instructions, and assistance regarding the technical details of teaching with the hope that the GTAs would then have more time to focus on teaching itself. This assumption was proved correct: When they had more time and knew help would be available, the GTAs became more concerned about student learning and trying different teaching styles. They also became more interested in teaching their own class; this number has increased by 300% since 2011. I will describe the initial program, the course this program has evolved into, and the positive effects it has had on the entire department. (Received August 30, 2015)

1116-F1-922 **Daniel J Katz*** (dkatz@math.brown.edu). *Teacher Training Revamped: Formalizing the Informal.*

At Brown University, graduate students in mathematics participate in a departmental training program the semester before they begin as teaching assistants. Having this system is extremely useful for readying instructors before they enter the classroom, but it has been run in many ways over the past decade, ranging from a two-semester-long program to an attempt to orient students in four meetings.

In 2013, I inherited the program and attempted to strengthen and formalize it, with goals of increasing student engagement and achieving consistency from year to year. In this talk, I'll summarize what we currently do in our program, some pros and cons of our approach, and how we dealt with the challenge of training one incoming class that was triple the size from previous years. (Received September 15, 2015)

1116-F1-1000 **Rachel Grotheer***, Department of Mathematical Sciences, O-110 Martin Hall, Box 340975, Clemson, SC 29634. *Inviting the Nations In: Aiding International Graduate Instructors at Clemson.*

The teaching of undergraduates by graduate students is an essential component of the mathematics graduate program at many universities. As a result, many universities require international graduate students to demonstrate proficiency in spoken English in order to maintain their assistantships and teach. At Clemson, we have recognized that this requirement existed without any support from the university to enable the students to meet it. At the request of the department's graduate chair, we have developed a class to aid international graduate students in developing their spoken English skills, as well as their awareness of cultural norms and differences in an American classroom, to help them succeed not only as graduate teaching assistants, but in all aspects of their professional and personal life in the United States. In this talk we will give an overview of the program, its early success, and the importance of and challenges in encouraging, supporting and welcoming students from all nations into a graduate mathematics program. (Received September 15, 2015)

1116-F1-1195 **Timmy Ma*** (timmym@math.uci.edu), Department of Mathematics, University of California, Irvine, Irvine, CA 92697. *Curriculum development for the California Alliance for Minority Participation Summer Science Academy.*

At the University of California at Irvine, the California Alliance for Minority Participation offers an intensive three week summer program where incoming freshmen transition from high school to college academics. In this talk, we give an overview of the program and my role in fostering a safe and healthy learning environment, as well as developing and implementing a unique curriculum to enhance their academic preparation and promote critical thinking. (Received September 17, 2015)

1116-F1-1492 **Mary Beisiegel*** (mary.beisiegel@oregonstate.edu), 368 Kidder Hall, Department of Mathematics, Oregon State University, Corvallis, OR 97331, **Emerald Stacey**, 368 Kidder Hall, Department of Mathematics, Oregon State University, Corvallis, OR 97331, and **Jesse Andrews**, 368 Kidder Hall, Department of Mathematics, Oregon State University, Corvallis, OR 97331. *Aligning Mathematics GTA Training with Research Findings.*

Based on recent research findings, the teaching assistant training program was significantly revised to include features of the best teaching assistant training programs. New aspects incorporated into the training program were: (1) significant time working on major mathematical ideas from lower-division courses for which the new graduate students would be teaching assistants (GTAs), (2) modeling active engagement, and (3) making explicit pedagogical moves that support learners in active engagement settings. The goals of these three aspects were to increase teaching assistants' pedagogical content knowledge and specialized content knowledge. Other aspects incorporated into the revised training were contextual, such as providing new teaching assistants with information about the department and its courses, as well making the communication with instructors more explicit and supportive of the new GTAs. Additionally, a new process for evaluating the new GTAs' initial teaching demonstrations was implemented. Each of these new aspects will be explained, and survey data from the previous and newest cohorts of mathematics GTAs will be presented. (Received September 20, 2015)

1116-F1-1545 **RaKissa Manzanares*** (rakissa.cribari@ucdenver.edu) and **Gary Olson** (gary.olson@ucdenver.edu). *Utilizing a Teaching Symposium as a First Step in GTA Teacher Preparation.* Preliminary report.

This talk will focus on the implementation of a full day teaching symposium for graduate teaching assistants (GTAs) designed to introduce new GTAs to pedagogical practices and classroom culture through a modeling approach. We will address both what worked and what needs improvement. Additionally, we will discuss other sessions offered during the symposium and how they support GTAs in their first year of teaching. (Received September 20, 2015)

1116-F1-2030 **Nathan Wakefield*** (nathan.wakefield@unl.edu), 203 Avery Hall PO BOX 880130, Lincoln, NE 68588, and **Allan Donsig** (adonsig@unl.edu), 203 Avery Hall PO BOX 880130, Lincoln, NE 68588. *Instructional Supports for Graduate Teaching Assistant at the University of Nebraska-Lincoln.*

Graduate teaching assistants are a valuable asset and represent the department to a large portion of the community. At the University of Nebraska-Lincoln GTAs are responsible for 70 sections a year. In our program, we have built a package of instructional supports that allow GTAs to develop high quality teaching skills with a focus on student interaction, collaborative teaching, and a broad understanding of the mathematics education literature. GTAs learn evidence based effective teaching methods. We train GTAs as apprentices who will graduate prepared to begin a career as a professional informed teacher of College-level mathematics. Our efforts have not been in vain. Utilizing well-trained GTAs and other course reform efforts, we have cut the DFW rates in half. In this talk, we will discuss some of the specifics of our GTA training package. (Received September 21, 2015)

1116-F1-2352 **Jess Ellis*** (jess.ellis84@gmail.com), **Natasha Speer** (natasha.speer@maine.edu) and **Jack Bookman** (bookman@math.duke.edu). *Preparing our future colleagues: A report on the national landscape of graduate student instructor professional development programs.* Preliminary report.

The MAA project, Characteristics of Successful Programs in College Calculus (CSPCC), identified seven features of more successful calculus programs across the country. One such feature was robust graduate teaching assistant professional development (GTA PD). In this report, we briefly describe two MAA led projects that extend and build on CSPCC findings: one builds on the CSPCC project by supporting institutions to implement these successful characteristics, and the other provides instructional resources for GTA PD to help start new programs and improve existing programs. We then describe results of a national survey of PhD and Masters degree granting mathematics departments. Of the 226 participating institutions, 149 reported that their department currently has a GTA PD program. Results indicate that there is considerable variation in the teaching preparation offered to mathematics graduate students, there are over fifty institutions seeking improvements to their GTA PD programs, and their needs are in line with the change strategies that the MAA projects are employing. Specifically, many institutions are interested in opportunities for faculty to learn more about GTA PD and to have conversations with colleagues at similar institutions. (Received September 22, 2015)

1116-F1-2390 **Emily Laura Braley*** (braley@math.duke.edu), Mathematics Department, Duke University, Box 90320, Durham, NC 27708-0320. *A framework for a graduate student teacher mentoring program.*

In the Mathematics Department at Duke University, preparation of graduate student teachers is considered an ongoing process that starts when a first year graduate student arrives and ends when a graduate student leaves Duke to pursue their career. Graduate students begin their involvement in the program before the start of their first semester at Duke by attending meetings in a teacher-training week. First year graduate students attend a teacher-training course in their first semester, observe classes, practice teaching, and work as TA's. Once graduate students are ready to teach their own classes, they work closely with a course coordinator who provides guidance, feedback, and direction throughout the graduate student's first teaching experience. I will discuss the structure of the teacher training program at Duke and how it continues to provide guidance and feedback after a graduate student's first year. (Received September 22, 2015)

1116-F1-2426 **Carrie Diaz Eaton** and **Ashley Rand*** (ashley.rand@blc.edu), 700 Luther Dr., Mankato, MN 56001, and **Eleanor Abernethy**. *Graduate Student-Driven Development and Delivery of a GTA Training and Mentoring Program.*

Not all graduates of PhD programs at research institutions go on to full-time positions at research institutions. The reality is that graduate students want and need to be prepared for teaching in their academic lives, both during graduate school and in their future careers. This talk chronicles the evolution of a GTA teaching training program at an R1 department co-developed and co-taught by senior graduate students. This program was modeled after the initiative "Preparing Future Faculty" and uses "Learning to Teach and Teaching to Learn Mathematics" by Matt Delong as a major resource. The program is designed to meet the needs of novice teachers with little education background, but sufficient content background, and encourages self-reflection and exploration of one's teaching. It also allows for further exploration after the initial semester. The integrated mentoring program creates connections between successful graduate students and new graduate students, primarily in teaching, but also research. It also supports these mentors in further exploring one's own strengths and weaknesses as a teacher and exploring new ideas as well as service to the professional community. (Received September 22, 2015)

1116-F1-2637 **Meredith Burr*** (burr3@clemson.edu). *Graduate Student Teacher Training and Support at Clemson.*

The Department of Mathematical Sciences at Clemson University has recently begun a teacher training course for its graduate students. Additionally, student are assigned teaching mentors who observe them and provide feedback during their first semester teaching. I will discuss our previous and current efforts in providing training and support, as well as the expectations and outcomes so far of the current TA professional development course. (Received September 22, 2015)

Helping Students See Beyond Calculus

1116-F5-191 **Deane E. Arganbright*** (argandeane@yahoo.com), 129 Gene Adams Road, Martin, TN 38237. *Find Trig Boring? Look Anew!*

We extend the traditional, and too frequently uninspiring, applications of standard trigonometry classes by the use of the interactive and animated graphics of Excel coupled with an extensive range of creative non-traditional applications. These applications illustrate the use of trigonometry in unexpected areas of future university study beside and beyond calculus. Our models can be presented in an interesting and intriguing manner – and created by students – at both the secondary and undergraduate levels. This talk provides illustrations of trigonometry in a wide range of disciplines, including mathematics (geometry, topology, linear algebra, modeling), art (Celtic curves, quilt patterns), computer graphics (animation, morphing), social sciences (human cultures), education (alphabet and counting books), and the sciences (electronics). We have used this approach in both advanced and developing nations, and we provide files for those interested. (Received August 12, 2015)

1116-F5-794 **Tanweer Shapla*** (tshapla@emich.edu), Mathematics Department, Eastern Michigan University, Ypsilanti, MI 48197. *Model Assessment Practice: See Beyond Calculus.*

Fitting models or functions to real data are common practice in a calculus class. It is with no doubt that the real data are not naive enough to follow a model deterministically. Therefore, the optimization rule of calculus comes handy in minimizing the error of the resultant model. However, in deciding the right model out of the other alternative models, the assessment of the adequacy of the resultant model is necessary. Unfortunately, the criteria of the model adequacy is often being ignored in calculus class, and thus the modeling is done superficially. In this presentation, we address several criteria of model adequacy, along with their applications in real data setting. (Received September 13, 2015)

1116-F5-1179 **Lisa M Rezac*** (lmrezac@stthomas.edu), OSS 201 University of St Thomas, 2115 Summit Avenue, St. Paul, MN 55105-1079. *Successful Activities used in Outreach and STEM Programs.* Preliminary report.

We will discuss the topics and resources we've used successfully in outreach and STEM programs to help students see beyond calculus. These programs include summer math camps for mathematically talented high school girls, seminars for elementary education majors with specialties in STEM, math content courses for high school teachers and outreach programs in the community. Specifically, we have used projects in coding, cryptography, geometry, discrete mathematics and integrated STEM. Our goal will be to provide our review of a list of resources that provide high quality active learning sessions focused on mathematics and mathematics in STEM disciplines in varied education and enrichment settings. (Received September 17, 2015)

1116-F5-1272 **Neil P. Sigmon*** (npsigmon@radford.edu), Department of Mathematics and Statistics, P.O. Box 6942, Radford University, Radford, VA 24073, and **Rick E. Klima** (klimare@appstate.edu), Department of Mathematical Sciences, Appalachian State University, Boone, NC 28608. *Increasing Student Interest in Mathematics using Cryptography.*

With society becoming more reliant on digital and computing technology, the ability to transfer information in a secure and confidential fashion using cryptography, the science of secret message writing, has increased dramatically in importance. Cryptography is used in everyday life, including Internet applications, banking, and in the military.

Cryptography can be taught at a variety of levels, including to students from non-technical fields. To understand many algorithms in cryptography, including some modern methods, a student only needs to recall concepts such as division, prime numbers, and basic algebra. In addition, cryptography provides an excellent mechanism for increasing student interest in exploring and studying more advanced topics in mathematics. Application mathematical topics used in cryptography include linear algebra, abstract algebra, number theory, probability, and statistics.

The purpose of this presentation is to demonstrate how cryptography can be integrated into courses for early college-level students and high schools. As a model, a course in cryptography that has been taught for Radford University's Honors Academy and at the Southwest Virginia Governor's School for high school students will be described. (Received September 18, 2015)

1116-F5-1603 **Susan L Schmoyer*** (sschmoyer@worcester.edu), 486 Chandler St, Worcester, MA 01602. *Secret sharing in College Algebra and Precalculus.* Preliminary report.

Lots of action movies have a scene in which there is a secret (like the code to launch a nuclear missile), but two or more people need to work together to unlock the secret. In this talk I will demonstrate the mathematical version of secret sharing using a classroom activity based on topics from college algebra and precalculus. This application provides a glimpse into more advanced topics such as linear algebra and cryptography. (Received September 20, 2015)

1116-F5-1964 **Maria Nogin*** (mnogin@csufresno.edu), Department of Mathematics, 5245 North Backer Avenue M/S PB 108, CSU Fresno, Fresno, CA 93740. *It is not a coincidence! On patterns in some Calculus optimization problems.*

Have you ever noticed that some families of optimization problems always have results (optimal dimensions) that follow an interesting (and sometimes quite unexpected) pattern? For example, the diameter of an optimal cylindrical can (one with the greatest possible volume given the surface area or, equivalently, one with the smallest possible surface area given the volume) is equal to its height. In this talk we show that this and some other patterns in optimization problems are not a coincidence, and, in fact, in many problems the optimal shape could be determined without any calculations. To show this we use symmetry, similarity, and other concepts and relationships that excite students more than a calculus-based computation. As an added bonus, our ideas allow us to have answers (optimal dimensions) to many new related problems, all at once, without any new computations. (Received September 21, 2015)

1116-F5-2026 **Violeta Vasilevska*** (violeta.vasilevska@uvu.edu), 800 W. University Parkway, Orem, UT 84058. *Math in action: solving crimes.* Preliminary report.

This presentation will demonstrate several applications of mathematics in forensic science. In particular, two projects will be presented: an application of Newton's Law of Cooling in estimating time of death and an application of graph theory in Fingerprint analysis. These projects were used during the Math Forensic Conference for high school students last summer, where they were very well received, but they can easily be adopted for use in college math classes as well. Additional math applications will also be mentioned such as applications in animation, mechanical engineering, origami and art. The presenter has been using these examples as short presentations in her Calculus class to excite the students with interesting applications that catch student attention and show them the usefulness of math and the value of having good math skills. (Received September 21, 2015)

1116-F5-2132 **Rebekah B. Johnson Yates*** (rebekah.yates@houghton.edu), 1 Willard Ave, Houghton, NY 14744. *On Beyond Calculus.*

Each February, 80 or so high school students descend on our small campus in western New York to take the American Math Contest and participate in several sessions designed to inspire them in math or science. Our department's goal is always to show them that there is more to math than the march to calculus. We have offered sessions on a variety of topics from voting to game theory to spherical geometry. In this talk, I will share some of the materials I've used to introduce high school students to infinity and to graph theory. (Received September 21, 2015)

1116-F5-2135 **James Kupetz*** (james.kupetz@gmail.com), Pittston Area High School, Pittston, PA 18640, and **Steve Leonhardi** (sleonhardi@winona.edu), Winona State University, Winona, MN 55987. *Squirrels, Electric Cars, and Hurricanes: DIMACS Applied Math Modules to Blow Away Your High School Students.*

We describe three NSF-funded collections of educational modules: BioMath Connection (BMC), The Value of Computational Thinking Across Grade Levels 9-12 (VCTAL), and Planning for a Sustainable Future (PS-Future). Each module is designed to provide anywhere from one 30 minute "teaser" mini-module up to 4 to 6 class periods of hands-on high school classroom activities that engage students in using mathematics, computational thinking, and technology to explore a variety of topics such as: Habitat Selection, Medical Imaging, Disease Transmission, Solar and Electric Power, the NFL Draft, Internet Privacy, and Sustainable Use of Water. Both a Student Version of self-contained text with problem material and a Teacher Guide are included. The modules allow flexible adaptation for use in a variety of courses (including math, science, and even social science courses) at a variety of grade levels (9-12). Sponsorship comes from the Center for Discrete Mathematics and Theoretical Computer Science (DIMACS), the Consortium for Mathematics and Its Applications (COMAP), Colorado State University, and the National Science Foundation. (Received September 21, 2015)

1116-F5-2145 **Robert Cohen*** (rcohen@western.edu), 600 N. Adams St., Gunnison, CO 81231.
Interactive Fractal Design.

Fractal design can provide exciting motivation to explore geometric transformations and matrix techniques. We have developed an interactive Mathematica presentation that guides students through a creative, mathematical process leading to the design of fractals. This material has been well-received by a variety of students including middle school math campers and non-math major college freshmen. Students were invited to interactively explore parameter space with Mathematica notebooks and many have been inspired to create their own fractals. This presentation has provided an enticing introduction to mathematical topics most young students have never seen while demonstrating an impressive variety of fractal images created from simple mathematical ideas. At this talk, the presentation will be outlined and all materials will be made available to interested instructors. (Received September 21, 2015)

1116-F5-2229 **Chad Awtrey*** (cawtrey@elon.edu) and **Taylor Cesarski**. *Symmetries of polynomial roots.*

Many high school math students are familiar with the quadratic formula. Some may also know there are similar formulas for expressing the roots of cubic and quartic polynomials. But it is unlikely that very many know such formulas do not exist for quintic and higher degree polynomials. Why do no such formulas exist in these cases? This question and its resolution have a fascinating history, culminating in the work of mathematician Evariste Galois. This talk introduces Galois' work to high school math students through a variety of materials that allow students to visualize and compute "symmetries" of polynomial roots. Created by the speaker and one of his undergraduate research students, activities introduce students to relevant history and allow them to discover how roots of polynomials can be permuted to form a group structure. Quadratic and cubic polynomials are the main focus, and only a facility with function composition is required. (Received September 22, 2015)

1116-F5-2301 **Robin Angotti*** (riderr@uw.edu), School of STEM, Campus Box 358538, 18115 Campus Way NE, Bothell, WA 98011. *Math in the 21st Century: Making Sense of Dynamic Visualizations.*

Graphing is a fundamental mathematics topic that all students are exposed to in K-16 education. In order to participate in a quantitatively literate society that uses graphical displays to synthesize information in the popular press as well as to be successful in most careers, students must be able to both create and interpret graphical displays of mathematical equations and data. In a typical math classroom, students use static displays and textbook data. However, with the emergence of dynamic data displays used by every major online newspaper and blog, how is the educational system helping students interpret these new displays of quantitative information so that educated students can make sense of them? This talk will share a classroom activity that has been used from middle grades through college mathematics courses in which students must extract data and useful information from a readily available, 5-dimensional, dynamic graphical display and use that information to tell a concise, coherent story displayed on static 2-D paper. This activity has shown that students at all levels have difficulty in both interpreting the data in ways that make sense and in transferring the data from a dynamic graphical display to a two-dimensional static paper in a coherent way. (Received September 22, 2015)

1116-F5-2336 **Laura M Singletary*** (lsingletary@leeuniversity.edu) and **Debra L Mimbs**.
Developing Young Mathematicians: An Undergraduate and Secondary Collaboration.

In this interactive session, Drs. Singletary and Mimbs will present the details of a mentorship program funded by the MAA's Dolciani Mathematics Enrichment Grant. The purpose of this program is twofold: to nurture an interest in mathematics in secondary students and to develop undergraduate mathematics majors as researchers and mentors. In this mentorship program, professors guide undergraduate students who in turn guide secondary students through a sequence of novel problems beyond Calculus I and into mathematical research. This process seeks to develop an appreciation for mathematics among secondary students by creating a deeper understanding of the major concepts learned in high school, constructing a knowledge base for secondary students that includes interesting topics not typically covered in the school mathematics curriculum, and producing college graduates who have served the mathematical community and have developed a love for such service. (Received September 22, 2015)

1116-F5-2525 **Daniel J Teague*** (teague@ncssm.edu), NCSSM, 1219 Broad Street, Durham, NC 27705.
Agent Based Models in the Social and Biological Sciences.

Many students who are quite good in mathematics leave the subject early because they see no reason to continue. They often do not view themselves as future engineers or physicists, and what other reason is there to continue in mathematics? Many have deep interests in the social and biological sciences which have historically be a-mathemaical. Mathematical modeling change can correct these misunderstandings. Agent based models, in particular, have an extraordinary ability to capture student interest in mathematics and to illustrate the importance of continuing in mathematics regardless of their career interests. In this presentation, we highlight the Schelling Segregation Model and demonstrate some models created by advanced high school students. (Received September 22, 2015)

1116-F5-2543 **Mike Pinter***, Dept of Mathematics and Computer Science, Nashville, TN 37212. *Hats, Hamming and Hypercubes.*

Bernstein (2001) describes a "hat game" that has a direct connection to Hamming Codes. In this presentation, I will describe some potential uses for the Hat Game. In particular, the Hat Game can be used freestanding from any other mathematics topics - for example, as a game of strategy and critical thinking in a first-year seminar course or as a fun activity for a high school or college mathematics student organization. On the other hand, the Hat Game can be used in connection with truth tables and symbolic logic. If desired, the connection between the Hat Game and the single-error correcting Hamming Code (Roman, 1998) can be made - requiring only some basic ideas about matrices and binary numbers. An interesting geometric interpretation of the Hat Game via hybercubes is also an option, with little additional mathematics required. After providing specifics of the Hat Game and its connections to Hamming Codes and Hypercubes, I will briefly describe my experience using it in different settings.

References Bernstein, Mira, "The Hat Problem and Hamming Codes", Focus: The Newsletter of the Mathematical Association of America, November 2001, pp. 4-6. Roman, Steven. Codes and Coding, Third Edition, Modules in Mathematics. Innovative Textbooks, Irvine, CA, 1998. (Received September 22, 2015)

Incorporating the History of Mathematics into Developmental Math Courses

1116-G1-77 **Amy Shell-Gellasch*** (`amy.shell-gellasch@montgomerycollege.edu`). *Physical models of the binomial expansion and completing the square.*

Expanding the quadratic and completing the square are core concepts in algebra and used throughout algebra and subsequent courses. A physical representation of both the quadratic and cubic binomial helps students visualize the expansion as well as understand the separate terms. The same models can help visualize completing the square. In fact, by examining the ancient Babylonian process for completing the square, the steps involved, and the name itself, become perfectly clear. (Received July 14, 2015)

1116-G1-81 **Ronald L Merritt*** (`ronald.merritt@athens.edu`), Athens State University, Dept. of Mathematical, Computer and Nat. Sci., 300 North Beaty Street, Athens, AL 35611. *A comparison of the mathematics problems solved by eighteenth century United States Presidents with the problems solved by students in developmental mathematics courses in the twenty-first century.*

While enrolled in mathematics instruction at the University of North Carolina during the early eighteenth century, President James K. Polk studied algebra and geometry primarily from Hutton's Mathematics. During the mid-nineteenth century, President James A. Garfield elected to study algebra, geometry, trigonometry, measurement and Calculus from textbooks authored by Elias Loomis. How do the mathematics problems from these mathematics textbooks likely solved by these two Unites States Presidents compare with the problems solved by students enrolled in developmental mathematics courses in the twenty-first century? (Received July 15, 2015)

1116-G1-92 **Cynthia J. Huffman*** (`cjhuffman@pittstate.edu`), Math Dept, Pittsburg State University, 1701 S. Broadway, Pittsburg, KS 66762. *The Great Art: Cardano's "Ars Magna" in College Algebra and Precalculus.* Preliminary report.

When Cardano's *Ars Magna* was published in 1545, it contained what were at that time the state of the art rules for solving polynomial equations of degrees 2, 3, and 4 (quadratic, cubic, and quartic equations). At first glance, these rules seem to look different from methods used today. For example, current students are taught a single quadratic formula for solving any quadratic equation, while Cardano considered three cases of quadratic equations with a separate rule for solving each case. We will discuss some activities that can be incorporated in college algebra and precalculus courses based on material found in the *Ars Magna* which may motivate students for a deeper understanding and greater appreciation of solving polynomial equations. (Received July 21, 2015)

1116-G1-167 **A S ELKHADER*** (a.elkhader@northern.edu), Dept. of Sciences and Mathematics, Northern State University, 1200 South Jay Street, Aberdeen, SD 57401. *Activities on using history of mathematics in a standard college algebra course.*

This work will focus on how incorporating the history of mathematics into solving some standard college algebra problems has led to a deeper understanding and appreciation of mathematics as expressed by students and course outcomes. In particular, students are asked to solve standard problems without any use of symbolic notation. With an anticipated complexity and difficulty, an introduction of symbolic notation would lead to efficiency and elegance in expressing solutions. Students then are asked to use Internet and library searches to investigate the origin and historical evolvement and development of each notation used. Special attention is given to the historical development of mathematical notations used in solving exponential and logarithmic problems, complex numbers, matrices and determinants, and notations used in solving probability and statistics problems. Additionally, attention is paid to the historical use of technology in solving such problems. Course assessment is based on writing components, group work and classroom presentation (Received August 11, 2015)

1116-G1-431 **John B Thoo*** (jthoo@yccd.edu), Yuba College, 2088 N Beale Rd, Marysville, CA 95901. *Experiences in Using HOM in Community College Prealgebra and Algebra Courses.*

Middle school prealgebra and high school algebra are bread-and-butter courses at (two-year) community colleges. Many community colleges even offer arithmetic courses that teach whole-number arithmetic. Many students have some recollection of the topics and skills that are taught in these courses, which makes keeping their attention a challenge, even if their recollections may be vague or faulty. Can drawing from HOM (anecdotes, algorithms, methods, non-symbolic algebra, &c.) engage students actively as they encounter new ways (to them) of "doing mathematics"? We relate our experiences in this. (Received September 01, 2015)

1116-G1-930 **Van A Herd*** (herd@austin.utexas.edu), Mail Code B7000, University of Texas at Austin, Austin, TX 78712. *Newton's Dark Secret: Using Historiographical Controversies to Introduce the Rudiments of Partial Differential Equations (PDE) into Developmental Mathematics Courses.*

The student populations who take developmental mathematics courses often are characterized as (1) non-mathematics majors and (2) as having untapped mathematical potential. As such, many of the populations do not advance through the mathematics sequence to study PDEs, yet have the intellectual ability to comprehend and do basic PDEs. In this session, the author will evaluate the manuscript evidence of PDEs in Sir Isaac Newton (1643-1727), and will then present his experience teaching developmental mathematics students the rudiments of PDEs using the historiography of the controversy surrounding Newton's development and use of PDEs. (Received September 15, 2015)

1116-G1-1040 **Suzanne Sumner*** (ssumner@umw.edu), 1301 College Avenue, Fredericksburg, VA 22401. *Why we shouldn't think we're smarter than ancient mathematicians!* Preliminary report.

Throughout history, techniques used by ancient mathematicians can be more insightful or more efficient than techniques taught today. For example, the Babylonians and Greeks used a form of geometric algebra that demonstrates common algebraic identities. The Babylonians also derived an efficient process for converting quadratic equations into a known form. And the Pythagorean use of figurate numbers is an intuitive way of confirming identities found useful for calculus. In addition, the Arabs introduced a compelling (and literal) method of completing the square in the middle ages. Given these and other examples, modern students would benefit from seeing how these ancient techniques aid in comprehending seemingly incomprehensible mathematics. (Received September 16, 2015)

1116-G1-1191 **Daniel E. Otero*** (otero@xavier.edu), Department of Mathematics, Hinkle 104, Xavier University, Cincinnati, OH 45207-4441. *Greek Chords and Hindu Sines: teaching trigonometry with original sources.*

Standard approaches to introducing trigonometry to students typically treat the sine, cosine, and other trigonometric quantities as functions whose properties derive from the geometry of the unit circle. They also tend to expose the standard trigonometric identities as mystical algebraic results. These approaches often don't provide students easy points of reference for scaffolding their understanding of these mathematical objects and their relations with each other. As many readers will know, taking a historical approach to mathematics can often address some of these pedagogical challenges quite effectively. This talk will track the author's development of classroom modules designed to introduce trigonometry to students through original sources, specifically, the construction of two brief tables, one of chord lengths attributed to Hipparchus (2nd c., BCE), and another of sines due to Varāhamihira (6th c., CE). (Received September 17, 2015)

1116-G1-1601 **Susan L Schmoyer*** (sschmoyer@worcester.edu), 486 Chandler St, Worcester, MA 01602. *Who Invented College Algebra?* Preliminary report.

Kronecker said, "God made the integers, all else is the work of man." By asking questions such as "Who invented function notation?" and "Why do we write exponents the way we do?" we begin to see how mathematicians shaped college algebra into what it is today. We also see that math itself is always evolving and that doing algebra means more than manipulating symbols. In this talk I will share questions and assignments that introduce students to the people who made the math we see in a typical college algebra class. (Received September 20, 2015)

1116-G1-1973 **Deepak Basyal*** (deepak.basyal@uwc.edu), 750 West Bay Shore Street, Marinette, WI 54143. *Uncommon mathematics from Tikārām Dhañanjaya's Śiśubodha Taraṅgiṇī.*

Śiśubodha Taraṅgiṇī II (1933) is a rare mathematics and astrology book from Nepal. Some of its mesmerizing Nepali mathematical ślokas (verses) written in standard meters such as anuṣṭup, vasantatilakā, śārdūlavikrīḍita et cetera contain uncommon mathematical procedures and examples, which are rarely seen in western mathematics curriculum. In this paper, I will present selected contents from the book. I will also discuss its possible uses in developmental mathematics classrooms, which may potentially enrich teaching and learning. (Received September 21, 2015)

1116-G1-2375 **Meghan M De Witt*** (mdewitt@stac.edu), St. Thomas Aquinas College, 125 Route 340, Sparkill, NY 10976. *Using Blood, Guts, and Gore to Keep their Interest.*

College students like violence, intrigue, mayhem, and the unusual. We discuss using such tales (both in class and by means of a research paper) from the history of mathematics to keep the students interested in the topic and help them to connect with the mathematics. (Received September 22, 2015)

Innovative Approaches to One-Semester Calculus Courses

1116-G5-99 **Raymond N. Greenwell*** (matrng@hofstra.edu), Department of Mathematics, 130 Hofstra University, Hempstead, NY 11549, and **Nathan P. Ritchey** (nritchey@edinboro.edu), College of Science and Health Professions, 200 Cooper Circle, Edinboro, PA 16444. *A Calculus Course Focusing on New Applications.*

One approach to a one-semester calculus course is to emphasize applications, especially those that are real (rather than created for a textbook) and new (beyond the traditional applications such as maximizing the volume of a box). Several such applications will be described, including: discharge from a creek; unemployment rate; transforming grades; chirped echos at Chichen Itza; the Pythagorean Theorem of Baseball; Humidex; plant growth; phytoplankton growth; foraging; and administrative intensity. (Received July 22, 2015)

1116-G5-683 **Patricia Baggett*** (baggett@nmsu.edu), Dept of Mathematical Sciences, MSC 3MB PO Box 30001, New Mexico State University, Las Cruces, NM 88003-8001, and **Andrzej Ehrenfeucht**. *A mathematically rigorous calculus course in a laboratory format for undergraduate and graduate non-math majors.* Preliminary report.

We offer a calculus course for students who are seriously interested in math education at any level, but who may not have sufficient prerequisites in algebra, analytic geometry and trigonometry to take a standard calculus course. The course covers operations on functions that include arithmetic operations, composition, derivatives and integrals. Students learn the intuitive meaning of all operations and technical definitions and how they are computed. All computations are carried out on TI-84 graphing calculators. The course is in a laboratory format where the tasks involve design and construction of physical objects, and their successful completion requires the use of calculus. In the talk we'll present informal and technical definitions used in the course; examples of a few tasks with brief descriptions of their solutions; students' comments and evaluations of the course; and internet links to most of the materials used so far, including calculator programs needed for processing data and for other computations. (Received September 10, 2015)

1116-G5-2115 **Tanya Huffman*** (thuffman@fgcu.edu), Florida Gulf Coast University, 10501 FGCU Blvd, South, Fort Myers, FL 33965, and **Cara Brooks**. *Project/Problem Based Learning as a Successful Approach to a One-Semester Calculus Course.* Preliminary report.

Elementary Calculus is a one-semester course designed for students majoring in business, economics, and biology. We present evidence that a problem/project based learning approach as a successful strategy to present the material in an interdisciplinary manner with real-life applications. The courses in our study were regularly structured in a "collaborative lecture" style; class time was segmented by short lectures followed by small group activities. The first term of the study (Fall 2014, three sections, N=180) involved the use of three mini-projects, each of which required students to apply course concepts to a real-world problem and work outside of class in teams of two or three. The second term of the study (Fall 2015, two sections, N=120) involved the use of increasingly open-ended projects. In addition, one section also completed writing assignments intended to support the development of positive mathematics learner identity. Lesson plans, projects, and sample writing assignments will be discussed. Student performance results and impact on attitude and confidence will also be presented. (Received September 21, 2015)

1116-G5-2218 **Erin M McNicholas*** (`emcnicho@willamette.edu`), 900 State St, Salem, OR 97301. *Quantitative Reasoning and Modeling in a One-Semester Calculus Course.*

Five years ago the Willamette mathematics faculty redesigned our calculus offerings to reflect the current need and demand for a meaningful one-semester applied calculus course that focuses on quantitative reasoning and modeling with real-world data. We have offered Modeling with Calculus for the past four years with much success (as measured by student satisfaction and reports from graduates who have gone on to use methods and ideas from our course in other contexts). A hallmark of the course is its focus on experiential learning through the completion of two open-ended projects involving the analysis of data using RStudio. In this talk I will discuss the design and implementation of our course, challenges we have encountered, and our success incorporating RStudio labs, projects, and in-class explorations. (Received September 22, 2015)

1116-G5-2292 **Chris Oehrlein*** (`cdoehrlein@gmail.com`). *Concept Reflection Exercises in Online and Blended Applied Calculus.*

In an Applied Calculus course that emphasizes data analysis, modeling and written interpretation, students need more immediate feedback when working homework. While computerized homework systems can be designed to address this issue, they cannot engage in a conversation with an individual student about misconceptions, improving communication or proper vocabulary. Blended and online course settings magnify the need. Prompts for short written responses and about conceptual or traditionally-tricky computational issues and rewriting opportunities after evaluation give the students and their instructor the opportunity to engage at each student's level of comprehension and communication ability. (Received September 22, 2015)

1116-G5-2434 **Yevgeniy V. Galperin*** (`egalperin@esu.edu`), 200 Prospect Ave, East Stroudsburg, PA 18301. *An Image Processing Approach to a One-Semester Calculus Course.*

We review the library of functions in the context of image-enhancement transformations and contrast stretching. We introduce the derivative in the context of several derivative-based edge detection methods, which accelerates the students' understanding of the definition and allows for the introduction of partial derivatives at an earlier stage. This approach also provides the students with a motivation to undertake projects relevant to their major fields. (Received September 22, 2015)

1116-G5-2639 **Robin A. Cruz*** (`rcruz@collegeofidaho.edu`) and **Lynda A. Danielson** (`ldanielson@collegeofidaho.edu`). *Yes, You Can Have It All.*

Faced with growing demand from very different student populations, The College of Idaho (a small liberal arts college) developed a three-year plan to redesign its entry-level mathematics courses. Our first objective was to streamline the sequence of courses for our bimodal audience of students, not all of whom enter college with calculus experience. Our second objective was to improve quantitative skills required by a variety of majors. This talk will focus on the redesigned Calculus courses and particularly, on our new course, Applied Calculus: A Modeling Approach based on a similar course developed at Macalester College. Our course is a terminal math course for Business and Biology majors that also provides adequate background for underprepared students who wish to major in Chemistry, Computer Science, Math or Physics. The redesigned curriculum has reduced the number of credits an underprepared student needs prior to Multivariable Calculus from 16 to 8. (Received September 22, 2015)

Innovative and Effective Ways to Teach Linear Algebra

1116-H1-75 **Steve J Bacinski*** (sbacinski@davenport.edu). *Applied MATLAB Projects for Linear Algebra Students.*

Applied MATLAB Projects for Linear Algebra Students

In the process of developing and teaching an undergraduate applied linear algebra course, I have developed eight MATLAB-based projects that serve as a foundation for the course. Because of the time constraint for the session, I will focus on two of my favorite projects.

Matrix Transformations with Puzzles – Students practice using matrix transformations to rotate, reflect, and translate shapes to solve a puzzle. First, students are given matrices containing the vector coordinates of the seven shapes of the classic Tangram puzzle. Students write a script in MATLAB that will arrange the shapes into a given square using matrix transformations. Once they solve the 2D puzzle, students move on to tackle a 3D puzzle arranging seven 3D blocks into the shape of a cube. (Topics: Vectors, matrix transformations in two and three dimensions, homogeneous coordinates)

Airplane Bounding Box – Students start with a 3D vector image of an airplane, and then use principle component analysis to construct a minimal bounding box made up of six orthogonal planes around the airplane. (Topics: Eigenvalues, eigenvectors, principle component analysis, matrix transformations, equation of a plane, dot product, intersection of 3 planes) (Received July 13, 2015)

1116-H1-236 **Crista L Arangala*** (ccoles@elon.edu), Campus Box 2320, Elon University, Elon, NC 27516. *Exploring Linear Algebra with Mathematica Labs.*

This talk will focus on hands-on labs that can be used in class every day to guide the exploration of linear algebra. These labs integrate inquiry learning, technology, *Mathematica*® visualization, and *Mathematica* CDFs that allow students to discover the theory and applications of linear algebra in a meaningful and memorable way.

Linear algebra application-driven projects which can be used as the basis for further undergraduate research will also be discussed. (Received August 16, 2015)

1116-H1-287 **Michael D Smith*** (smithm@lycoming.edu), Lycoming College, Campus Box 3, 700 College Place, Williamsport, PA 17701. *Use of Microsoft Excel for Gauss-Jordan Elimination.* Preliminary report.

The arithmetic involved in elementary row operations becomes tedious about two weeks into the semester, yet row reduction is a tool that's used in linear algebra problems throughout the whole semester. Microsoft Excel provides a happy medium between not allowing any technology beyond a calculator, and allowing students to row reduce an entire matrix with one command on Maple or Mathematica. Benefits of teaching students Excel include the following:

(1) Students have to program the row operations on Excel, meaning they still must determine the correct sequence of row operations.

(2) Excel allows you to swap labeled columns, which makes matrices in applications such as the linear programming and the Simplex Algorithm much easier to interpret.

This presentation will discuss my experience using Excel and demonstrate its use in solving a problem. (Received August 22, 2015)

1116-H1-745 **Christopher S Shaw*** (cshaw@colum.edu), Department of Science & Mathematics, 600 S Michigan Ave, Chicago, IL 60605. *Exploring personality profiles with matrices.*

We will present a short-term class project used in an introductory linear algebra course. For this activity, students responded to a survey of their pop culture tastes. Using the survey responses, they worked to design a series of matching algorithms, using matrices, with the goal of matching the students in the class to the person whose tastes most closely aligned with theirs. The class then explored various ways of testing the quality of the match. Topics covered along the way include: symmetric matrices, vector products, and numerical interpretation of qualitative data.

This presentation will address the assignment prompts, the collected data, and an overview of the student reactions to the project. (Received September 11, 2015)

1116-H1-895 **Mark Hughes*** (hughes@mathematics.byu.edu). *Exploring linear algebra with technology while being crunched for time.* Preliminary report.

One common challenge faced by educators involves finding time in class to discuss important definitions, theorems and examples, while still giving students the opportunity to investigate and explore new concepts on their own.

Indeed, the pressure to cover a fixed number of topics in a limited amount of time can lead to fewer opportunities for students to experiment with new ideas. In this talk I will discuss ways that inquiry based learning approaches can be used to teach linear algebra, without taking up large amounts of limited class time. These approaches involve the use of freely-available software, and help students connect principles being discussed in class with phenomena they observe through their own hands-on experimentation. (Received September 14, 2015)

1116-H1-962 **Jody Sorensen*** (sorensj1@augsburg.edu), Department of Mathematics, Augsburg College, 2211 Riverside Ave, Minneapolis, MN 55454. *Ancient Greek Linear Algebra?* Preliminary report.

In around 100 CE, Theon of Smyrna proposed an iterative method which allows for an approximation of $\sqrt{2}$. This method can be interpreted in a matrix form, rather like a Markov chain. After describing the original method and why it works, I will discuss how this could be extended to approximate other square roots. We'll also see how this could make an interesting project for Linear Algebra students. (Received September 15, 2015)

1116-H1-995 **Jeffrey L. Stuart*** (jeffrey.stuart@plu.edu), Mathematics Department, Pacific Lutheran University, Tacoma, WA 98447. *Specific Examples, Generic Elements and Restricted Dimensions - Overcoming Student Roadblocks in Linear Algebra.*

Linear algebra is the often the first math course in which sets play an explicit and fundamental role. Consequently students typically struggle with writing proofs for set-based results.

In this talk, I focus on three key strategies to improve student success.

(1) Emphasize the role of *specific* (*fully specified) examples* as examples to highlight definitions, and, more importantly, as counterexamples to universal statements.
(2) Emphasize what a *generic element* from a set is, how to write one, and what role it plays in proofs about sets.
(3) Emphasize the different and noninterchangeable roles of specific examples and generic elements.
(4) Thoughtfully tune the sizes of vectors and matrices in problems to focus students on the primary idea at hand. Specifically, use small shapes to encourage students to populate objects and to free students from dealing with the technical complications of large shapes. In contrast, use large shapes to discourage students from employing an entrywise approach, and from populating specific entries in an object.

These key strategies will be illuminated by a discussion about spans. (Received September 15, 2015)

1116-H1-1258 **Gilbert Strang***, Mathematics, E17-421, MIT, 77 Massachusetts Ave., Cambridge, MA 02139. *Eigenvalues and Singular Values in Theory and Practice.*

The Singular Value Decomposition completes the "big picture" of linear algebra. It finds orthonormal bases for all 4 fundamental subspaces, and it diagonalizes A. The SVD has become central in so many applications (like face recognition). This talk and the website math.mit.edu/linearalgebra of the new edition ILA5 will include videos to show ideas and applications of two diagonalizations: eigenvalues and singular values. (Received September 18, 2015)

1116-H1-1465 **Mian Arif Shams Adnan*** (maadnan@bsu.edu), Department of Mathematical Sciences, Ball State University, Muncie, IN 47304, **Khairul Islam** (khairul.islam@tamuk.edu), Department of Mathematics, Texas A & M University - Kingsville, Kingsville, TX 78363, **Asif Shams Adnan** (asif_kha786@yahoo.com), Department of Mathematics, Jahangirnagar University, Dhaka, 1342, Bangladesh, and **M Shamsuddin** (dr_md_shams2004@yahoo.com), Department of Statistics, IUBAT, Dhaka, 1230, Bangladesh. *A New Approach of Mathematical Operations for Volume Matrices.* Preliminary report.

An innovative approach of determining the mathematical operations of the higher dimensional matrices will be addressed. The mathematical operations will include addition, subtraction, multiplication, etc. Attempts have been made to unfold various properties of the volume matrices and their operations. Examples and real life applications will be demonstrated for their use in multi disciplinary ares. (Received September 20, 2015)

1116-H1-1556 **Naima Naheed*** (naheedn@benedict.edu). *Singular Value Decomposition: A thrilling inspiration in Linear Algebra.*

In recent years, the singular value decomposition (SVD) has become a very popular matrix factorization due to surge in applications, and increased computational memory and speed. An arbitrary $m \times n$ matrix A with $m \geq n$, can be factored as $A = U\Sigma V^T$, where U is m-by-m and satisfies $U^T U = I$, V is an n-by-n and satisfies $V^T V = I$, and $\Sigma = \text{diag}(\sigma_1, \ldots, \sigma_n)$, where $\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_n \geq 0$. The σ_i's which are determined by this factorization is unique and are called the singular values of A. The series of values are arranged in a decreasing order, so that the first few singular values contain more information about the original matrix of A than the later values. By taking only the first few singular values, it is possible to reduce the amount of information contained in an image and compress the image. The SVD can also be used to restore a corrupted image by separating significant information form the noise in the image data set. In addition to these, the SVD has fundamental importance in several different applications of linear algebra. With its bountiful theory and applications, the SVD is truly amazing. (Received September 20, 2015)

1116-H1-1566 **Karen E Clark*** (`kclark@tcnj.edu`), Department of Mathematics and Statistics, The College of New Jersey, PO Box 7718, Ewing, NJ 08628. *A computer graphics module to reinforce basic linear algebra concepts and engage non-majors.*

I will discuss a module on computer graphics that students in a first linear algebra course work through for two 50-minute computer lab sessions. This module serves to reinforce the elementary concepts of linear transformation and matrix multiplication, while exposing students to a basic application of linear algebra. In this lab students are introduced to homogeneous coordinates, which is beneficial for the computer science majors in the course. In addition, this lab serves to familiarize students with simple programming in Matlab. (Received September 20, 2015)

1116-H1-1975 **David Strong*** (`david.strong@pepperdine.edu`), Department of Mathematics, Pepperdine University, 24255 Pacific Coast Highway, Malibu, CA 91214. *Online Linear Algebra Tools from the MAA Course Communities.*

The MAA's Course Communities is a developing collection of reviewed resources, organized by courses. The collection of Linear Algebra resources was first compiled in 2014 and continues to grow. As a member of the Linear Algebra Working Group commissioned to help compile this collection, I will share some of what I find to be the most useful tools from this collection. (Received September 21, 2015)

1116-H1-2012 **Patrick R Gardner*** (`pgardner@columbiabasin.edu`), Department of Mathematics, Columbia Basin College, 2600 North 20th Avenue, Pasco, WA 99301. *Technology in Introductory Linear Algebra: Projects and Pedagogy.*

We use technology in Introductory Linear Algebra to illustrate concepts, facilitate learning, and, hopefully, inspire our students. In this session, I will describe experiences and insights gleaned from assigning Linear Algebra projects (content from Anton/Rorres, chapter 10; technology using Matlab/Octave and Mathematica), from programming online test questions (using WAMAP, a web-based mathematics assessment system provided free to Washington State public educational institutions), and from plans for incorporating an electronics learning lab into the course. I will also compare my current course expectations with those from some fifteen years ago to shed a bit of light on the purpose(s) of the course. (Received September 21, 2015)

1116-H1-2360 **Yevgeniy V. Galperin*** (`egalperin@esu.edu`), 200 Prospect Ave, East Stroudsburg, PA 18301. *Linear Algebra versus Conspiracy Theories.*

We discuss methods of introducing homogeneous coordinates in a linear algebra course. The emphasis is placed on examples taken from the field of digital image processing. Theoretical derivations, manual computations, and Matlab functions are used, and the students learn to apply the projective transform in a variety of real-life contexts. (Received September 22, 2015)

1116-H1-2422 **Christina Lee*** (`christina.lee@emory.edu`), Oxford College of Emory University, 180 Few Circle, Pierce Hall, Oxford, GA 30054. *Using Matlab and Blended Learning Techniques for a Successful Linear Algebra Learning Experience.*

Linear Algebra one of the most useful undergraduate mathematics courses, but it is often regarded by students as a difficult transitional course. Students who struggle with the theoretical and proof writing aspects of the course lose sight of the many applications of Linear Algebra. I used readings and pre-lecture assignments so that lectures focused on clarification and applications, weekly Matlab sessions so that students could understand the value of learning to code and tackle realistic linear algebra problems, and a final group project so students could reflect and apply what they learned. I was able to cover more material and my students were better able to make theoretical connections on material throughout the course than previous courses taught the traditional way. The most exciting outcome was how students who failed the first exam, stuck it out and were able to ace the last exam and final. (Received September 22, 2015)

1116-H1-2427 **John Hannah**, , New Zealand, **Sepideh Stewart*** (sstewart@math.ou.edu), 601 Elm Ave, Norman, OK 73019, and **Mike Thomas**, , New Zealand. *Linear Algebra in the Formal World of Mathematical Thinking.* Preliminary report.

Linear algebra is a required course for many STEM majors. Although, many students follow the study of matrices and are fairly successful in solving linear systems, they struggle with grasping the more theoretical aspects of linear algebra. In this study, a group of 16 students from a first course in linear algebra were interviewed and were asked about the purpose of proof in their understanding and whether they found proofs convincing. The qualitative analysis of the data is based on Tall's three world model of embodied, symbolic and formal thinking. (Received September 22, 2015)

1116-H1-2745 **James D. Factor***, James.Factor@alverno.edu, and **Susan F. Pustejovsky**, Susan.Pustejovsky@alverno.edu. *Dynamically Connecting Visual and Algebraic Representations of Linear Algebra Concepts Using GeoGebra.* Preliminary report.

This presentation will use interactive GeoGebra applets to show connections between algebraic and graphical perspectives of the following successively more complex linear algebra ideas:

a. Vector definition of a line in 2-space and in 3-space.

b. Two linearly independent vectors in 3-space generate a plane.

c. The role of linear combinations in transforming geometric objects from 2- to 3-dimensions, such as a line, or a circle. The interrelationship of linear combination, matrix multiplication, and linear transformation will be emphasized in the presentations of these concepts.

The GeoGebra applets presented here, as well as others from the NSF project, are freely available for an instructor to use as demonstrations in class. Activities have been designed to guide students in using the interactive applets to enhance learning. This work is part of the NSF project entitled *Transforming Linear Algebra Education with GeoGebra Applets (NSF TUES Grant DUE-1141045).* Additional information about applets with activities is available at the MAA/NSF Poster Session. (Received September 22, 2015)

1116-H1-2945 **Ton Boerkoel*** (dr_ton_boerkoel@msn.com). *A connection between skew projections and perspective projections.*

In linear algebra one rarely discusses affine transformations let alone the very non-linear perspective projections. All these transformations are important in for example the world of computer graphics. In this talk we'll take a wonderful detour through the world of affine transformations and discuss how we can use affine coordinates to fit them within the realm of linear algebra. In particular we'll discuss the general skew projection matrices in 2 and 3 dimensional real vector spaces. We'll then tackle the highly non-linear perspective projection and use homogeneous coordinates to also describe these transformations using linear maps, after which we unearth a beautiful link between skew projections and perspective projections. The theme of this talk is a unification of sorts through the lens of projective geometry by using homogeneous and affine coordinates. (Received September 23, 2015)

Innovative Targeted Solutions in Teaching Introductory Statistics

1116-H5-22 **Jeffrey A. McLean*** (jamcle01@syr.edu). *Eliciting Bootstrapping: The Development of Students' Informal Inferential Reasoning.*

This talk will focus on the development of introductory statistics students' informal inferential reasoning while engaged in an instructional unit eliciting the resampling method of bootstrapping. Researchers have asserted that bootstrapping is intuitive to novice statistics students and promotes student learning of the logic of inference. The instructional unit consisted of activities that: encouraged students to generate descriptions, explanations, and constructions of sampling and inference in order to reveal how they were interpreting situations; focused on the mathematical structure of sampling with TinkerPlots software; and transformed their developing reasoning of sampling and inference to investigate more complex problems. The first section of the unit elicited students to repeatedly sample from an available population and construct a means to make inferential claims from the data. In the second section the population was no longer available. Students had only one sample from the population and constructed the resampling method of bootstrapping to draw inferential claims. I will describe the development of students' reasoning of sampling and inference, the methods of resampling that they constructed, and how these methods were used to draw inferential claims. (Received May 16, 2015)

1116-H5-142 **Stanley Rothman*** (stanley.rothman@quinnipiac.edu), Quinnipiac University, Dept. of Mathematics, Hamden, CT 06518. *Undergraduate students can do original mathematical research.*

Believing that applying statistics to an area that a student both enjoys and understands will enhance the learning process and at the same time set the stage for them to do original math research led me to create the course "Baseball and Statistics" in 2008 at Quinnipiac University. The course, using the book "Sandlot Stats: Learning Statistics with Baseball", is open to any student. After studying the usual topics in probability and statistics, the students are presented original mathematical research topics such as: calculating the probability a given player duplicates DiMaggio's 56-game hitting streak and using linear regression to predict winning percentage. At the beginning of the course each student chooses a player they initially believe should be in the Hall of Fame. At the end of the course each student gives a Powerpoint Presentation justifying whether their chosen player should be admitted to the Hall. I will present a sample of one of my students' independent research projects done during the course. This student was invited to present his research at an Undergraduate Conference given by Sigma Xi. After taking my course, several students have obtained internships and jobs in sports analytic departments. (Received August 06, 2015)

1116-H5-218 **Samuel Luke Tunstall*** (luke.tunstall@gmail.com). *Lies, Popcorn, Barbie, and the Spelling Bee: Bringing Life into the Statistics Classroom.*

Teaching statistics to the same students for seven hours a day requires innovation. This summer I had the opportunity to work with gifted middle-school students in such a capacity, and along the way, I developed and adapted a number of hands-on activities to teach specific topics to students. In this talk I will share these activities, which include lying with statistics, modeling popcorn with the normal distribution, as well as teaching linear regression through a spelling test and the dropping of Barbie dolls from high places. I will share my experiences from this summer and provide insight for those looking to do this at the post-secondary level. (Received August 14, 2015)

1116-H5-792 **Khairul Islam*** (khairul.islam@tamuk.edu), Department of Mathematics, Texas A&M University-Kingsville, Kingsville, TX 78363, and **Mian Arif Shams Adnan**, Department of Mathematical Sciences, Ball State University, Muncie, IN. *Sampling Distribution Made Easy: A Simulation Approach.*

Sampling distribution is the key component of a statistical inference. By its nature, the topic is tougher for many students at introductory statistics class. It makes students lose their concentration in the course, which leads to a dropout or other adverse consequences. Often, the topic is being skipped or addressed superficially to introduce estimation and test of hypothesis, which eventually make students more confused. What is the way out of this problem, anyway? In this presentation, we intend to address sampling distribution with multiple examples, and simulations via an open source software R, which has been proven to be very effective. It is expected that instructors of introductory statistics class would benefit from adapting our approach. (Received September 22, 2015)

1116-H5-810 **Tanweer Shapla***, Mathematics Department, Eastern Michigan University, Ypsilanti, MI 48197. *Technology Blended Teaching for Statistics Education.*

The use of technology has been an indispensable tool in teaching an introductory statistics class. Generally, enrollments in introductory statistics are in increasing trend, and students are coming from multidisciplinary areas with very little mathematics and computational skills. On the other hand, by its nature, an introductory statistics class incorporates ideas ranging from descriptive statistics to various forms of inferential statistics. Under this reality, the emphasis is primarily on the conceptual understanding of basic statistical techniques and interpretational aspects of analytical results. Therefore, an efficient planning in teaching and an appropriate use of technology are in great demand towards achieving most of the course objectives set forth in an introductory statistics class. In this presentation, we address an open source software R, along with its flexibility of commands for teaching an introductory statistics class with examples and applications. (Received September 13, 2015)

1116-H5-863 **Wei Wei*** (wei.wei@metrostate.edu), Metropolitan State University, Department of Mathematics, 700 East 7th Street, Saint Paul, MN 55106, and **Katherine Johnson** (katherine.johnson@metrostate.edu). *The fair use of graphing calculators in an introductory statistics course.*

Graphing calculators have been used for teaching introductory statistics courses for decades. They help students to obtain accurate statistical analysis results. However, heavily relying on graphing calculators may hinder students understanding of certain statistical concepts such as the normal distribution, p-value, and test statistic.

In this study, we focused on the effects of using a graphing calculator on students' performance of calculating normal probabilities, performing a hypothesis test and understanding basic concepts related to the normal distribution and hypothesis testing. We also studied whether using a graphing calculator helped with students' short-term retention. Our findings were: 1) using the normal functions on a TI calculator, normalcdf and invnorm, significantly increased students' performance of calculating probabilities and significantly improved their understanding of the normal transformation; 2) the hypothesis testing functions, T-Test and 2-PropZTest, significantly helped students to conduct hypothesis tests, but hindered students' understanding of p-value; 3) using TI calculators had no correlation with short-term retention. The authors will present a solution on the use of graphing calculator in teaching an introductory statistics course. (Received September 14, 2015)

1116-H5-933 **Rodney X. Sturdivant***, Sturdivant.11@osu.edu, and **Rebecca R. Andridge**. *A "Hybrid Flipped" Introduction to Biostatistics to Promote Research-Like Experiences.*

Introductory statistics courses often consist of in-class lectures, textbook exercises, and an over-emphasis on hand-calculation. In our introduction to biostatistics undergraduate course we take a different approach, emphasizing conceptual understanding and acquisition of skills that are immediately transferrable to projects outside the classroom. This is achieved through student-developed research questions for which they create and implement a short online survey, on a topic of their choosing. They collect, clean, summarize, and analyze their own data, culminating in a final poster presentation (in pairs) and written paper (individually). Not only does this provide motivation for students, as they are more invested in their projects than they would be in textbook assignments, but it gives them exposure to "real world" problem-solving, such as what to do with messy or incomplete data. In order to make this survey project the focus, we use a "flipped" and "hybrid" classroom model to free up time for active learning in the classroom. (Received September 15, 2015)

1116-H5-1015 **Jon Pierre Fortney***, Zayed University, Dubai, United Arab Emirates, and **Liane Sandrey**, Zayed University, Dubai, United Arab Emirates. *Language in the Statistics Classroom: When the Problem Isn't Just the Math.*

The globalization of higher education has meant that increasingly mathematics faculty are encountering not only individual students, but whole classes of students, for whom English is a Second Language (ESL). Mathematics faculty are generally not prepared to address these student's needs and frequently fail to appreciate the difficulties ESL students face. The cognitive demands placed on ESL students are essentially doubled; not only are they trying to learn mathematics, a difficult subject in the best of situations, but they must also deal with a new language. In this talk we will address some of the issues raised in teaching an introductory statistics course to a class of ESL students by highlighting the most frequently encountered difficulties experienced by ESL students. Next we will present several pedagogical strategies that have proven successful for ESL students in the introductory statistics course. Finally, we will illustrate these strategies with a few student examples. We believe paying close attention to the language issues of ESL students while teaching can not only have a positive impact on ESL students, but can also improve performance for struggling native English speakers as well. (Received September 16, 2015)

1116-H5-1188 **K. Scott Alberts*** (`salberts@truman.edu`), Department of Statistics, 100 E. Normal St., Kirksville, MO 63501. *Data-free Visualizations: A Project in the First Week of Introductory Statistics?* Preliminary report.

Traditional offerings of introductory statistics tend to start fairly slowly and then ending with a mad dash to finish on time. By starting a visualization project on the second day of class, students have a chance to be more engaged from the start, and to see the power of what they will be learning later. This project allow students to invent results around a fun, real-world topic, such as movies, food, or cars, which they use to create a variety of graphs and charts to reinforce their (made-up) thesis. As a secondary benefit, this project also gives them a chance to learn software graphing, and serves as a way to flip the classroom for the early chapter on charts and graphs. Students can also find real world examples of journalists, politicians, and others, who use data-free visualizations to demonstrate their points. Two later projects can scaffold concepts from this early project. Project materials and grading rubric will be provided to attendees. (Received September 17, 2015)

1116-H5-1321 **Troy Riggs*** (`triggs@uu.edu`), 1050 Union University Drive, Jackson, TN 38305. *From Conjecture to Conclusion: Achieving student engagement through an emphasis on the power and limitations of statistical ways of knowing.*

Statistical educators have recognized that conceptual understanding is an important goal in Introductory Statistics. Inadvertently, in pursuing this goal I have discovered that emphasizing statistical methods as a means of knowing galvanizes student attention and motivates them to reflect on the work that they are doing. Students engage with discussion about the basis of a claim to knowledge and the limitations of that knowledge in a given context. In particular, a strong emphasis on the logic of the falsifiability of beliefs has improved student performance and understanding with respect to hypothesis testing. (Received September 18, 2015)

1116-H5-1322 **Jeffery D Sykes*** (sykesj@obu.edu), Ouachita Baptist University, Arkadelphia, AR 71998. *Simulation methods and standards-based grading in an introductory statistics course overhaul.* Preliminary report.

For the Fall 2015 semester, the author undertook a complete revamp of his introductory statistics course. The traditional curriculum was replaced with one emphasizing simulation methods and an early introduction to inference. The classroom approach was changed from discovery learning to a mixture of lecture and group activities. The traditional, point-based grading system was replaced with an implementation of standards-based and specifications grading. The author will report on what has worked well, what has worked not so well, and what will be changed for the Spring 2016 semester. (Received September 18, 2015)

1116-H5-1335 **Lawrence M. Lesser*** (lesser@utep.edu), UTEP Mathematical Sciences Dept., 500 W. University Avenue, El Paso, TX 79968, and **John J. Weber III** (john.weber@gpc.edu) and **Dennis K. Pearl** (dkp13@psu.edu). *Using Targeted Fun in College Introductory Statistics to Decrease Anxiety and Increase Learning: Research, Resources, and Recommendations.*

In Nov. 2008 Journal of Statistics Education, we give 20 modalities of fun (e.g., humor, songs, cartoons, games) and potential benefits, with songs reviewed in spring 2014 Journal of Mathematics and the Arts and a case study in June 2015 Transformative Dialogues. Our March 2013 Journal of Statistics Education survey of (N=249) college instructors found genders had similar motivations for using fun, but different hesitations and modality preferences. Our NSF-funded (DUE 1140690/1141261/1140592) fall 2013 student-randomized experiment (see www.causeweb.org/ecots/ecots14/32/) investigated if students randomly selected for exposure to fun inserts (e.g., CAUSEweb.org cartoons or songs) in conventional self-contained mini-readings in their LMS (thus removing variable of instructor effect or talent) would experience improved learning (measured by embedded exam questions) or reduced statistics anxiety (by SAM). With songs, students randomized to the fun group correctly answered the embedded questions an average of 50.0% of the time, compared to 42.3% for the other students ($p = .04$). Use of cartoons and quotes showed no differences between groups on test item performance, anxiety or attitude. Our new NSF grant (DUE 1544237/1544243/1544426) will develop and assess interactive songs. (Received September 18, 2015)

1116-H5-1825 **Amy Wangsness Wehe*** (awehe@fitchburgstate.edu), Mathematics Department, Fitchburg State University, 160 Pearl St, Fitchburg, MA 01453. *Using a Shared Experiment to Bind the Class Together.*

We began this semester with the gummy bear launching experiment from G. Cobb and W. Miao. Each class day, part of the student's preparation work involved reading a section of the textbook and applying it to their gummy bear experiment data. This talk will report on how this worked, as well as comparative data from assignments given in this class and in a class from a previous semester. (Received September 21, 2015)

1116-H5-1849 **Bruce Liby** and **Kathryn Weld*** (kathryn.weld@manhattan.edu), Department of Mathematics, Manhattan College, Riverdale, NY 10471. *SAT and MCAT Data – An Introductory Statistics Research Project for Students in non-STEM fields.*

To what extent SAT scores predict MCAT scores? In Introductory Statistics, students with majors primarily in non-STEM fields were asked to consider this question as an ongoing semester long research project. The scholarly literature on this question is minimal, and the few studies found were published over a decade ago. The students analyzed a dataset containing the MCAT and SAT information of 555 students from nine volunteer institutions. This talk will detail how the class structure was modified to include the project, describe student analysis of existing literature, their own discoveries about the data, and discuss the students' responses to the experience of having engaged in a research project. (Received September 21, 2015)

1116-H5-2036 **Robin H Lock*** (rlock@stlawu.edu), St. Lawrence University. *Updating the GAISE College Report.* Preliminary report.

The Guidelines for Assessment and Instruction in Statistics Education (GAISE) College Report was endorsed by the American Statistical Association (ASA) in 2005 and has been widely used in updating introductory statistics courses. Now it's time for the report itself to be updated. The ASA asked a group of statistics educators to revise the report in light of 10 years of experience using the recommendations and recent changes in technology, pedagogy, and statistical practice. What's new in the revised recommendations for teaching an introductory statistics courses and in the supporting resources for helping make that happen? We discuss some of the highlights of the proposed new GAISE report which will be in draft form in time for the 2016 Joint Mathematics Meetings and encourage feedback before it is finalized. (Received September 21, 2015)

1116-H5-2285 **Kimberly A. Roth*** (roth@juniata.edu), Brumbaugh Academic Center, 1700 Moore Street, Huntingdon, PA 16652. *Using Plickers in Introductory Statistics.*

Classroom response systems or clickers are a popular way to get whole class feedback on a question. Used with peer instruction and discussion they can enhance students understanding of the material. However many systems cost both you and the students money. Plickers is a new free option for which the students use no devices to answer the question. Instead it uses pictures based on QR codes. I will discuss the reasons clicker questions are great to use in the introductory statistics classroom and the successes and challenges of doing so with Plickers. (Received September 22, 2015)

1116-H5-2289 **Adam F Childers*** (childers@roanoke.edu), 2521 Robin Hood Rd. Roanoke, VA 24014. *Facebook Consulting: A Semester-Long Project for Introductory Statistics.*

Facebook provides businesses and organizations with extremely detailed data that describes how users are interacting with their page. This data provides an excellent opportunity to put introductory statistics students in the role of consultants for a local business or organization and get their hands on real data. This presentation will outline how to use Facebook data to create a semester-long project that provides an exciting platform for teaching students descriptive and inferential statistics and making them think about the difference between observational and experimental data. Further, it forces the students to concentrate on articulating their findings to an audience of non-experts and integrate technical statistical ideas into a written report. (Received September 22, 2015)

1116-H5-2297 **Eleanor S. Farrington*** (efarrington@maritime.edu), 101 Academy Drive, Buzzards Bay, MA 02532. *Student Heights and Prediction Intervals.* Preliminary report.

For the most part, the idea of prediction intervals follows naturally from confidence intervals, but the differences are sufficient to warrant further investigation. This talk will describe a simple, in class activity doing just that. Working from first day class survey data, we construct confidence and prediction intervals for heights of students at our school. Then we test our predictions in the school population, creating opportunities to discuss random sampling and reinforce concepts from earlier in the semester, as well as explicitly seeing the power and limitations of prediction intervals in practice. (Received September 22, 2015)

1116-H5-2443 **Emily D Baum*** (emily.baum@bobcats.gcsu.edu) and **Brandon L Samples** (brandon.samples@gcsu.edu). *Effects of Supplemental Instruction on Student Achievement in an Introductory Statistics Course.* Preliminary report.

At most universities, an introductory statistics course is required for the majority of the students before they begin their specific major classes. Roughly 25% of undergraduate students at a given university will take a statistics class during a single academic year. Of these students, several will fail to retain the information, making future classes more difficult, or fail to successfully pass the course, increasing the likelihood a student will not graduate on time. Providing academic support through the implementation of a Supplemental Instruction (SI) Program gives students the opportunity to receive free, out-of-class help focused on student achievement in this course. Lead by a SI Leader, students are able to attend sessions to receive conceptual help while reviewing class material, developing study strategies, and collaborating with classmates. We will be focusing on the effects SI can have on student achievement in a statistics classroom. Since statistics is a necessary and important course in several disciplines, proper academic help is crucial for the success of the students. We will share our data analysis for using SI in a statistics course over a 4-year period, providing participants the opportunity to identify the positive effects SI has on student success. (Received September 22, 2015)

1116-H5-2455 **Sarah L. Marsh*** (sarah.marsh@okbu.edu). *Tailoring Introductory Statistics Assignments to Students' Interests.* Preliminary report.

Rather than try to explain to students when they will "actually use" statistics, why not show them—or let them show themselves? In this talk, we will explore two types of assignments that can be tailored to students' interests while emphasizing the importance of statistical knowledge and processes. First, a data collection and analysis project requires students to think through an entire experiment from choosing a question to drawing conclusions. Second, article review assignments encourage students to explore how statistics is used in fields of interest to their personal and professional lives. We will look at some details, pros, and cons of these assignments, as well as student and faculty reactions to this approach. (Received September 22, 2015)

1116-H5-2464 **Mary R Parker*** (mparker@austincc.edu) and **Hunter Ellinger**. *Using Visualize Applets in Statway and New Math Pathways.*

The Carnegie Foundation's Statway and the Dana Center's New Math Pathways projects prepare developmental students for college-level statistics in classes with activities and various other innovations. We developed these Visualize applets to illustrate many of the concepts for the students. Several of these illustrating statistical concepts will be discussed in this talk. These are open-source, HTML 5 applets, which teachers may use from our website or download and put on their own websites if they care to adapt the instructions (and even the applets) themselves. http://visualize.tlok.org/ (Received September 22, 2015)

1116-H5-2484 **Tonya S Adkins*** (tonya.adkins@jwu.edu). *The Misuse of Statistics in Political Campaigns.* Preliminary report.

With the approach of the 2016 Presidential election, data is inevitably used, misused, and abused in order to tell a story favorable to a particular candidate or party. Examples of these are collected from news and social media, then presented to students. Using scaffolding, students learn to recognize and refute how statistics are presented poorly, and (hopefully) become more responsible citizens and voters. (Received September 22, 2015)

1116-H5-2529 **Timothy Kelly**, **Larry Edward Knop*** (lknop@hamilton.edu) and **Chinthaka Kuruwita**. *Readin', Writin', and Calculatin': Our Intro Stats Course Foci.*

To paraphrase Madonna, so much to teach and so little time to teach it. The intro stats course at Hamilton College has three foci. I. Reading problems and exploring data carefully. Students need to understand the problems they encounter, they need to recognize and deal with ambiguities, and they need to identify the features and quirks in their data. II. Writing conclusions accurately. All the computations that students can do are worthless if students do not communicate their findings in ways that are understandable – both to others and to themselves. III. Calculating the relevant statistics efficiently. Life is too short for arithmetic; efficient calculation means using technology intelligently. Students are required to use software in class, when doing homework, and while taking exams. Although we have not included new approaches such as randomization or bootstrapping (those topics are covered in the follow-up course), Hamilton's intro stats course seems successful; the course is not a required part of any major, but approximately 25 percent of Hamilton's student body choose to take the course before they graduate. And it's fun to teach the material and the students. (Received September 22, 2015)

1116-H5-2603 **Annela R Kelly*** (a3kelly@bridgew.edu), 131 Summer Street, Barrington, RI 02325. *Flipping Coins to Normal Distribution.* Preliminary report.

The purpose of this activity is to better understand similarities and differences between discrete probability distribution, binomial distribution and normal distribution. First, my talk will use games with coins to introduce probability distributions and expected value computations. Next, the game outcomes will be modified to success and failure for binomial distribution and its expected value. We will compare these calculations. Finally, we discuss how to use normal approximation to binomial distribution to approximate the probabilities in the game. (Received September 22, 2015)

1116-H5-2628 **Alexander G. Atwood*** (atwooda@sunysuffolk.edu), Department of Mathematics, 533 College Road, Selden, NY 11784, and **Vera Hu-Hyneman** (huhynev@sunysuffolk.edu), Department of Mathematics, 533 College Road, Selden, NY 11784. *The Mathematical Analysis of Cancer Risk in a Statistics Class.*

In January of 2015, Tomasetti and Vogelstein published in Science Magazine a revolutionary, provocative and rigorous statistical analysis which strongly suggests that the accumulation of random mutations during division in healthy stem cells can explain two-thirds of cancers. Their mathematical analysis is a wonderful subject for exploration by students in an Introductory Statistics Class. Mathematics faculty will be able to directly use the information in our presentation to design a stimulating classroom activity about the risk for cancer. In particular, students will be able to see how linear regression can be used to understand the correlation between cancer risk in an organ and the number of cumulative stem cell divisions within that organ, and students will be able to understand how this correlation can lead to a quantitative understanding of some of the causes of cancer. Furthermore, this classroom activity can open the door to further discussion and debate about the many possible causes of cancer and the role that statistics can play in understanding cancer. (Received September 22, 2015)

1116-H5-2737 **Rachel M Chaphalkar*** (chaphalr@uww.edu), Whitewater, WI 53190. *Students' Conceptual Understanding of Variability throughout an Introductory Statistics Course.*

The Guidelines for Assessment and Instruction in Statistics Education and the Common Core State Standards for Mathematics have promoted a more conceptual understanding of statistics in general, and specifically in understanding of variability. This exploratory study looked at introductory statistics students' descriptions of variability and measures of variability at different times throughout a semester. Data were collected through surveys, interviews, and the final exam from approximately 100 participants. Student responses to both multiple choice questions and short answer questions will be discussed. (Received September 22, 2015)

1116-H5-2847 **Sheldon H Lee*** (shlee@viterbo.edu). *Excel-based interactive activities in an introductory statistics course.*

Although I have exclusively used SPSS or StatCrunch as the data analysis tool in my introductory statistics course, I use Excel as a way to get students to better understand the mathematics behind the statistical techniques. My goal is for students to write their own programs that can be used to analyze data, without requiring students to know procedural computer programming. I will discuss several activities I have implemented. Two of these are discovery activities used to determine reasonable formulas for the correlation coefficient as well as the F statistic for One-way Anova. I will also discuss a sequence of assignments in which students each make their own spreadsheet that can be used to do hypothesis testing and find confidence intervals for a variety of situations in which the summary statistics are known. (Received September 22, 2015)

1116-H5-2869 **Beverly M Reed*** (breed1@kent.edu), Department of Mathematical Sciences, Kent State University, Kent, OH 44242. *Introductory Statistics in a Scale-Up Classroom.* Preliminary report.

In this talk I will describe how we redesigned our Introductory Statistics course according to the GAISE guidelines and the Scale-Up model. Our Scale Up lab consists of 11 tables, each with seating for 9 students. We employ a flipped pedagogy with students working in collaborative groups of 3, submitting in-class activities on Blackboard each class period. Activities include working with interactive apps, analyzing data sets from the internet, and conducting statistics tests. Sample activities will be available. Managing assessment procedures in a class of 99 students has been a challenge and details will be discussed. Also discussed will be the classroom design, time management in a 100-minute classroom, and standardizing the course across sections and regional campuses. (Received September 22, 2015)

1116-H5-2996 **Kumer Pial Das***, Lamar University, Beaumont, TX, **Jasdeep Pannu**, Lamar University, Beaumont, TX , and **PJ Couch**, Lamar University, Beaumont, TX. *Investigating Students' misconceptions about confidence intervals.*

A solid understanding of confidence intervals (Cis) is of major i= mportance in designing and interpreting empirical results in any scientific= discipline. In practice, there are many misconceptions regarding this topi= c. Identifying CI misconceptions is a first step in designing teaching tool= s that can be used to prevent or reduce them. This study has been designed = to identify and reduce those misconceptions. Three sections of the Calculus= based Introductory Statistics course taught by the authors at a regional c= omprehensive university in the Southeastern United States have been chosen = to conduct the study. A pre-test and post-test have been conducted where a = list of possible misconceptions have been provided to all students in those= sections before and after the lesson of CIs delivered. Common lecture mate= rials have been prepared for this study. The results obtained from this stu= dy will not only identify common misconceptions, they will also propose an = educational tool that could be used to confront CI misconceptions. (Received November 11, 2015)

Integrating Research into the Undergraduate Classroom

1116-J1-756 **Michael Dorff*** (mdorff@math.byu.edu), **Suzanne Weekes**, **Linda Braddy** and **Reza Malek-Madani**. *PIC Math: preparing students for industrial careers through an undergraduate research course.*

PIC Math is a new program supported by MAA and SIAM and funded by a $2 million NSF grant. It aims to increase awareness among mathematical sciences faculty about non-academic career options for students, prepare undergraduate students for careers in industry, and provide research experience for undergraduate students through a spring semester course in which students work on research problems from business, industry and government (BIG). In this talk, we will discuss the program, the setup of the research course, and sample undergraduate research problems used in the course. (Received September 11, 2015)

1116-J1-817 **Veronika Furst*** (furst_v@fortlewis.edu), Department of Mathematics, Fort Lewis College, 1000 Rim Drive, Durango, CO 81301. *Image Processing in an Undergraduate Capstone Experience.* Preliminary report.

We will outline the curriculum of an undergraduate course on wavelet-based image processing, in which all preliminary material is presented while completing a class project and preparing the students for research. The material is aimed at students with only calculus and linear algebra backgrounds and no previous programming experience. We will describe how to manage both the introductory material and the students' individual research in a project centric environment. The focus will be on providing mathematical and programming content on an as-needed basis, towards the completion of a class project. Completion of this project will then serve as a guideline for students to pursue research of their own, not simply end-of-term projects, for the remainder of the semester. (Received September 13, 2015)

1116-J1-1976 **Rachelle Bouchat*** (rbouchat@iup.edu), Indiana University of Pennsylvania, 210 South Tenth Street, Stright Hall, Room 233, Indiana, PA 15705. *Mathematics Research . . . Not Just for Math Majors!*

Undergraduate research in mathematics is often thought of as research conducted by mathematics majors outside of their normal course load. However, research in mathematics can be brought into the mathematics classroom that is composed of non-mathematics majors. In this talk, research projects used in a mathematics course focused on non-STEM (Science, Technology, Engineering, and Math) majors will be shared. In particular, a research project on designing a spring break trip will be discussed, along with a project that has students analyzing survey data using forms created in www.SurveyMonkey.com. Examples of student work will be shown. (Received September 21, 2015)

1116-J1-2169 **Feryal Alayont*** (alayontf@gvsu.edu), GVSU Math Department, 1 Campus Dr., Allendale, MI 49401. *Mimicking Mathematical Research in Discrete Mathematics.* Preliminary report.

Discrete mathematics contains a wealth of problems that students can investigate with a minimal introduction. I will describe how I use such problems to create a research-like experience for my students in my discrete mathematics courses. Student teams first learn a topic not covered in class without using outside sources so that they are encouraged to be as original as they can be in their understanding. They then further investigate a specific direction within their research topic to obtain possibly new results. These directions could be results obtained by modifying definitions in their topic, looking for results on a specific graph family, providing new proofs to old results, and such. Project topics and the structure of the project as well as the student response to this research experience will be discussed in the presentation. (Received September 22, 2015)

1116-J1-2381 **Yevgeniy V. Galperin*** (egalperin@esu.edu), 200 Prospect Ave, East Stroudsburg, PA 18301. *Integrating Research into a College Algebra Course using MyMathLab.*

We redesign a course in college algebra with the goals of encouraging and preparing students to undertake research projects that promote the students' appreciation of the societal value of mathematics. The redesign is also intended to increase student understanding of environmental economics while deepening their environmental awareness. These goals are achieved by employing the capabilities provided by Pearson's MyMathLab Software in structuring assignments, setting up pre-requisites, creating custom-made problems, and in integrating problems from multiple textbooks and other sources within a single assignment. (Received September 22, 2015)

1116-J1-2662 **Marina Dedlovskaya**, **Malgorzata Aneta Marciniak*** (mmarciniak@lagcc.cuny.edu), **Marina Nechayeva** and **Vladimir Przhebelskiy**. *Mathematics in Flight.*

A series of aerodynamics-centered research projects, starting with pre-calculus and culminating with multivariable calculus, provides instructors with an opportunity to effectively incorporate research-based learning into post-algebra STEM curriculum. Using the common context throughout the entire sequence augments the benefits students gain from applying college mathematics to the real world by allowing a deeper and more meaningful association with the area of research, increasing engagement, retention of the material and strengthening inquiry and problem solving skills. Gradual, systematic immersion in the subject allows students to develop necessary technological and collaboration skills. During this presentation we will showcase research into topics of aerodynamics performed by Undergraduate Summer Research student in collaboration with faculty members representing engineering and mathematics. (Received September 22, 2015)

1116-J1-2833 **Joseph Hibdon*** (j-hibdonjr@neiu.edu), Northeastern Illinois University, Mathematics Department, 5500 N. St. Louis Ave., Chicago, IL 60625, and **Lidia Filus**, **Elisabet Head**, **Sudha Srinivas**, **Kenneth Nicholson** and **Paulo Acioli**. *The Peer Enhanced Experiential Research in STEM (PEERS) project at Northeastern Illinois University: Mathematics Component.* Preliminary report.

A group of STEM faculty at Northeastern Illinois University (NEIU) recently obtained an NSF Improving Undergraduate STEM Education (IUSE) grant to strengthen the mathematics and science curriculum at NEIU. The project seeks to engage STEM majors at NEIU and advance their research skills through the inclusion of research components in the curriculum. The curriculum changes and implementations are being done in the introductory 200-level (sophomore) courses of the STEM disciplines. The targeted mathematics courses are Calculus II and an applied and computational statistics course for non-math STEM majors. A group of peer leaders will be trained in an interdisciplinary 300 level (junior/senior) course to support the students taking the 200-level courses, with a goal for the peer leaders to develop a sense of the interdisciplinary nature of research in the STEM fields. In addition, the faculty have the opportunity to refocus their learning objectives and outcomes in these courses to allow for inquiry-based learning. The ultimate goal is to enhance the retention of students in the STEM fields. Each discipline has piloted the changes, and an overview of the modifications of the courses and an analysis of the effect of these changes on student learning outcomes will be presented. (Received September 22, 2015)

1116-J1-2866 **Theresa A. Jorgensen*** (jorgensen@uta.edu). *ASSURE Calculus - Achieving Success through Undergraduate Research and Engagement.*

With the goal of igniting a passion for inquiry, freshmen STEM students at the University of Texas at Arlington were connected with authentic research experiences in ASSURE Calculus (Achieving Success through Undergraduate Research and Engagement). In this year-long Calculus sequence, students developed and explored research questions which they could investigate utilizing the mathematical tools of calculus that they were simultaneously learning in the course. These research projects were completed in groups of 4 or 5 students, spanned the entire semester, comprised 10% of their overall semester grade, and culminated with written reports and poster presentations. Calculus I research questions were based in issues related to their university community. Calculus II research projects arose out of issues affecting the broader community. I will describe the structure of the courses including the timeline for the research projects. Impact on the students was measured using the Student Assessment of their Learning Gains (SALG) instrument. The SALG focuses on students' self-reflection of their learning and summarizes the learning progress that the students perceived they made as a consequence of the class pedagogy, including the embedded research component. (Received September 22, 2015)

Inquiry-Based Teaching and Learning

1116-J5-190 **Reva Kasman*** (rkasman@salemstate.edu), Salem, MA 01970. *From Patterns to Proof: Using Inquiry-Based Learning to Turn Elementary School Classrooms into Communities of Mathematicians.* Preliminary report.

When mathematicians "do mathematics", they pose questions, play with examples, and eventually develop conjectures which they test and attempt to prove. Peer collaboration and review play significant roles in this process. When elementary students are able to similarly build knowledge within a community, they have the opportunity to become deeply engaged with mathematics. Inquiry-Based Learning provides an ideal basis for these experiences, which are well-aligned with the Mathematical Practice Standards outlined in the Common Core.

This session will share a research project in which 2nd-5th grade students are involved in IBL as they explore the structure of arithmetic operations. Lesson sequences guide the class through noticing patterns, articulating conjectures, and using representations as vehicles for understanding and early notions of proof. Teachers facilitate 20-minute lessons several times a week throughout the year, supplemental to their standard mathematics curriculum. The collaborative nature of the process will be highlighted, as well as the potential impact that behaving as mathematicians can have on students' perception of mathematics and their role in the subject. (Received August 12, 2015)

1116-J5-300 **Benjamin Braun*** (benjamin.braun@uky.edu). *Constructing a Growth Mindset Environment: Using Psychological Interventions to Support IBL Pedagogies.* Preliminary report.

Over the past thirty years, research in educational and cognitive psychology has uncovered the profound impact that student beliefs about intelligence and ability have on achievement and deep learning. While IBL environments often implicitly challenge students' beliefs, explicitly incorporating these ideas into IBL courses provides a robust psychological foundation for many of the activities and pedagogical strategies used in IBL classes. In this presentation, I will provide a "user's guide" for constructing a classroom environment built around growth mindsets, including classroom activities and homework assignments that have been successfully used to support IBL pedagogies with ideas from psychology. (Received August 24, 2015)

1116-J5-413 **Jonathan K Hodge*** (hodgejo@gvsu.edu), Department of Mathematics, Grand Valley State University, Allendale, MI 49401. *An Inverted, Inquiry-Based, Points-Free Abstract Algebra Course.* Preliminary report.

Inquiry-based learning is compatible with and supports a number of other innovative approaches to instruction and assessment, including the flipped classroom and standards-based grading. In this talk, I will discuss my attempts to combine these approaches in an undergraduate abstract algebra course that serves a significant number of preservice teachers. (Received August 31, 2015)

1116-J5-491 **Susan B Crook*** (susan.crook@loras.edu). *Using my Imposter Syndrome to be a Better IBL Professor.*

This talk will discuss how professors can embrace their imposter syndrome to help them better understand student reaction to IBL classrooms. The speaker will give specific examples of how her evaluations of her own imposter syndrome have influenced her behavior in the classroom. Anecdotal evidence will be given to demonstrate the benefits of this understanding to students. (Received September 04, 2015)

1116-J5-598 **Melissa Tolley Nink*** (m.tolley@wingate.edu). *How Low Can We Go? Flipping in Lower Levels.* Preliminary report.

As a second year flipper, I looked in to the differences associated with flipping a lower level class (College Algebra) and a higher level (Calculus), as well as the results of flipping vs. traditional lecture. There are many theories surrounding the benefits and problems with flipping a remedial class, and my goal is isolate these with concrete data from my experiences. (Received September 08, 2015)

1116-J5-675 **Ekaterina Lioutikova*** (elioutikova@usj.edu), University of Saint Joseph, Department of Mathematical Sciences, 1678 Asylum Avenue, West Hartford, CT 06117. *Teaching an IBL course for the first time: successes, challenges and lessons learned.* Preliminary report.

In this talk, I will share my experience teaching an IBL-style abstract algebra course for the first time. Unlike in a pure Moore method course, the students were allowed to refer to a traditional textbook; however, at the heart of the course was a wide variety of inquiry-based activities, and most of the class time was spent on student presentations, discussions, and collaborative problem-solving sessions. I will describe some of the activities and strategies that I used and report on what was successful, what didn't quite work, and what challenges were encountered along the way. (Received September 10, 2015)

1116-J5-716 **sarah-marie belcastro*** (director@mathily.org). *Branching out within IBL: Guides to Support Experimentation.*

Instructors who are new to teaching with inquiry-based learning (IBL) have distinct curricular and guidance needs. There are workshops to help convert courses to IBL, and a growing community of instructors committed to IBL are willing to help newbies. There are course notes available at jiblm.org. But these resources do not cover extant needs—for example, what about instructors who don't fully control their courses, or who can only experiment within externally imposed limits? Or faculty who don't have nearby/accessible IBL mentors? Or teachers who simply aren't ready to go whole-hog into IBL and want to branch out in a limited way?

If you are in one of the groups listed above, come to this talk! It's especially for you. (It's also for people who are experienced in IBL and want to help guide interested colleagues. Actually, all are welcome, but the presenter knows that people read these abstracts from a variety of perspectives.)

In this talk, we present three how-to guides intended to help instructors plan IBL activities for single class sessions and across-a-few-classes threads. And, bonus!, we reveal one great older resource that you never heard about. (Yes, that's intentionally clickbait-y. But you really most likely *will* be surprised by the answer!)
(Received September 10, 2015)

1116-J5-748 **Frederick M Butler*** (fbutler@ycp.edu). *Getting Better at Using Inquiry-Based Learning.* Preliminary report.

This talk details efforts to incorporate inquiry-based learning into several mathematics courses. The structure of the courses, the types of assignments, and grading systems will be discussed. The different strategies needed for a sophomore-level course (Introduction to Proofs) compared to junior/senior level courses (Abstract Algebra and Topology) are noted. Additionally, the author explains how classroom results and student feedback helped him to improve his approach from one semester to the next. (Received September 11, 2015)

1116-J5-841 **Mark L. Daniels*** (mdaniels@math.utexas.edu), Prof. Mark Daniels - Mathematics Dept., 2515 Speedway Stop C1200, Austin, TX 78712. *Lessons Learned from an Inquiry-based Precalculus MOOC.* Preliminary report.

This presentation will explore the triumphs and challenges associated with offering an inquiry-based Massive Online Open Course (MOOC) in Precalculus. Examples of student-generated discussion within the MOOC, student-learning outcomes, and general data associated with the course offering will be shared. A discussion of "lessons learned" will also be presented. (Received September 14, 2015)

1116-J5-854 **Randall E Cone*** (recone@salisbury.edu), 128 Henson Hall, Salisbury University, Salisbury, MD 21801. *An IBL Life: The Story of Mr. Harry Lucas, Jr.*

The intellectual facility and prowess gained by studying mathematics in an Inquiry-Based Learning (IBL) format are skills which are transferable to any domain of interest. As a student of R.L. Moore, Mr. Harry Lucas, Jr. adopted the strategies and methods of IBL and effectively transferred them to the worlds of business and petroleum exploration. Throughout his successful career, Mr. Lucas maintained a life-long interest in mathematics, IBL, and the power behind each. In this paper, we examine the story of Mr. Lucas and his continued dedication to IBL and its numerous communities. (Received September 14, 2015)

1116-J5-908 **Audrey Malagon*** (amalagon@vwc.edu). *A Mathematical Easter Egg Hunt in IBL Proofs Course.* Preliminary report.

Over the past 3 years, Virginia Wesleyan College has been implementing an inquiry based introduction to proofs course. This talk highlights a hands on activity used to help students study relations by searching for elements in their relation in a friendly but competitive Easter egg hunt during our spring course. (Received September 15, 2015)

1116-J5-1122 **Tuck Choy Francis Chow*** (francis.chow@zu.ac.ae), Zayed University, P.O. Box 144534, Abu Dhabi, AZ, United Arab Emirates. *How wide is the river? Teaching through Problem Solving: A case study.*

This case study discusses an attempt by a group of teachers who were undergoing a professional development course to model a pedagogical practice of teaching mathematics through problem solving. The author argues that this can help them gain a sense of efficacy over their practice as they learn that there are avenues for them to reliably enhance students' mathematical thinking in a creative manner and to be able to apply their mathematical knowledge to problem solving in real-world contexts. Three recurring themes emerged from the case study were the experience of creative and collaborative problem solving, learning mathematics through mathematical discussion, and planning lessons that adapt to the emerging needs of learners. (Received September 17, 2015)

1116-J5-1149 **Shiv Smith Karunakaran*** (shiv.karunakaran@wsu.edu), 725 SW Mies Street, Pullman, WA 99163, and **Abigail L Higgins**. *Inquiry-based approach to teaching an introduction to proving course.*

An "Introduction to Proof" or "Transition to Proof" course is widely offered as an essential part of the undergraduate mathematics curriculum at most institutions of higher learning. The importance of such a course cannot be understated as the concepts and skills learned in this course are foundational to any subsequent mathematics courses. However, research suggests that undergraduate students continue to have issues understanding the function of proof and proving and also gaining access to the "private" aspects of proving. This session will report on an introduction to proving course that used an Inquiry-based approach to the teaching and learning of mathematical proving and proof, along with more traditional lecture-based approaches. The session will report on findings regarding changes in student attitudes regarding proof and proving, and on possible changes to the student approaches to proving strategies. (Received September 17, 2015)

1116-J5-1168 **Aviva A. Halani*** (ahalani@exeter.edu) and **Thomas D. Seidenberg**. *Secondary School Mathematics without a Textbook.*

The mathematics department at Phillips Exeter Academy has written a comprehensive, integrated secondary school mathematics curriculum in which all concepts are presented via a problem-solving format. Students are constantly reviewing and building upon concepts as all topics spiral throughout the curriculum. We will briefly explain the curriculum and present examples of student work from algebra through calculus. (Received September 17, 2015)

1116-J5-1261 **Daoud Salman*** (salmanddfr@yahoo.fr), 27 rue de la pompe, paris, 75016. *A New Method to develop the Logical-Mathematical Intelligence for solving the Mathematical problems.*

Abstract

Our Method, in fact, includes two new ideas, interrelated with each other. Their goal is to develop the Logical-Mathematical Intelligence of the students for solving the Mathematical problems and to find a new way for teaching Mathematics. The research focuses on the students at age (12-16 years), which is the interval of age where the child (student) is in the higher mental and cognitive development. The first idea set forth a new concept and design a scheme that shows the relationship between the types of the eight intelligences adopted by Gardner in his theory (Multiple Intelligences Theory), where we classified the Mind of the human into two types: 1. Complex Mind 2. Simple Mind The second idea, based on the first idea, we have designed a new model called the "Logical-Sequential Model", with which we aim to develop the Logical-Mathematical Intelligence of the students and to develop the cognitive abilities to overcome difficulties they suffer in solving mathematical problems. This model presents a new way to teach mathematics, a far cry from the traditional-typical way used in all schools, helping mathematics teachers and students together to facilitate the solution of mathematical problems in interactive and forward looking way. (Received September 18, 2015)

1116-J5-1285 **Patrick X Rault*** (rault@geneseo.edu), Geneseo, NY 14454, and **Ryan Gantner** and **C Yousuf George**. *A Model for Expanding Active Learning Regionally: The Greater Upstate New York Inquiry-Based Learning Consortium.*

What began as a group of professors getting together for dinner to discuss inquiry based learning (IBL) in our classes has developed into a strong network of IBL practitioners and instructors interested in IBL located across Upstate New York and beyond. Through a generous grant and a lot of hard work, we created the Upstate New York IBL Consortium with mission to build, grow, and maintain a network of instructors across the region. We have done this through mentoring, workshops, opportunities for conversation (both formal and informal), and systematic communication. In this presentation, we'll describe how the consortium was formed, the way it operates, and some we will provide some suggestions for forming one creating of your own regional network for supporting the adoption and enhancement of IBL techniques. (Received September 18, 2015)

1116-J5-1288 **Steven Schlicker*** (schlicks@gvsu.edu), Department of Mathematics, Mackinac Hall, 1 Campus Drive, Allendale, MI 49401, and **Feryal Alayont**, Department of Mathematics, Mackinac Hall, 1 Campus Drive, Allendale, MI 49401. *Inquiry-Based Activities for Linear Algebra.*

Linear algebra is often one of the first college-level mathematics courses in which students are expected to understand and work with a beautiful, yet complicated, web of deep mathematical concepts. In one semester students are expected to understand and become comfortable using algorithms needed for future courses, connecting a variety of mathematical concepts, and learning how to read and write proofs in the context of linear algebra statements. We will describe how we use a collection of preview and in-class activities throughout the semester to help improve student success in linear algebra. In each preview activity, students are exposed to the day's material through concrete examples of newly defined concepts or algorithms, or through questions asking them to reflect on previous concepts. In-class activities build on students' work in the preview activity to develop the topic more formally and precisely. Students work in small groups to practice algorithms and develop and strengthen their conceptual understanding during in-class activities. We will share examples of the activities during the talk. We will also report student feedback on activities through anonymous evaluations and weekly activity reviews, and our evaluation of the course when these activities were used. (Received September 18, 2015)

1116-J5-1330 **Forest Fisher** and **Jared Warner*** (jared.warner@guttman.cuny.edu). *"Build a City..." - exploring ratio and density through an urban planning board game.* Preliminary report.

In the context of a quantitative reasoning section of a multi-disciplinary course focused on the gentrification of New York City, we designed a board game to give students the opportunity to explore the concepts of ratio and density. "Build a City..." is a multi-player game with simple rules to be implemented in class in groups of 3-5 students. In the game, students assume the role of urban planner, and are asked to design cities (using a number of different "city pieces") that satisfy certain ratio and density requirements. With multiple levels of difficulty, and flexible city pieces and ratio requirements, this game could be adapted for many different levels of K–16 curriculum. In this talk, after describing the simple rules of the game, we'll have the audience play one round in small groups. We'll finish by discussing our experience in implementing the game in the classroom, highlighting potential challenges and helpful group discussion topics to address in class. (Received September 18, 2015)

1116-J5-1403 **David M McClendon*** (mcclend2@ferris.edu), ASC 2021, Department of Mathematics, Big Rapids, MI 49307. *Teaching the nth derivative test with inquiry-based Mathematica activities.* Preliminary report.

In this talk, I will discuss an ongoing program at Ferris State University to revamp the calculus curriculum, in part by developing technology-centered, inquiry-based activities to teach calculus concepts. I will focus on one such activity, in which students discover various methods of classifying local extrema (especially the Second Derivative Test and the more general n^{th} Derivative Test) by performing *Mathematica* computations, making and testing conjectures based on the results. (Received September 19, 2015)

1116-J5-1685 **Heather A. Lewis*** (hlewis5@naz.edu). *Jumping In: The switch to lecture-free inquiry-based calculus.*

In 2014 our department made the switch to offering all of our calculus sections through inquiry-based learning. Specifically, the courses are now taught through student problem-solving, with little to no lecture. I have now taught both single- and multi-variable calculus this way, and enjoy it much more than I expected. In this talk I will discuss my initial reservations; the logistics of prep, classtime, and grading; student response; and my own reflection. (Received September 21, 2015)

1116-J5-1770 **Vincent J. Matsko*** (vjmatsko@usfca.edu). *Writing Original Problems in Calculus Classes.*

Having students write their own original mathematics problems requires that they interact with calculus in a fundamentally different way than the traditional "solving book problems" approach. This assignment has been successfully implemented in calculus and other courses for several years. Practical details of classroom implementation will be discussed, as will the results of a research study on this assessment. In addition, a few brief examples of other IBL activities will be presented. (Received September 21, 2015)

1116-J5-1808 **Angie Hodge*** (amhodge@unomaha.edu). *Utilizing IBL to Effectively Engage Youth in Mathematics.*

This session will describe a STEM outreach program, Eureka!–STEM, that's founded on IBL principles. Eureka!–STEM program is a five year program sponsored by Girl's Inc., in which the goal is to increase interest in and encourage underprivileged female students to continue in STEM fields throughout high school and college. For the first two years of the program, the middle school girls spend the month of June on a university campus, participating in a variety of engaging STEM and physical activities. All of the activities are hands-on, minds-on and are meant to show the girls what STEM is, beyond the classroom. This session will include information on the program itself, as well as provide samples of interactive IBL mathematics lessons that can be used in any university outreach program. The lessons/activities could also be used in IBL mathematics content courses for future teachers. (Received September 21, 2015)

1116-J5-1813 **Vseta Coufal*** (coufal@gonzaga.edu), 502 E Boone Ave, Gonzaga U., Spokane, WA 99006. *Guided Inquiry in Calculus II.* Preliminary report.

I have taught Calculus II (mainly integration and series) for many semesters. I became concerned that my students did not understand the material at a deep enough level and did not retain the skills I thought they had mastered as they moved through other courses. After much exploration and deliberation I decided that using something like the Process Oriented Guided Inquiry method might address my concerns. In short, students work through carefully crafted worksheets in highly structured groups. The worksheets are written so that the students really dig into the material, developing their own conceptual understanding as well as applying the concepts and gaining computational skill. The group structure helps them move efficiently and collaboratively through the worksheets. I will share examples of successful worksheets, give a preliminary report on my experiences and successes, and address the accessibility of this method for new faculty and novice IBL users. (Received September 21, 2015)

1116-J5-1886 **Frank Savina**, The Charles A. Dana Center, The University of Texas at Austin, 1616 Guadalupe, Suite 3.206, Austin, TX 78701, **Stuart Boersma*** (boersmas@cwu.edu), Central Washington University, 400 E. University Way, Ellensburg, WA 98926, and **Rebecca Hartzler**, Seattle Central College, 1701 Broadway, Seattle, WA 98122. *An Active STEM Prep Curriculum.*

The STEM Prep Pathway is designed as two one-semester courses created by the New Mathways Project that prepares students beginning at the elementary algebra-level to succeed in college-level calculus. All Lessons are designed to be contextual, meaningful, with guided student inquiry at the core. Each Lesson is 25 minutes long and is typically preceded by a short Preview Assignment, which students complete before class. The Preview reviews skills required for the upcoming Lesson, provides problems to orient the student and also asks a reflection question for the student to determine if they need additional support prior to class. Each Lesson begins with an easily accessible Opening Question designed to include the experience and opinions of all students. Students complete Practice Assignments to cement their learning. All lessons include detailed instructor notes suggesting pedagogical approaches, facilitating questions, and the lesson's Constructive Persistence (CP) level. Early in the course Lessons are designated as CP 1 and 2 as students build their ability to work independently. CP 3 level promotes productive struggle with engaging problems that are more open-ended. For this talk we will share examples from the curriculum that exemplify these design principles. (Received September 21, 2015)

1116-J5-1957 **Sarah Wolff*** (wolffs@denison.edu). *Introducing Inquiry-Based Mathematics Learning Materials into South African Public Schools.* Preliminary report.

This talk will discuss joint work with Johann Engelbrecht and Caroline Long at the University of Pretoria in South Africa. We partnered with the Ukuqonda Institute to help integrate and monitor new inquiry-based mathematics learning ma- terials in South African public schools. Specifically, the project included a small-scale but in-depth study that involved introducing and observing the use of the materials in the classroom at Bogkoni Technical School in the Attredgeville Township. This study served as the pilot phase for an ongoing project of larger scope.

The Ukuqonda workbooks were developed under a theoretical framework centered around the themes of richness, pro-activeness, vitality, and variety. Above all, the materials are meant to promote conceptual understanding and inquiry-based learning, while still being acceptable to an audience of traditionally-oriented teachers. From this study we determined that while the materials promoted some inquiry and self-guided learning, this was largely dependent on how the teacher shaped his or her class around the materials. In this talk we will discuss the reactions of South African teachers and students to inquiry-based learning materials and the necessity of teacher training to accompany the introduction of such materials. (Received September 21, 2015)

1116-J5-2208 **Yun Lu*** (lu@kutztown.edu), Department of Mathematics, Kutztown University of PA, Kutztown, PA 19530. *Teaching Graph Theory Course Using Modified Inquiry-Based Method.*

In this talk, I will share my experience of using modified inquiry-based method to teach graph theory course for the first time. I will discuss some of my successful and unsuccessful approaches, as well as students' feedback and performance if time allows. (Received September 22, 2015)

1116-J5-2303 **Dywayne A Nicely*** (nicely@ohio.edu), Ohio University-Chillicothe, 101 University Drive, Chillicothe, OH 45601, and **Steven Widmer** (steven.widmer@unt.edu), General Academics Building 423B, 1155 Union Circle #311430, Denton, TX 76203-5017. *Flipping Precalculus through Guided Notes.* Preliminary report.

Other instructors have had success in implementing the flipped classroom model in their mathematics courses. Therefore we decided to analyze the effects of the flipped classroom model in our precalculus sections. This intervention is a collaborative effort between the University of North Texas (UNT) and Ohio University-Chillicothe (OUC). UNT represents a large university setting with annual enrollments greater than 35,000 and OUC represents a small regional campus setting with annual enrollments of around 2,500. Part of the motivation of this intervention is to determine if the effects of implementing a flipped classroom model are different when conducted with students at a large university setting versus a small university setting. In this preliminary report, we offer data from the control groups which are populated from students from the past fall semester. Along with the data, we will detail the methods and procedures to be conducted during this flipped classroom intervention with a particular emphasis on guided notes. (Received September 22, 2015)

1116-J5-2317 **May Mei*** (meim@denison.edu). *Active Calculus: An Activity-Driven, Student-Centered Approach.*

In this talk, I describe my first semester using a completely activity-based approach to calculus with Matt Boelkins' Active Calculus. The course is Essentials of Calculus, which is meant to be calculus for students who have never taken calculus before. I hoped that students would experience mathematics as a generative process, that they would feel capable of creating their own mathematics, and that this would dissuade them of the notion that they are not "math people." To this end, I present some results from surveys conducted at the beginning and end of the semester. (Received September 22, 2015)

1116-J5-2387 **Spencer Payton*** (spayton@math.wsu.edu). *Student mathematical connections in an inquiry-oriented introductory linear algebra class.* Preliminary report.

In an introductory linear algebra course, students are introduced to a large number of new concepts and definitions; further, they are expected to understand how these various concepts are all connected. In an attempt to improve the teaching of these various mathematical connections, this session will report on an action research study that focuses on the implementation of inquiry-oriented teaching in an introductory linear algebra class. The goals of this study were two-fold: to determine how inquiry-oriented teaching can be effectively implemented in an introductory linear algebra course and to determine the mathematical connections students appear to evoke in an inquiry-oriented linear algebra course. Data was collected over the course of two action research cycles, with each cycle taking place in an introductory linear algebra classes that I taught; the first class was taught in the summer of 2015, and the second in the fall of 2015. Data sources include video and audio recorded classroom observations, my own personal reflections on those observations, interviews with my students, and student work submitted through homework, exams, and in-class work. (Received September 22, 2015)

1116-J5-2475 **David H Crombecque*** (crombecq@usc.edu), 3620 S.Vermont Avenue, KAP 104, Los Angeles, CA 90089. *Introduction to Proofs in Topology and Geometry Using IBL.* Preliminary report.

Working in a program that does not offer an Introduction to Mathematical Proofs for undergraduate Math Majors, we have been using a sequence of two classes, Geometry as well as Modern Topology, to develop problems and activities using IBL to develop students' proof skills. The choice of problems and activities lead students to think about various common mathematical questions necessitating a common approach: e.g showing existence or non existence of a mathematical object, unicity, independence of choice. In this talk, we will give a sample of such questions students have to tackle in the class while discovering a fun new mathematical world. (Received September 22, 2015)

1116-J5-2497 **Pamela Pierce*** (ppierce@wooster.edu), Department of Mathematics and CS, The College of Wooster, 1189 Beall Ave., Wooster, OH 44691, and **Jim Hartman**. *Learning to Ask Questions: A Matrix Project.* Preliminary report.

As educators, we want to prepare our students to be able to solve complex problems in a changing world, in fields that perhaps do not even exist today. Toward this end, we see the importance of developing within our students the ability to ask deep questions and to approach these questions as researchers. Here we present the Matrix Project, an assignment that we have used in our Linear Algebra classes that is designed to develop both student curiosity and a research mindset that welcomes open-ended questions. (Received September 22, 2015)

1116-J5-2508 **Ali S Shaqlaih*** (ali.shaqlaih@untdallas.edu), University of North Texas at Dallas, Dep. of Mathematics and Information Sciences, 7400 University Hills BLVD, Dallas, TX 75241. *Developing Elementary Teachers' Pedagogical Knowledge through Improving their Math Content knowledge.*

Having a strong content knowledge is necessary for successful teaching, however it is not sufficient. In this talk, we will show how an inquiry based learning approach was used in a math content course to improve elementary teachers' content and pedagogical knowledge. Qualitative and quantitative methods will be used to analyze pre-service teachers and elementary students work. Students' engagement, class dynamics and the correlation between teachers' content and pedagogical knowledge will be discussed. (Received September 22, 2015)

1116-J5-2555 **Adrian P. Gentle*** (apgentle@usi.edu). *Towards an Inquiry-Based, Writing-Intensive Number Theory Course.*

An introductory course on elementary number theory is well suited to an instructor's first foray into inquiry-based learning. In this talk, I discuss my experience transitioning a writing-intensive number theory course from a primarily lecture-based format to a more student-centered approach, inspired by the "inquiry Friday" model of Mahavier (2009). Classes were typically a mix of lecture and activities on Monday and Wednesday, with Fridays devoted to student presentations which explore and extend the ideas introduced earlier in the week. Writing activities were designed to complement the inquiry approach, prompting students to reflect on their attitudes and approach to mathematics. After a semester spent coaxing students to believe in the value of mistakes and the centrality of questions, I will describe some of the activities that worked well, and reflect on the (many) mistakes. The questions raised may be helpful to other instructors considering transitioning to an inquiry-based classroom. (Received September 22, 2015)

1116-J5-2600 **Teresa D Magnus*** (tmagnus@rivier.edu), Dept. of Mathematics and Computer Science, Rivier University, 420 S. Main Street, Nashua, NH 03060. *Introducing IBL to Future Elementary Teachers and Others in a Geometrical Explorations Course.* Preliminary report.

In Geometrical Explorations, my goal was to break the cycle of rote learning that takes place in so many classrooms and help future teachers embrace the idea of IBL. At the same time, I wanted to develop a deeper understanding of the concepts of geometry and the connections with other areas of mathematics. The course had no textbook and lecture was rare. Instead, the students worked in groups to explore the area model of multiplication through pentominos, the Pythagorean theorem through puzzles, angle measure through tiling, and many other geometric concepts through hands-on exploration, observation of patterns, and guided questioning. Students were also encouraged to develop their ability to write mathematical explanations and informal proofs as they summarized their discoveries. This presentation will give an overview of the course with some sample lessons along with a summary of plans for enhancing the course further. (Received September 22, 2015)

1116-J5-2631 **Matt Roscoe*** (matt.roscoe@umontana.edu). *A Technology-Assisted, Inquiry-Based Approach to Teacher Education Using GeoGebra.*

GeoGebra is free dynamic geometry-algebra-statistics software that provides new and exciting possibilities for the mathematical preparation of teachers. In this session I will give a brief introduction to GeoGebra and then describe the affordances of the use of GeoGebra in promoting technology-assisted, inquiry-based learning as part of the regular training of future mathematics teachers at both the elementary and secondary levels. Specifically, I will describe an inquiry-based series of laboratory activities aimed at elementary school teachers in a geometry content course and a series of investigations aimed at secondary school mathematics teachers in a course on mathematical modeling. Web resources, lab activities, investigations and examples of student work will be shared. (Received September 22, 2015)

1116-J5-2656 **Cheri Boyd** and **C. Yousuf George*** (cgeorge0@naz.edu), Nazareth College, 4245 East Avenue, Rochester, NY 14618, and **Nicole Juersivich**, **Matt Koetz** and **Heather Ames Lewis**. *A Departmental Transition From Lecture To IBL In Calculus.*

Beginning in Fall 2014, our entire department began teaching our full sequence of calculus courses via Inquiry Based Learning. In this talk we discuss how we were able to make this transition as a department initially, which aspects of teaching this way we all agreed on and which aspects are left up to individual instructor preference, what the current state of our courses is, and our plans for the future. We will also discuss the effects this wholesale change has had on our department – both for students and for faculty. (Received September 22, 2015)

1116-J5-2792 **Talitha M Washington*** (talitha.washington@howard.edu), Howard University, Department of Mathematics, Washington, DC 20059. *A Lab-Style Proof and Problem Solving Course.*

Most proof and problem solving courses involve students rummaging through logic, and then learning proof structure by example. In this talk, I will define a lab-style proof course. In each class, I give students minimal direction as they disperse quickly into teams to solve problems via proofs. When active in engagement, students can seek knowledge from their peers. This encourages students to take ownership of creating mathematics on the foundation of logical structures. In this talk I will describe in detail my challenges and experiences in creating and teaching this course. (Received September 22, 2015)

1116-J5-2862 **Carol G. Gee*** (carolg@stedwards.edu). *Specifications Grading in an IBL Proofs Class: Managing Student Expectations.* Preliminary report.

Grades in an inquiry-based introduction to proof writing course are often based on the number of proof credits students earn across a semester. Quantifying the expected performance in such a course, where students typically progress slowly at first and hit their stride at different stages, can be a challenge for instructor and student alike – especially so in the pilot offering of a course! We will discuss how specifications grading helped communicate expectations to students in the syllabus, how literacy exams and progress appointments provided individualized feedback at critical points during the semester, and how these practices impacted student perception and performance. (Received September 22, 2015)

1116-J5-2954 **Belin Manuel Tsinnajinnie*** (btsinnajinnie@iaia.edu), 83 Avan Nu Po Road, Santa Fe, NM 87508. *Integrating Complex Instruction to Promote Engagement in Developmental and Liberal Arts Mathematics Courses Through Groupwork.* Preliminary report.

Many instructors view the notion of collaborative learning as a valuable strategy intended to promote learning through multiple forms of communication and student-centered engagement. Yet pitfalls of groupwork, which include students dominating discussion, students feeling isolated, and tasks failing to elicit the participation of each group member, often prevent students and instructors from fully benefiting from activities designed to elicit collaboration. This paper describes pedagogical approaches that draw from principles of Complex Instruction (CI) (Cohen, 1994) implemented in developmental mathematics and college level liberal arts mathematics courses at a tribal college institution focused on fine arts. The author addresses how principles of CI not only address common pitfalls of groupwork, but are also designed to raise levels of engagement and expectations. A summary of these implementations include a reflection of both the effectiveness and challenges in practice. (Received September 23, 2015)

1116-J5-2980 **Volker Ecke*** (vecke@westfield.ma.edu<mailto:vecke@westfield.ma.edu>), **Christine von Renesse**, **Julian Fleron** and **Phillip K Hotchkiss**. *Discovering the Art of Mathematics: Evaluating our Student Goals.*

For students in the liberal arts, the learning objectives typically extend beyond a particular set of specific mathematical skills. Taking a long-term perspective, the key goals include a deeper appreciation for the nature and culture of mathematical inquiry, a shift towards more balanced beliefs and attitudes in the students' role as mathematicians, and a more positive engagement with mathematical ideas outside the classroom. As part of the "Discovering the Art of Mathematics" project (artofmathematics.org), we hypothesized that students' deep, active engagement in authentic mathematical investigation in an inquiry-based learning classroom would: strengthen reasoning skills, broaden awareness of and foster interest in mathematics outside the classroom, offer enjoyment in doing mathematics, support insight into the role of beauty, creativity, and curiosity in the pursuit of mathematical truth, as well as increase students' sense of agency, confidence, and authorship in developing mathematical ideas. Our results show that all changes occur in the hoped-for direction with most changes showing statistical significance and meaningful effect sizes. We will discuss our study, findings, limitations, and areas for future research. (Received September 30, 2015)

Mathematical Modeling in the Undergraduate Curriculum

1116-K1-110 **Timothy J Pennings*** (tpennings@davenport.edu), 6191 Kraft Avenue, S.E., Grand Rapids, MI 49512. *Mathematical Modeling: Dirac, Einstein, and Barging the Big Easy.*

We begin briefly with the same question which should begin a modeling class: "Why does mathematical modeling work?" This adds a bit of humility and mystery to a subject that is often devoid of it at the college level. Some notable quotes will show that the answer is deep and illusive. Failing to answer that, we successfully address the more practical question, "What are some features of a good modeling project?" Finally, we spend the bulk of the time becoming acquainted with a favorite modeling project which the author and his colleagues have used for years in calculus and ODE courses: Barging Ahead: Optimizing a Trip Upriver. (Received July 27, 2015)

1116-K1-219 **Jakob Kotas*** (jkotas@uw.edu), University of Washington, Dept. of Applied Mathematics, Lewis Hall #202, Box 353925, Seattle, WA 98105. *Introducing linear programming in mathematical modeling courses.*

Linear programming (LP) is a branch of mathematics concerned with the optimization of a linear objective function under linear equality and/or inequality constraints. LP is frequently taught in operations research curricula but is not commonly discussed in undergraduate-level applied mathematics and mathematical modeling courses, perhaps because it strays from a typical calculus-based modeling approach. Nevertheless, the ability to formulate an applied problem as an LP is a valuable skill due to the preponderance of very efficient solution methods. Furthermore, there exists an elegant geometric interpretation of such problems, strengthening intuition between branches of mathematics. This talk will cover some benefits and challenges encountered in incorporating concepts from linear programming into an undergraduate-level mathematical modeling course. (Received August 14, 2015)

1116-K1-294 **James Walsh*** (jawalsh@oberlin.edu). *An ODE-based climate modeling course.*
Conceptual models of climate provide for a host of interesting and relevant mathematical modeling experiences for undergraduates. After recounting my incorporation of climate modeling into the sophomore-level ODE course, I will discuss successes and failures encountered when I recently offered a junior-level mathematical modeling of climate course. As a group we carefully analyzed two models—a surface temperature-ice sheet coupled model and a model of the Atlantic Overturning Circulation—while introducing topics from the qualitative theory of ODEs as needed (and relying fairly heavily on *Mathematica*). Students devoted the latter part of the semester to independent research projects, culminating in both a paper and a presentation.

Colleagues from each of the Physics and Chemistry departments at Oberlin kindly gave guest lectures. I also benefited from discussions with a colleague in our Geology Department. It is not difficult to envision a course such as this evolving into a team-taught enterprise, to the benefit of students and to each participating faculty member. (Received August 23, 2015)

1116-K1-322 **Anna Varvak***, Pauling Hall 428, 1 University Drive, Aliso Viejo, CA 92656. *Explore the world through Worldbank: using open data in Liberal Arts Math to explore the world's past and project future trends.*
Introduction to the philosophy and basic techniques mathematical modeling is quite accessible to college students who have little more than shaky high-school Algebra. Various reliable statistics about countries around the world are freely available for free through Worldbank and other reliable sources, to anyone with an internet connection and a spreadsheet software. For some of the statistics, it's important to discuss their definitions (e.g. "fertility rate"). Some statistics are clear outright (e.g., number of births and deaths) yet even then, it's important to consider how these statistics are collected and recorded, and how the recorded estimates may differ from reality. Many of these statistics have been reliably collected and recorded for decades. Graphing lets students make hypotheses about possible trends. The students extend the trends into the future: they clarify how they expect the country's statistic to change from year to year, and use the spreadsheet to compute the projected values. The students then examine the plausibility of their model, and compare different models. Models include discrete versions of linear, exponential and logistic models, and models predicting changes in first and second derivatives. (Received August 25, 2015)

1116-K1-327 **Michael Olinick*** (molinick@middlebury.edu), Department of Mathematics, Middlebury College, Middlebury, VT 05753. *Arms Races, Fair Voting, and the Bible: Examples from a Case Studies Oriented Modeling Course.*
Nontraditional applications in such fields as the social sciences and humanities provide an appealing way for undergraduates lacking a background in the physical sciences or engineering to investigate and develop models as they learn new mathematical tools. We describe a case studies oriented course at the sophomore-junior level that introduces students to deterministic, probabilistic, axiomatic and simulation models. Illustrative examples will show how the dynamics of arms races can be modeled with systems of differential equations, how classic Biblical tales can be investigated with decision and game theory, and how Arrow's Theorem explains the frustration in trying to build just voting mechanisms. (Received August 25, 2015)

1116-K1-363 **Eric Alan Eager*** (eeager@uwlax.edu), 1725 State St., La Crosse, WI 54601, and **James Peirce** and **Patrick Barlow**. *Math Bio or BioMath? Flipping the Mathematical Biological Classroom.*
Mathematical and computational methods are vital to many areas of contemporary biological research, such as genomics, molecular modeling, structural biology, ecology, evolutionary biology, neurobiology, and systems biology. As such, the contemporary life science student needs to be exposed to, if not well-versed in, many of the techniques of mathematical modeling to keep pace. However, traditional ways of teaching mathematics may not be able to provide these students with the skills and experiences necessary to effectively use modeling in their careers as practitioners and/or researchers, as these skills and experiences (interdisciplinary collaboration, for example) are difficult to teach using traditional, lecture-style approaches. In this talk I describe the development, implementation and assessment of a flipped-classroom approach to teaching a sophomore-level mathematical models in biology course for life science majors. (Received August 27, 2015)

1116-K1-422 **Ricardo Cortez*** (rcortez@tulane.edu), Mathematics Department, Tulane University, New Orleans, LA 70118, and **Cynthia O Anhalt** (canhalt@math.arizona.edu), University of Arizona, Mathematics Department, 617 N. Santa Rita Ave., Tucson, AZ 85721. *Design and Implementation of an Undergraduate Mathematical Modeling Course with no College Prerequisites.*

Most mathematical modeling courses are at the upper-division level. Students build their mathematical knowledge (e.g. linear algebra, ODEs, numerical methods, probability) and develop a broad background before being exposed to modeling. In contrast to this paradigm, a new course, Understanding our World Through Math Modeling, was offered at Tulane University in 2015. The goal of the course was to expose students to the modeling process as a way to describe, explain, understand or predict situations arising in everyday life. The course was open to all undergraduates; was problem-driven; and required group work, written reports and frequent presentations. Examples of situations included settling discrepancies on the number of sand bags needed to raise a river bank, predicting the number of daylight hours at different cities, analyzing the consequences of child support payment formulas, and estimating the capacity of trees to capture sunlight energy from leaf size data. Students created models based on their knowledge and learned new content. The modeling process emphasized making assumptions, translating the situation into mathematical language, drawing and validating conclusions in context, and revising assumptions. I will describe the benefits and challenges of this course. (Received August 31, 2015)

1116-K1-443 **Angela B. Shiflet*** (shifletab@wofford.edu) and **George W. Shiflet**. *Using Agent-Based Modeling to Gain Insight into the Natural World.*

With enhanced computational abilities and upsurge in quantities of data, scientists routinely implement computation to test hypotheses and direct their research. We have developed a course that employs computational approaches to investigate scientific questions. In the course, students explore science concepts and, using computational tools and algorithmic thinking, apply the scientific method to understand the natural world. Fulfilling a science requirement, the course is designed to be taught by faculty from any mathematics, science, or computer science department. We report here on the implementation of the course over a two-semester period with different instructors. (Received September 01, 2015)

1116-K1-628 **Jason Cantarella*** (jason.cantarella@gmail.com), Boyd GSRC, Athens, GA 30602, and **Harrison Chapman**. *A robotics-based calculus class.*

This talk discusses a one-semester calculus class organized around a simple problem: throw a ball bearing one meter into a coffee cup using a rotating arm. In the class, we have a computer-controlled throwing arm which spins at a defined speed and releases the bearing at a known angle– the calculus I class is organized around the problem of choosing rotation speed and release time to land the bearing in the cup. This requires students to learn a nontrivial application of calculus as they learn the material. Given time, we'll bring the robot arm and give a live demonstration of the throwing process. (Received September 09, 2015)

1116-K1-829 **Paul T Taylor*** (pttaylor@ship.edu). *Using challenge problems to motivate exploring models.* Preliminary report.

In a general education level class, it is often a success to teach students to understand a model well enough to apply it as intended. The more creative aspects of mathematical modeling can seem out of reach, especially in a course not specifically focused on the modeling process. In this talk we explore using extra credit challenge problems to motivate students to adapt, combine, and improve models in a general education class in financial mathematics. (Received September 13, 2015)

1116-K1-902 **Michael Bader***, Department of Informatics, Technische Universität München, Boltzmannstr. 3, 85748 Garching, Germany. *Tsunami Simulation for Teaching CSE and HPC.*

The open source code SWE (https://github.com/TUM-I5/SWE/) implements a simple Finite Volume method to solve the shallow water equations. With small extensions, the code can be applied to simulate basic tsunami scenarios. It has been used in several undergraduate courses focusing on education in Computational Science and Engineering and Parallel Computing, as well as for graduate students in the context of summer schools.

In a Bachelor-level programming lab, students implement their own version of SWE from scratch, starting with Riemann problems and also dealing with software developement issues, such as testing and I/O. As project activities, students have implemented versions of SWE in diverse languages, such as Java, OpenCL or CUDA. In addition, the SWE code has been the basis for various undergraduate research projects dealing with diverse topics, such as the extension of shallow water models, uncertainty quantification or novel approaches in parallel programming. (Received September 15, 2015)

1116-K1-920 **Maeve Lewis McCarthy*** (mmccarthy@murraystate.edu), Mathematics & Statistics, Murray State University, 6C Faculty Hall, Murray, KY 42071. *Flexibility in a Mathematical Modeling class.*

Mathematical Modeling at Murray State University is taught as a cross-listed undergraduate and graduate course with different syllabi. Given the mixed mathematical backgrounds, the course must incorporate examples that are both accessible and challenging. In this presentation, we discuss a content outline that has this kind of flexibility while still maintaining an appropriate standard for both audiences. The course includes optimization, dynamical systems and stochastic models and focuses on building a wide range of models and solving them with Matlab. (Received September 15, 2015)

1116-K1-1170 **Emma Smith Zbarsky*** (smithzbarskye@wit.edu). *Bringing current events to life: modeling the 2014 Ebola outbreak in Engineering Calculus I.*

Our first year engineering calculus sequence endeavors to instill in our students an understanding of mathematical concepts and their applications to the greater world. During the fall of 2014, I chose to develop my students' familiarity with spreadsheets, numerical derivatives, basic integrals and modeling by having them use current data on the Ebola outbreak in five countries in West Africa. They computed first and second derivatives of the number of deaths in each country with respect to time, created a simple model fitting the observed second derivative and then integrated their model back up using known initial conditions to create a predictive model for the number of deaths that would occur in coming months. They were graded, luckily for them, on their correct use of the modeling process rather than the accuracy of their model as many students predicted that the entire population of the Earth had died as of July. We finished the project by discussing why their models diverged from the data. (Received September 17, 2015)

1116-K1-1239 **Tim Chartier*** (tichartier@davidson.edu), Department of Math and CS, Davidson College, P.O. Box 6908, Davidson, NC 28035. *Discrete sports modeling.*

Your students can find sports models and be discrete about it. This talk will present mathematical modeling techniques in the context of sports, with an emphasis on discrete math modeling. Sports vary and can include baseball, football, basketball or even mixed martial arts fighting. We'll also discuss a few problems posed to the presenter and his students by ESPN's Sport Science show. The talk will discuss the importance of building and evaluating a math model. Math techniques for our modeling playbook will include Monte Carlo simulation, linear algebra, statistics and probability. We will also discuss how such ideas can be adapted to contexts outside athletic performance. (Received September 18, 2015)

1116-K1-1448 **Jennifer R. Galovich*** (jgalovich@csbsju.edu). *Agent Based Modeling Across the Curriculum.*

When individuals (human or not) act autonomously, interesting collective behavior may develop. For example, individual choices may affect how neighborhoods become racially segregated. Agent based modelling examines such emergent behavior and can be an especially effective way to teach students how to ask the "what if..." questions that lead to deeper understanding. I will present examples from a course in mathematical modeling in biology and ideas for use in mathematics courses as well as courses outside our discipline. This is a pedagogical (and research) tool that can be used successfully, even if you are not an expert programmer! (Received September 19, 2015)

1116-K1-1789 **Alexander Y Vaninsky** and **Daniel De La Cruz***, 500 Grand Concourse, Room B409, Bronx, NY 10451, and **Stephen Darko**, **Jesus Garcia** and **Cory Tambourine**. *Bridging Mathematics, Physics, and Computer Science in an undergraduate research project "Modeling the Earth – Moon Satellite Orbit".*

This project was aimed to exploit the synergy of cooperative learning, focused on a topic that is challenging and important practically. Participants in the project investigated a rescue operation designed for an urgent delivery of a crew working on the Moon back to the Earth. A specific goal was to investigate the trajectory of the cosmic vessel. The project included the study of the dynamics of the jet motion in space, devising a system of differential equations for modeling the trajectory of the motion in a fixed and rotated coordinate systems, and using the Maple software for solving differential equations and exploration of the solution. One of the obtained results was the counterintuitive bus-orbit shape of the trajectory in the rotated coordinate system. Another result was finding the escape velocity resulting in leaving the Solar system. We discuss the experience obtained by the participants and the impact of the project on their educational and professional goals and communication and writing skills. This project was funded under Title V Grant Award from the United States Department of Education, aimed at the developing Hispanic-Serving Institutions Program. (Received September 21, 2015)

1116-K1-1945 **Leon H Seitelman*** (lseitelman@aol.com), 110 Cambridge Drive, Glastonbury, CT 06033. *A National Mathematical Modeling Contest to Seed the STEM Pipeline.*

The need for more STEM-trained graduates is an often stated national priority, success in expanding the STEM pool has been limited. High school students thinking about possible career paths can benefit from an opportunity to learn how mathematical modeling can help us understand and solve a broad spectrum of real-life problems, a powerful demonstration of the practical value of mathematics in today's world.

The Moody's MegaMath (M^3) Challenge, funded by the The Moody's Foundation and organized by the Society for Industrial and Applied Mathematics, enters its eleventh year in 2016 with national reach. The M^3 Challenge provides this kind of educational experience for teams of three to five high school juniors and seniors. Each team has 14 hours to study an open-ended, real-world problem and present its solution in the form of a jargon-free report that is understandable to the non-scientific community.

More than 1100 solution papers were submitted in the 2015 contest. Selecting the best of the solution papers for recognition (and cash prizes!) is a multistage process that was developed and repeatedly refined over the past decade. In this paper, we review this development process, and discuss essential characteristics of successful solutions. (Received September 21, 2015)

1116-K1-2243 **Debra L Mimbs*** (dmimbs@leeuniversity.edu). *Modeling, Inquiry, and Discovery in Calculus.*

I present a problem from a standard Calculus 1 course with an emphasis on mathematical modeling. Even students in Calculus 1, without advanced mathematical knowledge, can benefit from introducing a modeling perspective early. The problem is presented with adaptations and further considerations offered, and an evaluation of the impact this method has on student learning is also analyzed. (Received September 22, 2015)

1116-K1-2273 **Ethan Berkove*** (berkovee@lafayette.edu). *A Modeling Capstone Course.*

Case Studies in Mathematical Modeling is an upper level course offered at Lafayette College. It is a capstone course for the joint math-economics major, but open to all majors, and many math majors elect to take it. Students in Case Studies work in groups on three projects during the semester, then report on their findings both orally and in writing. In this talk I will address the structure and goals of the Case Studies course, teaching tips, lessons learned, and student reactions. I will also describe some community-based learning projects that have been successfully incorporated into the class. (Received September 22, 2015)

1116-K1-2420 **D. Brian Walton*** (waltondb@jmu.edu), 60 Bluestone Drive, MSC 1911, Harrisonburg, VA 22807. *A Modeling Approach to Calculus: Using the framework of modeling in the motivation and development of calculus.* Preliminary report.

A significant number of students interested in STEM fields enter college with experience in pre-calculus and calculus but without adequate understanding or skills to succeed in a standard first semester calculus course. Sending these students to a traditional college pre-calculus course risks providing an experience in which the students' sense of familiarity prevents their addressing faulty cognitive models for understanding mathematics. An alternative is to use an approach where students encounter an unfamiliar paradigm and thereby work to address the dissonance between their thinking and the challenge presented. The author is developing a two-semester course designed to address these needs by integrating learning objectives from pre-calculus and calculus (differentiation and integration) where the motivation and the development of the mathematics are centered on the process of mathematical modeling. This report will include the organization of the course, examples of activities in which students engage in the modeling process, a discussion of how communication is emphasized as a part of modeling, and observations about outcomes and challenges. (Received September 22, 2015)

1116-K1-2482 **Jean Marie Linhart*** (jmlinhart@cwu.edu), Department of Mathematics, 400 E. University Way, Ellensburg, WA 98926. *What is Mathematical Modeling?*

When I started teaching mathematical modeling, one thing I wanted my students to know is what mathematical modeling is and the process of creating mathematical models. I thought this would be an easy learning outcome, but I was wrong. This talk will discuss the evolution of my teaching and assignments addressing this learning outcome, and how a deeper understanding of the modeling process influenced student's perspectives on the course. (Received September 22, 2015)

1116-K1-2538 **Sarah Iams*** (siams@seas.harvard.edu) and **Margo Levine** (mlevine@seas.harvard.edu). *Offering individualized modeling experiences at a large university.* Preliminary report.

Applied Math is the sixth largest undergraduate program at Harvard with approximately ninety majors per year, (36% women), serving students with application interests ranging across the physical and social sciences. Students study a range of mathematics, build foundational knowledge in statistics and computer programming, as well as three other mathematical areas, and gain a quantitative introduction to a field of application, such as economics, linguistics, physics, government, music, or environmental science.

Modeling is an important skill for applied mathematicians, and we require a substantive mathematical modeling experience, either via coursework or a senior thesis, to earn Honors in the major. We teach two modeling courses, one at the introductory level (with no calculus prerequisite) to introduce students to a range of application areas. The other course, which about half of majors take, is at the junior/senior level, and involves group and individual modeling projects. In addition, about 20 - 25% of our students write a senior thesis, which is a year-long modeling project where they attempt to develop and analyze a new model in their area of interest. We will highlight the benefits and challenges in offering these modeling experiences to our students. (Received September 22, 2015)

1116-K1-2560 **Audrey Malagon*** (amalagon@vwc.edu) and **Lisa Driskell** (ldriskel@coloradomesa.edu). *Snails in a Tide Pool & Other New Modeling Applications for Mathematics Courses.*

In this talk, we discuss new and innovative modeling scenarios for common calculus and differential equations topics using real world data. Specifically we present an application of linear first order differential equations and limited growth that relates to temperature change in ocean tide pools and the insulation provided by a snail's shell. This project can be done in or out of class. Data used in this scenario was gathered from Virginia Wesleyan College's marine research vessel in collaboration with biology students and faculty with support from the SIMIODE: Systemic Initiative for Modeling Investigations and Opportunities with Differential Equations project. (Received September 22, 2015)

1116-K1-2831 **Joel Kilty*** (joel.kilty@centre.edu), 600 W. Walnut Street, Danville, KY 40356, and **Alex M McAllister** (alex.mcallister@centre.edu), 600 W. Walnut St., Danville, KY 40356. *Mathematical Modeling and Applied Calculus.*

In the modern world we are inundated with data. As mathematicians, we are typically more comfortable discussing the behavior of functions presented analytically, in contrast with data-driven or tabular presentations. In this talk, I will present an approach to an entry level Mathematical Modeling and Applied Calculus course for students who will only take one mathematics course in college. The course is designed to develop the student's ability to model data with elementary functions and then improve their models using the Method of Least Squares, which is fully developed in the course. The tools of Calculus are then used to analyze these models in both the discrete and continuous contexts. Students are exposed to many elements of the modeling cycle including the need to refine their models in light of new data. (Received September 22, 2015)

1116-K1-2883 **Michael A Karls*** (mkarls@bsu.edu), Department of Mathematical Sciences, Ball State University, Muncie, IN 47306. *Using a Sand Tank Groundwater Model to Investigate Groundwater Flow Models.*

A Sand Tank Groundwater Model is a tabletop physical model constructed of plexiglass and filled with sand that is typically used to illustrate how groundwater water flows through an aquifer, how water wells work, and the effects of contaminants introduced into an aquifer. Mathematically groundwater flow through an aquifer can be modeled with the heat equation. We will show how a Sand Tank Groundwater Model can be used as-is or slightly modified to simulate groundwater flow through an aquifer with various boundary conditions. Data can then be collected from the physical model and used to verify the mathematical models. We will illustrate with some specific examples. (Received September 22, 2015)

Mathematics and the Arts, I

1116-K5-94 **John W Watson*** (jwwatson@atu.edu), Tomlinson 126H, 1507 N. Boulder Ave, Russellville, AR 72801. *Using art to present mathematics in a freshman general education math course for non-STEM majors.*

During the spring and summer of 2015 I have been researching open resources to use in teaching a freshman level general education mathematics course for non-STEM majors. The first unit in the course will be titled "Art and

Mathematics". The purpose of this presentation is to report on the resources used which includes works of John Edmark, Hiroshi Sugimoto, Ichiyo Yamamoto, and tessellations found in the Alhambra as well as more widely known art such as the works of Escher. (Received July 21, 2015)

1116-K5-334 **Godfried T. Toussaint*** (gt42@nyu.edu), New York University Abu Dhabi, Saadiyat Island, P.O. Box 129188, Abu Dhabi, United Arab Emirates. *Phylogenetic Analysis of the Ancient Greek Paeonic Rhythmic Forms.* Preliminary report.

There are very few documented examples in the history of the evolution of musical rhythm that provide evidence of the gradual development across centuries, of a prototype rhythm evolving to a set of its variants. The ancient Greek rhythmic paeonic (quintuple time) genus discussed by Aristotle and Aristoxenus is one such notable example, thus providing a unique and much needed opportunity to test the evolutionary efficacy of the mathematical phylogenetic tools available. A paeonic rhythm has durational ratio 2:3, and can be notated succinctly using binary sequences of five symbols in length such as [x - x x -], where each symbol denotes a unit of time, the symbol 'x' denotes a sounded pulse (note onset), and the symbol '-' denotes a silent pulse (a rest). The rhythm [x - x x -] is the root of the paeonic genus, and is called the cretic. M. L. West documents seven variants of this prototype rhythm that appeared gradually over a period ranging from the 7th Century BC to the 2nd Century AD. Here a phylogenetic analysis using the tools available in the SplitsTree software package provides mathematical evidence that supports the evolution of the paeonic genus documented by M. L. West. (Received August 25, 2015)

1116-K5-371 **Anil Venkatesh*** (anilvenkatesh@ferris.edu). *Pythagoras to Secor: a Mathematical Approach to Musical Temperament.*

In music theory, a temperament is a system of tuning. The concept of temperament has been studied since antiquity; it arises as a consequence of the unique prime factorization property of integers, applied to pitches of musical notes.

Most instruments are capable of minutely adjusting the pitches of notes during performance, allowing them to play in any temperament. However, keyboard-based instruments such as the piano cannot adjust pitches in this way. Consequently, temperament is most relevant to keyboard-based instruments. A crowning achievement of the western musical tradition is the well tempered scale, which is the tuning convention used in modern pianos.

In this talk, we briefly review historically significant temperaments such as Pythagorean tuning and the well tempered scale. We then introduce George Secor's "miracle temperament." Discovered in 1974, the miracle temperament closely approximates an astonishing number of acoustically fundamental intervals (i.e. those arising from the Fourier decomposition). We present a mathematical formulation of the "miracle" criterion and a classification of the space of all temperaments according to this criterion. The talk includes relevant audio samples and is accessible to undergraduates. (Received August 28, 2015)

1116-K5-377 **Simei Tong*** (tongs@uwec.edu), Department of Mathematics, UWEC, 524 Hibbard Humanity Hall, 105 Garfield Ave, Eau Claire, WI 54701. *Power of Mathematical Quilting.* Preliminary report.

Every mathematician agrees that mathematics is beautiful. However, one challenge is to inspire students to see the beauty that exists within this field. This talk presents several mathematical quilts made by the speaker that will demonstrate the connection between mathematics and arts. For example, quilts representing the sine curve, spiraling Pythagorean triples, polar coordinate integration, mobius band in topology, and many more will be shown. Mathematical thinking is powerful! You can even use mathematics and a piece of fabric to represent 362,880 solutions of sudoku! (Received August 28, 2015)

1116-K5-548 **Paul R McCreary** (mccrearp@evergreen.edu), 1210 6th Avenue, The Evergreen State College - Tacoma, Tacoma, WA 98405, and **Peter Boome*** (boomep@evergreen.edu), 1210 6th Avenue, The Evergreen State College -Tacoma, Tacoma, WA 98405. *Drawing and Discrete Mathematics.*

What does discrete mathematics have in common with a cartoon story board? How can drawings help bring continuity to discreteness? And what about paths on a graph? The discrete math content of the course was required for pre-service middle school math teachers. The drawing content was a fine arts hands-on practice. Together we explored the connections between cultural symbols, persistence in skill development, and motivation for new learning. Further, the interdisciplinary context of the course led to greater diversity in the student body and greater opportunities to integrate social justice into the curriculum. (Received September 22, 2015)

1116-K5-564 **Randall E Cone*** (recone@salisbury.edu), 128 Henson Hall, Salisbury University, Salisbury, MD 21801. *Nevermore: Mathematics of 'The Raven'.*

In this paper, we explore mathematical visualizations and analyses of Poe's most famous work. (Received September 07, 2015)

1116-K5-579 **L. Kerry Mitchell*** (lkmitch@gmail.com). *Dynamic Chaos Game.*

The standard Chaos Game is a simple demonstration that is often used as an introduction to chaos, fractals, strange attractors, iterated function systems, and fractal dimension. While easy to implement and accessible to non-specialists, it is aesthetically limited to variations on the Sierpinski triangle (whose vertices are the three anchor points in the standard implementation). The present work expands the Chaos Game by allowing the anchor points to move during iteration. Thus, the single attractor is replaced with a family of attractors, which are then combined into the final image.

With this method, there can be any number of anchor points (as opposed to three for the Chaos Game). Rather than being fixed, the anchor points may be moved each iteration, like points in an animation. Several classes of closed curves are investigated: circle, astroid, rose curve, and Lissajous curve. Also, the points can slide along line segments. The probability of each anchor point being used can be set, as well as the position of the new iterated point, relative to the old point and the chosen anchor. Example images are shown for the various classes of anchor point trajectories and recommendations for further investigation are given. (Received September 07, 2015)

1116-K5-806 **J. White*** (jacci.white@saintleo.edu). *Fractals, writing, and applications of Geometry.* Preliminary report.

Art inspires many mathematicians, just as mathematics can inspire artists. Assignments that combine art and mathematics can help a student show their strengths in order to build confidence in mathematics which they often see as a weakness. An early exploration of fractals can appeal to many students through digital computer software that lets them explore ways that changes in the mathematics changes the artistic appeal of the result. Writing is seen by many as an art, but can also be used to express artistic ideas. Students can begin to see the useful nature of mathematics when they write about the similarities between geometry and architecture, or explore the mathematics behind a piece of art. A field trip to a museum to reflect upon how mathematics is used by some artists can strike a spark of interest in a student who was previously bored with the mathematics. Examples from these activities and more will be shared in this session. (Received September 13, 2015)

1116-K5-881 **Lina Wu*** (lwu@bmcc.cuny.edu), 529 West 42nd Street Apt. 5K, New York, NY 10036. *Exploration of Mathematics Teaching and Assessment through Maple-Software Projects of Art Diagram Design as Undergraduate Student Research Projects.* Preliminary report.

The presenter is interested in conducting research of teaching pedagogy as well as assessment strategies by incorporating art in mathematics education. During a series of pilot summer Calculus courses from 2013 to 2015 at Borough of Manhattan Community College-The City University of New York, the presenter has integrated a series of art-related undergraduate student research projects in the Calculus sequence. Mathematical subjects taught in art-related context can be meaningful and memorable to facilitate students' learning. Visualization through artwork can enhance students' intuitive understanding of mathematical concepts and theories. Working on art-related projects in Math Labs can encourage students to use mathematical formulas in the creation of computer-generated graphic art images. Projects of "Polar Art Calendar"(in 2013)and "Funny Face"(in 2014)and "Geometric Abstract Art Calendar"(in 2015) attached with students' artwork will be presented. The series of pilot courses were supported by the grant from Minority Science Engineering Improvement Program through US Department of Education and also supported from Enhanced Classroom Teaching Funds at Borough of Manhattan Community College. (Received September 14, 2015)

1116-K5-986 **Vi Hart**, **Andrea Hawksley**, **Henry Segerman*** (segerman@math.okstate.edu) and **Marc ten Bosch**. *Hypernom.*

Hypernom is a virtual reality game. The game is also playable on iOS and Android tablets, and is available at http://hypernom.com. The cells of a regular 4D polytope are radially projected to S^3, the sphere in 4D space, then stereographically projected to 3D space where they are viewed in the headset. The orientation of the headset is given by an element of the group SO(3), which is also a space that is double covered by S^3. In fact, the headset outputs a point of this double cover: a unit quaternion. The positions of the cells are multiplied by this quaternion before projection to 3D space, which moves the player through S^3. When the player is sufficiently close to a cell, they eat it. The aim of the game is to eat all of the cells of the polytope, which, roughly speaking, is achieved by moving one's head through all possible orientations, twice. (Received September 15, 2015)

1116-K5-1063 **David Thompson*** (dthomp9@students.towson.edu) and **Diana Cheng** (dcheng@towson.edu). *Complex Mazes with Simple Paths: Mathematics within the Art of Classical Labyrinths.*

Classical labyrinths / mazes, constructed using parts of concentric semi-circles and quarter-circles, are aesthetically visually pleasing and inherently have a wealth of mathematical relationships. We show the results of in-service and pre-service middle and secondary teachers' exploring patterns within the solution paths of labyrinths. The order of circuits traversed while solving the labyrinth, i.e, traveling from the outside to the inside of the labyrinths, can be defined algebraically as a function of the number of total circuits in the labyrinth. We also present labyrinth-based activities designed to address the Common Core State Standards for Mathematical Practice #4, Model with Mathematics. (Received September 16, 2015)

1116-K5-1573 **Gail Tang*** (gtang@laverne.edu), 1950 Third St., La Verne, CA 91750. *Invisible Theatre: Math and Metaphor on the Digital Stage.*

In an undergraduate honors program, we developed a unique course that integrates concepts from mathematics and theatre arts to strengthen students' understanding of both disciplines and to challenge the false notion that mathematics is an unapproachable topic that is unrelated to other fields. Through inquiry-based and hands-on learning, students were responsible for making connections across both disciplines using metaphor. Leveraging metaphors in plays, literature, poetry, and history, students investigated upper level mathematical fields that are not traditionally presented to math majors let alone non-math majors, such as knot theory, and also revisited elementary ideas, such as place-value. To deepen their understandings, students also researched the topics on their own and constructed objects in the theatre shop to tangibly grasp the abstract ideas presented. For example, a group chose to study the Klein Bottle for their final project; they knew that a Mobius strip was embedded in the surface, but they didn't fully grasp that idea until they welded the Klein Bottle. This talk will present some assignments from the class, their implementation, and some preliminary data on the effects of the interdisciplinary course on students' mathematical attitudes. (Received September 20, 2015)

1116-K5-1580 **Margaret Kepner*** (renpek1010@gmail.com), 3716 Livingston St, NW, Washington, DC 20015. *Catalan Connections.* Preliminary report.

The Catalan numbers are a sequence of positive integers that provide answers to certain combinatorial questions. For example, in how many ways can a polygon be cut into triangles? Other types of problems also lead to the Catalan numbers: counting binary trees, balancing parentheses, finding paths through a grid, shaking hands in a circle, etc. I will present visualizations of several solution sets related to the Catalan numbers, and show how connections can be found to map one set into another. Furthermore, I will show how my artistic work has drawn on these visualizations and relationships. (Received September 20, 2015)

1116-K5-1732 **Annalisa Crannell*** (annalisa.crannell@fandm.edu), **Marc Frantz** (mfrantz@indiana.edu) and **Fumiko Futamura** (futamurf@southwestern.edu). *The perspective image(s) of a square.*

Moving from the visual realm of perspective art into the mathematical realm of projective geometry yields some surprising and counter-intuitive results. One of these surprises is that *every* quadrangle (whether convex or not) is the perspective image of a square. We will describe implications of this result for computer vision, for photogrammetry, for topology of non-orientable surfaces, and of course for perspective art and projective geometry. (Received September 21, 2015)

1116-K5-1866 **Debra L. Hydorn*** (dhydorn@umw.edu), University of Mary Washington, 1301 College Avenue, Fredericksburg, VA 22401. *Classification of 4x4 arrangements of 16 2-color corner-matching Wang tiles.* Preliminary report.

The 16-possible arrangements that are produced by coloring or not coloring the corners of a square form a corner-matching variation of 2-color Wang tiles. Arrangements of all 16 tiles in a 4 by 4 grid are possible and have some interesting properties, including toral and cylindrical symmetries. These properties lead to a classification based on whether or not the resulting 4 by 4 arrangements can tile the plane. Preliminary results have identified three distinct groups of 4 by 4 arrangements, two of which allow for a periodic tiling of the plane. (Received September 21, 2015)

1116-K5-1916 **Heidi Burgiel*** (hburgiel@bridgew.edu), Mathematics Department, Bridgewater State University, Bridgewater, MA 02325. *Application of Doily Design to Hyperbolic Crochet.* Preliminary report.

In 2014, Joshua and Lana Holden modified a traditional granny square pattern to crochet afghans of hyperbolic squares and hexagons. The hyperbolic equilateral triangles presented in this talk were inspired by their work, but are based on crochet doily patterns. This modification leads to increased connectivity, decreased stretchiness, and a wider range of angle measures than are available in granny square based patterns. (Received September 21, 2015)

1116-K5-2174 **Susan Goldstine*** (sgoldstine@smcm.edu). *Thinking Outside the Torus: Geometric explorations in bead crochet.*

For the past six years, Ellie Baker and I have studied the mathematics of bead crochet rope bracelets. The traditional form for such a bracelet is an apparently seamless torus of beads arranged in a single spiral. This spiral structure introduces fascinating constraints on pattern design, and we have spoken about our discoveries at various conferences and published them in several papers and a book.

The underlying crochet in a standard bead crochet bracelet is very simple, with the same stitch repeated throughout the piece to produce a homogeneous torus; the intricate patterns and textures in a bracelet stem entirely from the choice and arrangement of beads. Incorporating different crochet stitches such as increases, decreases, and chain stitches can produce bead crochet with more complicated geometry and topology. This talk will cover some of these new explorations into the mathematical possibilities of the art form. (Received September 22, 2015)

1116-K5-2261 **T. M. Brown*** (patricia.brown@armstrong.edu). *Kaleidoscopes, chessboards, and symmetry.*

In this talk, we introduce the n-queens problem on a $n \times n$ chessboard. We discuss the possible symmetries of n-queens solutions and show how solutions to this classical chess question can be used to create colorful artwork. (Received September 22, 2015)

1116-K5-2276 **Ethan Berkove*** (berkovee@lafayette.edu). *Half a Menger Sponge is Better than the Whole.*

Jeannine Mosley completed the first modular origami level three Menger sponge out of over 65,000 business cards around 2005. A small number of other level three sponges have been built since then, including 17 that were part of the October 2014 Mega-Menger project. This talk will discuss the background and construction of the recently completed half sponge sculpture based on the hexagonal cross section of a cube. Evident in the sculpture are a number of features that aren't visible in the whole Menger sponge, including six-pointed stars of various sizes that come from the fractal nature of the object. This crowd-sourced project was part of a focus semester on origami at Lafayette College in Fall 2013, which included a curated origami art exhibit as well as public lectures. (Received September 22, 2015)

1116-K5-2302 **Spring Cooke*** (sicooke@northpark.edu). *Children are Mathematicians: Seeing Math in the Art Children Create.* Preliminary report.

Mathematical inquiry is one of the natural expressions of childhood curiosity. Engaging children in mathematical inquiry is both possible and probable when the environment encourages it, when followed by appropriate mathematical questioning and dialog and when rewarded with appropriate, critical feedback. In this exploration, children will be invited to create art using a variety of media. Each piece will be carefully considered for evidence of mathematical thinking and, when appropriate, children will be invited to inquire into their own mathematical representations through questioning and dialog. The goal of this project is to encourage teachers, educators and others who work with school-aged children, to engage them in open-ended art experiences and to use those experiences as opportunities for mathematical dialog and inquiry. Children will be invited to participate from a variety of backgrounds and lived experiences. Ultimately, this project will show that all children can and should be engaged in mathematical inquiry and their own creative work provides regular opportunity for it. (Received September 22, 2015)

1116-K5-2496 **Mary D. Shepherd*** (msheprd@nwmissouri.edu), Maryville, MO 64468. *Drunkard's Path and other quarter circle quilting patterns.*

The folk art of quilting includes some beautiful mathematics. Most quilt blocks, the building blocks of quilt tops are squares and involve straight line seams. An interesting variety of quilts are ones with portions of circles and have seams that are not straight lines. One of the older types of block, called Drunkard's Path, involves two contrasting colors (red and white, or blue and white being very common), one color is a quarter circle (in one of the corners of a square block) and the other color is the remainder of the square block. A second type of block is actually called in mathematics circles, a Truchet tile. It is a square with two quarter circles joining midpoints of adjacent sides. This Truchet tile block is considered a variation of the Drunkard's Path block. This past summer, while investigating and attempting to understand and classify quilt patterns using the Drunkard's

Path blocks, I found a quote about a specific quilt in the pattern called "Snake in a Hollow Maze" that used the Truchet tile block. The quote stated the directions for setting the blocks in a maze pattern were carefully hoarded and passed from quiltmaker to quiltmaker. This talk will classify Drunkard's Path quilt patterns and demystify creations of the maze patterns using a Truchet tile block. (Received September 22, 2015)

1116-K5-2532 **Robert W Fathauer*** (tessellations@cox.net). *Spatially-Developing Fractal Gaskets.*
A wide variety of fractal gaskets have been designed from self-replicating tiles (reptiles), both regular reptiles (all of the constituent tiles being congruent) and irregular reptiles (all of the constituent tiles being similar but not congruent). In contrast to the Sierpinski Carpet and Sierpinski Triangle, these gaskets generally have fractal outer boundaries, and the holes in them generally have fractal boundaries. Novel solids have been created by spatially developing these gasket fractals over the first several generations. Successive generations are separated in a direction orthogonal to the plane of the gasket, and simple polygons are used to connect the external and internal edges of the gaskets. Since all of the faces in the resulting structures are polygonal, these solids can be described as polyhedra. By varying the spacing between generations, the form of these polyhedra can be varied, creating three-dimensional constructs evocative of architectural forms such as castles and geological forms such as rock spires or mesas. Furthermore, construction rules can be employed that result in varied height within a given generation of a gasket, allowing an even wider variety of three-dimensional forms. (Received September 22, 2015)

1116-K5-2541 **Gareth E Roberts*** (groberts@holycross.edu), Dept. of Mathematics and Computer Science, 1 College Street, Worcester, MA 01610. *Change Ringing, Dance and Memory: An Embodied Learning Approach to Abstract Algebra.*
The musical "sport" of change ringing involves a small group of people ringing n large bells according to some prescribed pattern. To perform a legitimate piece of change ringing music (an extent), certain rules must be followed. For example, an extent always begins and ends on rounds, an ordering of the bells that corresponds to the identity element in the symmetric group S_n. Using Liz Lerman's embodied learning techniques, students in a math and music class physically moved to the sequence of permutations in *Plain Bob Minimus*, an extent on four bells. They were then given 30 minutes to memorize and perform the full sequence of 24 permutations in front of their peers. The results were impressive, suggesting that embodied learning is an effective and fun way to teach concepts from abstract algebra. (Received September 22, 2015)

1116-K5-2609 **David A. Reimann*** (dreimann@albion.edu), Mathematics and Computer Science, 611 E. Porter St., Albion, MI 49224. *Forms resulting from replacing edges with flexible plates in convex equilateral polyhedra.*
The convex equilateral polyhedra include Platonic Solids, Archimedean solids, prisms, antiprisms, and Johnson solids. Additionally, the class of near-miss Johnson solids have faces that are almost regular. The edges in these polyhedra can be replaced with flexible two-dimensional shapes (plates). The connection points at the ends of the edges are replaced with four holes located in the corners of the plates. Faces and vertices are transformed into open space, while edges become solid plates, resulting in open lattice structures that simultaneously provide a sense of lightness and enclosure. Examples will be shown with edges replaced by squares, rectangles, and annulus sectors. A wide variety of materials can be used for the plates such as paper, cardboard, wood veneer, and corrugated plastic. Forms have been made using found objects such as business cards, coffee cup sleeves, and package condoms. A material's stiffness, weight, and flexibility all contribute to the final form. Fasteners such as split pin brads and cable ties have been used. These constructions yield surprising and visually interesting forms that are significantly different from the underlying base polyhedra. (Received September 22, 2015)

1116-K5-2870 **Matthew A Morena*** (mamorena@yhc.edu) and **Kevin M Short**. *Music Synthesis from Controlled Chaos.*
Sound synthesis is a field that bridges the disciplines of music, physics, mathematics, and psychoacoustics. Many synthesis techniques utilize a dynamical systems approach, whereby sounds, rhythms, and melodies can be created from iterated mappings or from differential equations. The goal of our present work is to synthesize the sounds of musical instruments by way of controlling a chaotic dynamical system onto its periodic orbits. The control method is adapted from one developed by Hayes, Grebogi, and Ott, and the resulting (stabilized) orbits are known as *cupolets* (*Chaotic, Unstable, Periodic, Orbit-LETS*). Cupolets exhibit the interesting property that a given set of controls will uniquely identify a cupolet, independent of its initial condition. We demonstrate how cupolets can be made to produce periodic waveforms whose harmonic spectra contain the overtones that give musical instruments their distinctive qualities. Thus, a set of controls may be used to produce cupolets that

sound like a harpsichord or a banjo, while other cupolets may be generated that share tonal qualities with an electric piano. (Received September 22, 2015)

1116-K5-2959 **Belin Manuel Tsinnajinnie*** (btsinnajinnie@iaia.edu), 83 Avan Nu Po Raod, Santa Fe, NM 87508. *Exploring the Integration of Culture, Nature, Art and Mathematics from Indigenous Perspectives.* Preliminary report.

This presentation will provide descriptions of how a Native American tribal college geared for fine arts integrates aspects of culture, nature, and art in the mathematics curriculum. For contemporary Indigenous artists, art is often impossible to separate from culture and identity. Integrating art and mathematics in this context then must go beyond an exploration of connecting visual aesthetics and mathematics, but must also delve into sociocultural and at times sociopolitical perspectives when exploring the roles of culture, creativity, and power in art and mathematics. (Received September 23, 2015)

Mathematics and the Arts, II

1116-K6-73 **Seth I Zimmerman*** (zimls@earthlink.net). *Dante the Mathematician.*

Is it possible that in the fourteenth century Dante Alighieri modeled the universe as a three-sphere? Precise descriptions in the Comedy seem to have no other interpretation. We will investigate this topological mystery as well as the poet's skillful manipulation of the number three, and his remarkable use of symmetry. (Received July 13, 2015)

1116-K6-465 **Reza Sarhangi*** (rsarhangi@towson.edu), Towson University, Department of Mathematics, 8000 York Road, Towson, MD 21252. *Some Girihs and Puzzles from the Interlocks of Similar or Complementary Figures Treatise.*

This presentation is about the second part of my study with some puzzle problems and girih constructions that have been recorded in the Interlocks of Similar or Complementary Figures. Most problems in the treatise are full of sketches and some of them are incomprehensible. Nevertheless, this is the only document that has survived for many centuries that gives instruction for girih construction. It is believed that the document was written sometime between the 13th and 15th centuries by an anonymous mathematician/craftsman. This is the only document remaining from the medieval Persia that demonstrates how a girih can be constructed using compass and straightedge. Moreover, the treatise includes some puzzles for polygon transformations from one geometric shape to another. This may happen either by dissecting one shape and rearranging the pieces to make another shape, or by solving the problem mathematically. (Received September 02, 2015)

1116-K6-618 **mostafa aref haghi*** (mostafaaref1977@gmail.com), Unit.4-No.5-Sepahii.Aleey-Soohani.Av-Soohanak, 1678688581 Tehran, Tehran, Iran, and **samane barjasteh delforooz** (samanebarjaste1980@gmail.com), Unit.4-No.5-Sepahii.Aleey-Soohani.Av-Soohanak, 1678688581 Tehran, Teahran, Iran. *The role of geometry in architecture, Case study: QAL'EH DOKHTAR, in Firuzabad, Iran.*

Is geometric rules, combined with the natural conditions of human life? Are human beings to discover the laws of geometry and use them in past centuries and millennial, were trained so much? So they can use them to create architectural spaces? To what extent could use the law to architecture design? And build some architectural space for themselves? In this article, dealing with a case study of hundreds of Iranian architecture, called this QAL'EH DOKHTAR, in Firozabad, which was built during the Sassanid period, about 1700 years ago, will try to show that what has been shaped of geometry and how to use it in Iranian architecture? Because of religious beliefs, techniques, performance and production of building materials as well as environmental conditions that placed in the hands of Iranian architects, geometric proportions, human scales Iran had been the most important role in architectural design. The tradition and heritage remained for Iranian architects of the first millennium BC, to the middle of the last century, with the emergence of new architectural ideas in Iran, was very pale and almost disappeared. Some designers used the geometry for exceptional and special, while others used it as normal and simple, but no one was exempt from the rules of geometry. (Received September 09, 2015)

1116-K6-644 **Srividhya Balaji*** (sbalaji@math.ou.edu), 312 E Boyd St #3, Norman, OK 73069. *Exploration of Quotient Spaces and Group Actions with Application to Visualizing Music.*

Various authors have explored how the mathematical area of geometric topology can be used to visualize musical concepts and shed light on the structure of a musical composition. For example, Tymoczko and others have modeled the set of chords as an orbifold. We explore the definitions of quotient spaces and group actions on spaces with the aim of visualizing Raagas (Modes) in Indian Carnatic Music. A raaga is a melodic scale, which takes a definite set of notes, from the twelve notes in an octave. Extempore raaga elaboration involves the permutation and combination of these notes, which gives rise to an infinite number of patterns. (Received September 09, 2015)

1116-K6-685 **Rosanna Iembo*** (rosannaiembo@libero.it), via Federico Cozzolino, 18, 84018 Scafati, Salerno, Italy, and **Irene Iaccarino** (irene.iaccarino@hotmail.it), via Interna Marina, 19, 88900 Crotone, Italy. *Pythagorean Women, Symphony of Science.*

Between VI and V century b. C. something unique happened in Italy. In a school of southern Italy, women played a leading role. And this was for that period something really innovative. While in the ancient west, women could not study nor participate in public life, in the school founded by Pythagoras, a Greek, and his wife, Theanò, an Italian, women had rights and education. They could study like males and became musicians, mathematicians, doctors and scientists and they played an important role in making decisions for that school and the city. Their teachings were able to permeate public life of the city making it a beacon of ethics and culture around the Mediterranean. Women were respected and praised in the school and in the city for their wisdom, for the scientific and philosophical knowledge, their organizational skills. That school became a model for the ancient west. After the death of the great philosopher and mathematician Pythagoras, his wife Theanò together with their daughters held an important training for their followers so their thought continued to live on. Even today the pythagorean style of life is still a model for future generations. (Received September 10, 2015)

1116-K6-1182 **Hossein Behforooz*** (hbehforooz@utica.edu), 1600 Burrstone Road, Utica, NY 13502. *On the Artistic Aspects of Magic Squares.* Preliminary report.

Abstract: We know that the magic squares are the major component and the most important part of the Recreational Mathematics. But in the same time, in the traditional literature and these days in the internet, we can find many artistic aspects of different magic squares. For example we can see magic square as part of the masterpiece engraving from Albrecht Durer, which is 500 years old now. In this short presentation I will present many magic squares related to art including Durer Magic Square and its interesting properties. Then we will use the pattern of this magic square to transform the dates on a calendar and make a magic square. This is a brand new way to construct magic squares. We will conclude this lecture by demonstrating a three dimensional weighted magic square. Come and join us and have fun. Math is ART and Math is FUN. (Received September 17, 2015)

1116-K6-1404 **Susan McBurney*** (smcburney108@gmail.com). *Bit-wise Artwork.*

This presentation will explore the computer generation of bit-wise curves (curves which join seamlessly, without a "bump"). In fact, all smooth curves can be created from arcs of appropriately sized circles. We will examine the methods for doing this, proof of the results, various algorithms for generating appropriate circles, and then explore the ways in which computer-generated art can even venture into the realm of hand-made art. (Received September 22, 2015)

1116-K6-1827 **Douglas G. Burkholder*** (burkholderd@lr.edu), 625 7th Ave NE, Hickory, NC 28601. *Quilts & Lace: Unexpected Beauty Hidden in Radin-Conway's Pinwheel Tiling.*

In 1994, John Conway and Charles Radin created a non-periodic Pinwheel Tiling of the plane using only 1 by 2 right triangles. By selectively painting either every fifth triangle or two out of every five triangles, based only upon their location in the next larger triangle, we discover 15 unexpected, distinctive, non-periodic patterns each with their own beauty. These patterns can be combined into artwork which mimics quilts and lace by selecting different rules for different places within the tiling. (Received September 21, 2015)

1116-K6-1865 **Fumiko Futamura*** (futamurf@southwestern.edu), 1001 E. University Ave, Georgetown, TX 78626, and **Robert Lehr**. *Finding the Viewpoint at a Museum: A How-To Guide.*

In a perspective drawing, there is an exact spot where we need to place our eye in order to view it without distortion, called the "viewpoint". When we place our eye at this viewpoint, the flat drawing suddenly acquires three-dimensional depth and we are almost magically transported into the world of the drawing. In this talk, we'll review the known geometric and algebraic methods for finding this viewpoint for one and two-point perspective and introduce a new method for two-point perspective developed by an undergraduate student which uses both geometric and algebraic techniques. (Received September 21, 2015)

1116-K6-1960 **Frank A Farris*** (ffarris@scu.edu), Dept of Mathematics and Computer Science, Santa Clara University, 500 El Camino Real, Santa Clara, CA 95053, and **Ryan Tsao**.
Polyhedral Painting in WebGL with Group Averaging.

The technique of group averaging produces colorings of the sphere that have the symmetries of various polyhedra. The concepts are accessible at the undergraduate level, without being well known in typical courses on algebra or geometry. The material makes an excellent discovery project, especially for students with some background in computer science; indeed, this is where the authors first worked through the material, as teacher and student, using WebGL to produce a previously unseen type of artistic image. The process uses a photograph as a palette, whose colors and textures appear in kaleidoscopic form on the surface of a sphere. We depict tetrahedral, octahedral, and icosahedral symmetries, with and without mirrors, along with the source photograph for comparison. We also describe a method to make images with color-reversing symmetry. (Received September 21, 2015)

1116-K6-2812 **Douglas Dunham*** (ddunham@d.umn.edu), Department of Computer Science, 320 HH, 1114 Kirby Drive, Duluth, MN 55812-3036, and **John Shier** (johnpf99@frontiernet.net), 6935 133rd Court, Apple Valley, MN 55124. *An Algorithm for Creating Wallpaper Patterns from Random Fractals.* Preliminary report.

We describe an algorithm that creates wallpaper patterns whose fundamental regions are filled with fractal patterns composed of progressively smaller copies of a motif. The motifs can be quite simple or very complicated. The local part of the algorithm starts by placing the largest copy of the motif at a random location in the fundamental region. After placing i motifs, the algorithm keeps trying random locations within that region at which to place the next motif until a location is found for which the new motif does not overlap any previously placed motif. Then i is incremented and this process is repeated. The sizes of the motifs obey an inverse power law which guarantees they will fill the fundamental region in the limit, though we stop after a finite number of successful placements. The global part of the algorithm copies the contents of the fundamental region to other copies of the fundamental region by using the transformations that generate the entire wallpaper pattern from the fundamental region. We have implemented this algorithm for the wallpaper groups $p1$, $p2mm$, $p4mm$, $p3m1$, and $p6mm$ ($= o, *2222, *442, *333$, and 632, respectively in orbifold notation). We have also made progress in extending the algorithm to other wallpaper groups. (Received September 22, 2015)

1116-K6-2941 **Darrah P Chavey*** (chavey@beloit.edu), Beloit College, 700 College St., Beloit, WI 53511. *Sidewalk Patterns: Symmetry at Home.* Preliminary report.

The availability of multiple colors of patio bricks makes it possible to design sidewalk or walkway patterns with a wide variety of symmetric patterns, and symmetrically colored patterns. Several available sizes of patio bricks, in multiple colors, come in dimensions with a ratio of 1:2, such as 4" X 8", 6" X 12", and even 12" X 24", and our work focused on the types of designs we could construct with this shape of brick. To help search the space of such designs, we developed software that allowed us to specify various constraints on the designs. These constraints include which linear symmetry group is desired, the maximum number of classes (or "orbits") of bricks acceptable in the design, restrictions against "gutters" (straight lines that cross the design without cutting across any brick), constraints on the coloring (requiring symmetric colorings or perfect colorings), etc. We demonstrate the software, and show some of the highlights of the designs it found. (Received September 23, 2015)

Mathematics Experiences and Projects in Business, Industry, and Government

1116-L1-243 **William P Fox*** (wpfox@nps.edu), Department of Defense Analysis, NPS, Monterey, CA 93943, and **Sean Everton** and **Chris Couch**. *Mathematical Modeling and Analysis of a Dark Money Network.*

In this article, the authors present background and analysis on a dark money network. An AHP/TOPSIS hybrid model is used to find the key nodes of the network. The analysis of the key nodes leads to improved targeting strategies against the network. Game theory applications using kinetic versus non-kinetic strategies in dealing with the network is developed after using AHP to obtain cardinal utility from the ordinal ranking originally provided. These methods provide additional metric that can be employed in dealing and analyzing any dark network. (Received August 17, 2015)

1116-L1-590 **Daniel J Heath*** (heathdj@plu.edu) and **Rob Rydberg**. *Mathematical Proof and Digital Camera Design.*

Based on a true story. We use polyominoes, group theory, and probability to show that a high resolution camera cannot be manufactured according to a client's specifications. This is a nice example of the use of undergraduate mathematics in engineering. (Received September 08, 2015)

1116-L1-918 **Mark A Branson*** (mbranson@stevenson.edu), Stevenson University, 1525 Greenspring Valley Road, Stevenson, MD 21153. *Changes in the Geometry of Baltimore's Public Transit System during the 2015 Protests.*

On April 28th, 2015 protests broke out in the city of Baltimore following the funeral of Freddie Gray, a young black man, who died in police custody. The Maryland Transit Authority (MTA), anticipating violence, canceled all scheduled public transportation in Mondawmin, a low-income area of West Baltimore where much of the later violence was centered. We analyze how this change in service altered the geometry of the city, using a metric of public transportation travel time. Using publicly available data from the MTA and the city of Baltimore, we construct this metric and analyze the curvature. Finally, the changes in this geometry are examined near violent incidents to determine whether cessation of public transit affected the events of that day. (Received September 15, 2015)

1116-L1-1124 **James H. Fife*** (jfife@ets.org), Educational Testing Service, 660 Rosedale Road, Princeton, NJ 08541. *Modeling the Difficulty of Constructed-Response Items.*

The advantages of automatic item generation over the traditional hand-crafting of individual items have been well-documented (Bejar et al., 2003). The automatic generation of items can reduce test development costs and, when item models are written as part of an evidence centered design approach, can increase validity (Mislevy, Steinberg, & Almond, 2003). Additionally, when the factors that determine difficulty are carefully controlled, items can be generated at prescribed difficulty levels (Graf & Fife, 2013), perhaps making possible the calibration of the item model rather than the calibration of the individual items, further reducing costs. In this talk, I will describe a project in which ten item models were created, using disclosed GRE items as parent items, with an attempt to control for difficulty. Five items were generated from each model; these child items were piloted along with the parent items on a self-selected population of GRE registrants. The results were used to determine the difficulty of the child items, compared with each other and compared with the parent item. For nine of the models, the variants had similar difficulty and discrimination, but for one of the models, there were non-construct-related factors that resulted in items of varying difficulty. (Received September 17, 2015)

1116-L1-1388 **sarah-marie belcastro*** (director@mathily.org), **Max Engelstein**, **Jonah Ostroff** and **Thomas C. Hull**. *Scheduling the Week of Chaos.* Preliminary report.

We have a problem. At MathILy, MathILy-Er, intensive summer programs for talented high-schoolers, we have a Week of Chaos during which 10–15 courses are offered across 5 time slots (with 2–3 classes per time slot). We are only given instructor-course pairings and students' semi-ranked topic preferences. At base, this is a partition problem, as each student must be assigned a class in each time slot and we optimize student preferences. However, there are two wrinkles: (1) We simultaneously assign classes to time slots and students to classes, and (2) there are additional non-obvious constraints for class size, student preparation, instructor/student exposure, instructor/instructor exposure, and student/student social dynamics.

This situation—even with our small data sets—is too complex for straightforward scheduling algorithms, but it is amenable to ad-hoc approaches augmented with elbow grease. We will describe the code we use to reveal features of the data, and then compare/contrast two human-executable algorithms we have used to solve the problem. We will also describe a reframing of the problem that promises to simplify the production of solutions, and what happens when we ask some Week of Chaos students how *they* would set up the scheduling problem. (Received September 19, 2015)

1116-L1-1922 **Emilie Purvine*** (emilie.hogan@pnnl.gov), **Michael Robinson** and **Cliff Joslyn**. *Categorification in the real world.* Preliminary report.

Categorification, as the process of enriching a set or category by lifting it to a category with deeper structure, has been a part of pure mathematics for many years. Examples include taking the natural numbers to the category of finite vector spaces, the integers to Euler characteristic, and the Jones polynomial to Khovanov homology. Our recent joint work between Pacific Northwest National Laboratory and American University has been in the field of heterogeneous information integration for Business, Industry, and Government (BIG) applications using sheaf theory. In doing this work it is necessary to ground many different information types - e.g., semantic, partial ordinal, interval valued - within a common data type, namely, finite vector spaces. In order to achieve this, we have developed a two step categorification process. First we define categories for each of our data types (e.g., semantic data becomes SET). We then categorify each into FVECT, the category of finite vector spaces. In this talk I will describe this categorification process and how it is relevant to the problem of heterogeneous information integration. (Received September 21, 2015)

1116-L1-2260 **Irina Seceleanu*** (iseceleanu@bridgew.edu), Bridgewater, MA 02325, and **Ward Heilman**, **Matthew Shipman** and **Robert Guillette**. *"Wherehouse" Route Optimization Software for the Warehouse Picking Problem.*

A well-known problem in warehouse management is the Warehouse Picking Problem (WPP), which has the goal of visiting each item in an order to be picked in the shortest possible path through a warehouse. With as much as half of the operating expenses in a warehouse associated with the cost of order picking, reducing the cost of the labor-intensive picking process can lead to significant efficiencies in a warehouse. The essence of the difficulty underlying this problem is the fact that the WPP is a variation of the Traveling Salesperson Problem, and thus is intractable for large pick sizes. In this talk we present software designed as a tablet-based application, under the aptly named title "Wherehouse", in which we employ various heuristic algorithms to find reasonable solutions to the WWP. This work was performed as part of the Center for Entrepreneurship Studies at Bridgewater State University, which promotes student and faculty research into problems of importance to business. The "Wherehouse" software is now being licensed and will be marketed to businesses with small to moderately-sized warehouses. We discuss the process which led to this collaboration between business and academia, the funding model for the product development and demonstrate the product produced. (Received September 22, 2015)

1116-L1-2695 **Ron Buckmire*** (ron@oxy.edu), Fowler Hall Room 313, Occidental College, 1600 Campus Road, Los Angeles, CA 90041. *My PIC Math Experience: Teaching An Industrial Mathematics Course At A Small, Liberal Arts College.*

In this talk I will discuss my experiences in teaching in the PIC Math program (funded by NSF DMS-1345499 and run by MAA and SIAM) in the 2015-15 academic year. I was a member of a cohort of faculty at colleges and universities around the country who were selected to teach an industrial mathematics course at our home institution in Spring 2015. In this course students were given actual problems from sources in business, industry and government (BIG) and faculty members were encouraged to find and provide problems from local BIG sources. I will discuss the entire process and provide a summary of the lessons learned as I prepare to teach the course again in Spring 2016. (Received September 22, 2015)

1116-L1-2779 **Bonita Saunders*** (bonita.saunders@nist.gov), NIST, 100 Bureau Drive, Stop 8910, Gaithersburg, MD 20899, and **Bruce Miller**, **Marjorie McClain**, **Daniel Lozier**, **Andrew Dienstfrey**, **Franky Backeljauw**, **Stefan Becuwe** and **Annie Cuyt**. *DLMF Live! Tables: NIST/Antwerp Collaboration for Standard Reference Tables on Demand.*

In 2010 the National Institute of Standards and Technology (NIST) launched the Digital Library or Mathematical Functions (DLMF) and its companion book, NIST Handbook of Mathematical Functions to replace the popular, but outdated Abramowitz and Stegun handbook on special functions. While no provision for a computational component to the DLMF was made, NIST has decided to take on that task by collaborating with the University of Antwerp Computational Mathematics (CMA) Research Group to build the DLMF Standard Reference Tables (DLMF Tables) web service. DLMF Tables will provide a standard of comparison for testing numerical software by computing, on demand, special functions to user-defined accuracy with guaranteed error bounds. Features of the beta site recently released will be discussed and demonstrated. (Received September 22, 2015)

1116-L1-2848 **Kristen Abernathy*** (abernathyk@winthrop.edu), **Lindsay Bradley**, **Emili Moan** and **Zoe Vernon**. *Fusion in Card Collecting Games: A Probable Outcome.* Preliminary report.

Card Collecting Games (CCGs), as well as many games in other genres, often employ a mechanic referred to as gacha-fuse-evolve where players randomly draw items with different levels of rarity (common, uncommon, and rare) that can be fused and evolved to create stronger items. With the free-to-play model that many online companies use, it is important that CCG developers keep the game easy enough that players want to continue to play but difficult enough that players want to spend money to better their experience. To achieve this, developers need to ensure fusions occur often enough to keep the non-paying players engaged, but seldom enough to entice players to purchase additional fusion opportunities. For this talk, we explore the probability of players drawing four different types of fusion (unique fusion, quad-fusion, evolutionary trees, and recipe fusion) in a given time period. We also run a sensitivity analysis to determine which parameters - deck size, number of rare cards, or length of play - are most sensitive. (Received September 22, 2015)

Mathematics and Sports

1116-L5-84 **Diana S Cheng*** (dcheng@towson.edu), 8000 York Road, Towson, MD 21252, and **Tetyana Berezovski** (tberezov@sju.edu), 5600 City Ave., Philadelphia, PA 19131.
Getting on top of spinning: Modeling the figure skating upright spin.

We demonstrate mathematical modeling activities developed for undergraduate pre-service middle and secondary teachers based on the figure skating upright spin. The upright spin is not only an eye-catching sports movement to watch, but also an intriguing subject to study since the Guinness Book of World Record for fastest spin on the ice was set in 2015 by a middle school student! Our activities are based on video recordings and dynamic geometry representations of the upright spin. These activities span multiple mathematical content areas, including proportional reasoning, algebra, geometry, trigonometry, and calculus. Since the Common Core State Standards for Mathematical Practice promote the use of modeling in the classroom, activities such as these are particularly useful for pre-service and in-service teachers. (Received July 18, 2015)

1116-L5-178 **James R Henderson*** (jrh66@psu.edu). *Statistics, Past Champions, and the Most Important Points in Tennis.*

Given the hierarchical scoring system in tennis (matches are broken up into points, games, and sets), not all points are equally valuable. Indeed, in roughly 5% of professional matches, the winner wins fewer points than the loser (games, in this sense, are also not all created equal). This has spawned discussion among commentators for the last century about which points are most important. Similar conversations have arisen about the most important games and even sets, but only in the last few decades has computer technology made a mathematical analysis of these issues tractable. This analysis has implications for strategy: for instance, should players "coast" on some points and give extra effort on others? Interestingly, modern analysis has addressed only one sense of the term 'point', when, historically, it has been used in several senses. Because of this, the views of Bill Tilden, one of the greatest players (and analysts) in the history of the game, are left out of the conversation. In the light of modern research, the views of Tilden and others on the most important points, games, and sets will be assessed, as well as Tilden's thoughts on strategy with respect to "taking points off" and what he takes to be the characteristic mark of a champion. (Received August 11, 2015)

1116-L5-430 **Eric Eager** (eeager@uwlax.edu), La Crosse, WI 54601, **Megan Eberle** (eberle.megan@uwlax.edu), La Crosse, WI 54601, and **James P Peirce*** (jpeirce@uwlax.edu), La Crosse, WI 54601. *How Infectious Was #Deflategate?*

On Monday January 19, 2015 a story broke that the National Football League (NFL) had started an investigation into whether the New England Patriots deliberately deflated the footballs they used during their championship win over the Indianapolis Colts. Like an infectious disease, discussion regarding Deflategate grew rapidly on social media sites in the hours and days after the release of the story. However, after the Super Bowl was over, the scandal slowly began to dissipate and lost much of the attention it had originally had, as interest in the NFL wained at the completion of its season. We construct a simple epidemic model for the infectiousness of the Deflategate news story. We then use data from the social media site Twitter to estimate the parameters of this model using standard techniques from the study of inverse problems. We find that the infectiousness (as measured by the basic reproduction number $\mathcal{R}_0$) of Deflategate rivals that of any infectious disease that we are aware of, and is actually more infectious than recent news stories of greater importance - both in terms of $\mathcal{R}_0$ and in terms of the average amount of time the average tweeter continued to tweet about the news story. (Received September 01, 2015)

1116-L5-456 **John K Mayberry*** (jmayberry@pacific.edu). *How does losing team bias affect water polo games?*

Exclusion fouls play an important role in elite men's water polo generating over half of all goals. Here we investigate the impact of losing team bias in exclusion calls on the final outcome of such games by simulating pairs of random water polo contests between two equally matched teams. In one simulation, the game evolves according to a Markov chain where at each step, a goal is scored by the offensive team with probability g or possession changes with probability $1 - g$. In the other coupled simulation, losing team bias is incorporated by decreasing g to $g - b_w$ when the offensive team is winning or the game is tied and increasing g to $g + b_\ell$ when the offensive team is losing. Using parameters based on data from the 2012 Olympics, 2013 World Championships, and 2014 European Championships, our simulations suggest that losing team bias alters the final score in over 50% of all contests and changes the actual outcome in about 15%. The most common alteration is from a victory for one team to a tie. We conclude by examining the dependence of the fraction f of games altered on the size of the losing team bias in the symmetric case $b_w = b_\ell = b$ and derive a simple formula for estimating f when b is small. (Received September 02, 2015)

1116-L5-865 **Anne M. Triplett*** (tripleam@mountunion.edu), Dr. Anne M. Triplett, Mathematics Dept. UMU, 1972 Clark Ave., Alliance, OH 44601. *Motivating Student Learning Through Sports-Related Projects.*

How important is a player to a team? What is the highest score that one could get in bowling without any strikes? Is a 5'11" basketball player more likely to be a WNBA player or NBA player? Can a team's previous record be used to accurately predict future performance? These are the types of questions that are being studied using statistics, sabermetrics and the theory of win shares.

The author has created projects that motivate students to discover the use of models to analyze data related to sports. The projects guide the student, in small steps, using the sports-related data, toward an understanding of various mathematical concepts. Examples will be shown that use WebAssign to accomplish this goal. Challenges in making these projects machine-gradable will be presented and discussed. The alignment with mathematics curriculum standards will also be considered. (Received September 20, 2015)

1116-L5-1051 **Reza O. Abbasian*** (rabbasian@tlu.edu), Texas Lutheran University, Dept. of Mathematics and Computer Science, 1000 W. Court St., Seguin, TX 78155, **John T. Sieben** (jsieben@tlu.edu), Texas Lutheran University, Dept. of Mathematics and Computer Science, 1000 W. Court St., Seguin, TX 78155, and **Amy L. Gastauer** (agastauer@tlu.edu), TLU, Dept. of Math and CS, 1000 W. Court St., Seguin, TX 78155. *The five star ranking system of football recruits and their future success in College and the NFL.*

Since about 2002 several agencies have implemented a star ranking system for graduating high school football players. Players receive a ranking of one to five stars. Of the approximately 300,000 high school football players, on average only 30 get the five- star ranking and about 400 are awarded the four- star ranking. In our presentation, we will explore the correlation between the star ranking of an athlete and his future athletic success. Specifically, we will use a Logit model to determine the probability of earning honors such as All-American or All-conference in college and being drafted by an NFL team, based on an individual's high school star ranking. We will also use regression to investigate the relationship between an athlete's position in the draft and the athlete's star ranking. Finally we will look at other factors affecting an athlete's chance in the NFL draft such as playing in a BCS power conference versus less prestigious conferences. (Received September 16, 2015)

1116-L5-1274 **Doug Drinen*** (ddrinen@sewanee.edu) and **Will Matson**. *The Probability of Streaks in Sports, in Theory and in Practice.* Preliminary report.

In this talk, we extend the work of Le and Rothman (2010) to find an exact expression for the probability of a run of at least k successes in n Bernoulli trials with probability p. We will also discuss the history of this problem and present some interesting non-DiMaggio examples of streaks from the sports world. (Received September 18, 2015)

1116-L5-1296 **Richard Yan** and **Carl Yerger*** (cayerger@davidson.edu). *Handicapping No-Tap Bowling.* Preliminary report.

In the alternative no-tap bowling scoring system, bowlers earn a strike if they knock over nine or all ten pins on their first ball. For many no-tap tournaments, organizers use averages and handicaps based on standard bowling scoring to equalize differences in skill. We investigate whether modifications to these systems should be made for no-tap competition and whether these modifications should depend upon the difficulty of the tournament's oil pattern. (Received September 18, 2015)

1116-L5-1334 **Thomas W Polaski*** (polaskit@winthrop.edu), Department of Mathematics, Winthrop University, Rock Hill, SC 29733, and **Alison P Tighe** (tighea2@winthrop.edu), Department of Mathematics, Winthrop University, Rock Hill, SC 29733. *The Measure of a Manager: Various Methods for Assessing the Ability of Baseball Managers.*

While much effort has been spent on using and combining various metrics to rate baseball players, very few methods seem to have been used to rate baseball managers. In this talk, the presenters will review several potential ways to rate managers based on skills "a good manager" should possess, particularly producing a productive lineup and using the bullpen effectively. These various methods will be aggregated to produce a model for managerial prowess. We will apply this model to famous (and infamous) managers to see how they measure up, and will note the difficulties inherent in attempting to quantify managerial leadership. (Received September 18, 2015)

1116-L5-1396 **E Lee May*** (elmay@salisbury.edu), 606 Irene Avenue, Salisbury, MD 21801.
Season-Long Batting Slumps In Major League Baseball.

Fans of baseball are accustomed to hearing the term "slump". Remarks about batting slumps are heard from approximately the third game of the season in early April until the end of the World Series in October. Unlike every other major sport, baseball is played on almost every day during this time. Perhaps this is why consistency is valued so highly by baseball writers and announcers, fans, and players, and why the deviation from consistency that a slump seems to represent so fascinates all of the former and frightens the latter. Fortunately, most slumps end. Some, however, stretch over the entire season. Even so great a batter as Babe Ruth once remarked, "I changed from batting champion in 1924 to the big bust of 1925. My batting average caved in..." In this talk, results will be presented of a study of season-long slumps–or "off-seasons", as they are often called. The study involved both theoretical and real-world data. The theoretical data were derived by modeling batting seasons with binomial probability distributions. The real-world data were generated from statistics recorded and maintained by Major League Baseball. The talk is accessible to anyone who has taken or taught a course in introductory statistics. (Received September 19, 2015)

1116-L5-1532 **William P Abrams*** (abramswp@longwood.edu), Department of Mathematics and Computer Scienc, Longwood University, 201 High Street, Farmville, VA 23909. *Baseball as a General Education Mathematics Course.* Preliminary report.

Longwood University has a general education course called Math And. This course can be taught various ways: Math And Social Issues, Math And Music, etc. In the Fall semester 2015 I taught a course on Math and Baseball. This course focused mostly on sabermetrics and was taught assuming that the students knew nothing but a little bit of Excel, how to use a TI calculator, and high school Algebra II. The hope was that the specific subject matter would help students in a general education introductory math class be more connected with and thus interested in what they were learning. I will talk about how the topics and assignments were chosen, what resources (books and online resources) helped me or the students, the advantage and disadvantage of various databases of baseball statistics available online, how the students responded, and what worked and what did not work. (Received September 20, 2015)

1116-L5-1880 **Andrew B Perry*** (aperry@springfieldcollege.edu). *Win Expectation Values and Pete Carroll's Decision to Pass in Super Bowl 49.*

Seattle Seahawks coach Pete Carroll's decision to pass the ball on 2nd and goal from the 1-yard line in Super Bowl 49 was controversial to say the least. The ball was intercepted and the Seahawks lost the game. Most football fans ridiculed the decision. Sports analytics experts disagreed; an unscientific study showed that a strong majority of speakers and attendees at the 2015 MIT/Sloan Sports Analytics Conference viewed the decision to pass as either a smart move that happened to backfire, or as a slight miscalculation. Many casual fans looked only at the probability of scoring on second down itself, which would certainly have been higher on a running play. On the other hand, intelligent football analysts computed the probability of the Seahawks winning the actual game after a second down pass, considering all possible contingencies. For example, the probability of an interception on a short second down pass can be taken as about 1%, considering many factors such as Russell Wilson's 1.5% interception rate on the season. We will present some estimates for particular play outcomes, and then crunch the numbers and "prove" that Carroll's decision, right or wrong, was much smarter than the average fan realized. (Received September 21, 2015)

1116-L5-1925 **R. Drew Pasteur*** (rpasteur@wooster.edu), **Emily Howerton**, **Preston Pozderac**, **Stuart Young** and **Jonathan Moore**. *Evaluation of NFL Punters.* Preliminary report.

In recent years, statistical evaluation metrics for NFL football players have become increasingly sophisticated. However, among the positions at which individual performance can be readily isolated, punters may be the least-studied. Considering both environmental and situational factors, we construct a model for the expected result of any NFL punt, and evaluate punters relative to this benchmark. (Received September 21, 2015)

1116-L5-1934 **Michael A Furuto*** (mfuruto@hawaii.edu). *Touchdowns, 3 pointers, and Real-World Math.* Preliminary report.

Engaging students in real-world problems is crucial to developing their conceptual understanding and appreciation of math. Math is ubiquitous in the world of sports, and participants will explore a variety of sports applications in curriculum. Content covered will include statistical and data analysis, problem solving, and the connection between math and sports. The purpose is to not only pique student interest in real-world math, but to also deepen student conceptual understanding, increase procedural fluency, and solidify skill proficiency. (Received September 21, 2015)

1116-L5-2056 **Connor R Loken*** (lokenccr17@mail.vmi.edu), VMI BOX 937, Lexington, VA 24450, and **John A David** (davidja@vmi.edu), Virginia Military Institute, Lexington, VA 24450. *Predicting NCAA Basketball and Football Using an Adaptive Neuro-Fuzzy Inference System.* Preliminary report.

In this work we develop an innovative model for predicting NCAA Basketball and Football using Adaptive Neuro-Fuzzy Inference Systems (ANFIS). ANFIS is a type of neural network based on mapping each of the inputs to a particular membership function then learning their relationship with the output of interest. The model adjusted the Las Vegas prediction of a game based on Google trend data, a metric for the amount of web searches for each team. We found that this model generally gains several percentage points in terms of games predicted correctly in accuracy from the Las Vegas prediction and would be one of the best predictors on the Prediction Tracker website. These results were evaluated over the entire 2012, 13 and 14 seasons. The real improvement over the Las Vegas prediction was where the games were predicted as being even. Our model tends to pick the victor of these games the majority of the time. We will present preliminary results on how we are extending this approach to professional football and basketball. (Received September 21, 2015)

1116-L5-2461 **Michael A Jones***, 416 Fourth Street, Ann Arbor, MI 48103, **Alexander Webb** (awebb@macalester.edu), Macalester College, St. Paul, MN 55105, and **Jennifer Wilson** (wilsonj@newschool.edu), Eugene Lang College, New School University, New York, NY 10011. *Tennis Rankings over Time.*

In 2010, Kim Clijsters won the U.S. Open, but had her world ranking drop from #3 to #5 by the Women's Tennis Assocation (WTA). How can a tennis player win a tournament but drop in the rankings? The WTA uses a moving window to determine the rankings. We explain how discounting older results in the window can prevent such counterintuitive behavior and consider geometric and arithmetic discounting methods. We examine real data from the WTA, and comment on discounting methods already in use by the Federation Internationale de Football Association (FIFA) for ranking national teams for the World Cup and by the Professional Golf Association for ranking golfers. (Received September 22, 2015)

1116-L5-2739 **Franklin H. J. Kenter*** (franklin.h.kenter@rice.edu). *An Analysis of the Basketball Endgame: When to Foul When Trailing and Leading.*

A common tactic near the end of a basketball game is for the trailing team to foul in order to gain an advantage by forcing the opponent to shoot free throws. While this tactic is widely used at almost all levels of play, deeper investigation into if and when a team should foul is nearly absent. In this paper, we model basketball as a combinatorial game to provide, for the first time, a well-supported quantitative description of when to foul. The results are surprising: not only should trailing teams foul earlier and more often than they actually do, but also, the leading team should foul more often than the trailing team. Using play-by-play data from NBA games, we illustrate the potential impact of this model. (Received September 22, 2015)

1116-L5-2784 **Jeffrey W Heath*** (jeffrey.heath@centre.edu), 600 W. Walnut St., Danville, KY 40422, and **Trevor Brewer** and **Eric Murrell**. *A New Sports Rating Methodology.*

Oftentimes the final point margin of a game is not indicative of the competitiveness of the matchup. We develop a new metric, Win Decisiveness Factor, which measures the decisiveness of a victory in a sporting matchup by incorporating estimates for the in-game win probabilities. This metric is the basis for our development of a new sports rating methodology. We present results from recent college basketball and football seasons. (Received September 22, 2015)

1116-L5-2929 **Rolando Cardenas*** (rcardenas4@yisd.net), 8100 Turquoise Street, El Paso, TX 79904. *The Bayesian Quarterback: A New Model for Rating NFL Quarterbacks.* Preliminary report.

Our fascination with the National Football League stems primarily in the adoration of its athletes. The passion exuded by fans is apparent in the billions of dollars of television revenue, merchandising, and legalized gambling participation through various fantasy leagues. Fans want to be a part of the game itself; to judge and evaluate a player's performance. For many years, one of the most controversial statistics is the NFL Passer Rating which consisted of four main descriptive statistics in evaluating a quarterback's performance. In 2011, ESPN introduced the "Total Quarter Back Rating" which including controversial metrics such as "the clutch index" referring to quarterback performance under duress. These rating systems are intriguing and also frustrating because neither one can be considered the definitive system capable of projecting or rating quarterback's performance. A football game is not static, but rather a contest that ebbs and flows based on the strengths and imperfections of the players themselves. I propose a new model for rating NFL quarterbacks; a dynamic model that includes descriptive statistics in addition to a Bayesian-Recursive algorithm which considers “a priori” and “a posteriori” information to adjust the scale of the traditional QB calculations. (Received September 23, 2015)

New Ideas in Teaching Upper-Level Statistics Courses

1116-M1-503 **Lisa J. Carnell*** (lcarnell@highpoint.edu). *Using a Practicum in a Surveys and Sampling Course.* Preliminary report.

In this talk I will discuss how to integrate a practicum into a course on surveys and sampling. When our course was under development, it was important to us that students get real-world experience in constructing questions, gathering data, and analyzing data from surveys. Therefore, we partnered with our on-campus Survey Research Center to provide students the opportunity to participate in the process of state-wide polling. (Received September 04, 2015)

1116-M1-1245 **Aimee D Schwab*** (schwaba1@xavier.edu), Cincinnati, OH 45207. *Using Peer Consulting in Applied Statistics Courses.*

Statistical consulting is a vital skill for students and future professionals to develop during their undergraduate education. At many institutions, a fully-fledged statistical consulting center is not a viable option, and students may miss out on opportunities to experience hands-on statistics. This paper presents a peer-based consulting project that can be implemented in upper-level statistics courses. Students may consult for an introductory course or for their peers at the upper level. During the project students develop expertise in study design, analysis, and statistical writing and communication. (Received September 18, 2015)

1116-M1-1295 **Hyun-Joo Kim*** (hjkim@truman.edu), 100 normal, Kirksville, MO 63501. *Interdisciplinary research project in Stat 2 class.*

Research can be the most challenging but rewarding experience in statistics class. It is rather natural to apply statistical method in other content areas. However, interdisciplinary research is rarely utilized directly in the undergraduate curriculum as part of a normal course. A well-crafted interdisciplinary research project in Stat 2 class can provide undergraduate students a valuable experience. Cutting edge biology research problem was introduced and used throughout Biostatistics class and a team of students from multiple disciplines produced a research paper as a final project. The process is closely monitored as a part of the course. Student survey shows great improvement on their growth in statistical knowledge, communication skill, and project management skills. (Received September 18, 2015)

1116-M1-2629 **Beth Chance*** (bchance@calpoly.edu), San Luis Obispo, CA 93401. *Simulation-based inference beyond the introductory course.*

Simulation-based inference provides an alternative introduction to statistical inference that focuses on visualization and building on student intuition of what could happen “just by chance.” In this talk, we will address how this logic can be extended to introduce more advanced inferential procedures such as regression, chi-square, and anova. In particular, with regression, we will discuss how the design of the simulation impacts the analysis. Students see how the standard error of the slope is affected by different factors, and why modern statistical learning methods include consideration of the variability in the potential predictor variables. (Received September 22, 2015)

1116-M1-2852 **Soma Roy*** (soroy@calpoly.edu), 1 Grand Avenue, Statistics Department, California Polytechnic State University, San Luis Obispo, CA 93407. *Design of Experiments: Helping Students Understand the Importance of Identifying Sources of Variability.*

In our introductory statistics class at Cal Poly, we introduce students to the logic of inference by saying that in well-designed studies there are always two possible explanations for the study results - random chance and something other than random chance. In our upper-level design of experiments (DOE) class, I revisit this idea of possible explanations, and have students now focus on what makes an experiment ‘well-designed.’ When designing an experiment, as statisticians we focus on identifying as many sources of variability as possible that might affect the response variable. Then, we design the experiment in such a way so as to isolate some of these sources and minimize/control the effect of the other sources on the response variable. In this talk I will describe an activity I use in week 1 of this DOE course that motivates the importance of identifying sources of variability, requires students to brainstorm such sources in the context of different studies and use design tools, such as, direct-control and randomization, to account for the effects of these sources on the response. I will provide examples of how I use such activities to help students progress from simple design structures to more complicated ones, all while thinking about accounting for sources of variability. (Received September 22, 2015)

Origami in the Mathematics K–12 Classroom

1116-M5-145 **Philip R Mallinson*** (pmallinson@exeter.edu), 74 Court Street, Exeter, NH 03833. *Constructing The Conic Sections By Paper Folding.*

The Common Core State Standards for Mathematics urge that topics be presented in a variety of representations, such as tactile and visual as well as analytic. The analytic study of the conic sections is a standard topic in the precalculus curriculum. I argue that the analytic approach is enriched when accompanied by powerful visual and tactile methods. I show how the envelope of certain creases formed by folding a sheet of paper marked with a point, or a point and a fixed circle, will generate a parabola, an ellipse or a hyperbola, depending on the location of the point with respect to the circle. Finally I show that these geometric representations are consistent with the standard locus definitions of these conics. (Received August 06, 2015)

1116-M5-325 **Jeanine Meyer*** (jeanine.meyer@purchase.edu), Mt. Kisco, NY 10549. *First Lessons in Origami with suggestions for incorporating mathematics.*

A sequence of simple origami models (business card frog, magazine cover box, water bomb, simple water bomb base modular) will be presented along with ways to incorporate mathematical concepts. Participants are encouraged to follow along and fold (2 models) and will be given challenges to complete in their own time. The underlying strategies for the K-12 classroom or informal instruction are to focus the students' attention on spatial relations and geometric concepts; to encourage students to teach others; and to explore origami on their own. (Received August 25, 2015)

1116-M5-549 **Arnold Tubis*** (tubisa@aol.com). *Origami-inspired deductive threads in pre-geometry, and the geometric modeling of aesthetically pleasing folded structures in grades 8-12.* Preliminary report.

Origami may be used to inspire basic postulates in pre-geometry from which can be inferred many of the standard mainstream geometric inferences relating to intersecting and parallel lines, congruence and area formulae of polygons, and the Pythagorean theorem. Moreover, many of these inferences may also be easily demonstrated/verified by folding. Also, the crease pattern analysis of simple and more complex decorative origami boxes provides a novel platform for producing interesting useful and aesthetically pleasing folded structures while at the same time providing extensive experiences in the integrated application of geometric concepts and techniques. (Received September 06, 2015)

1116-M5-575 **Norma J Boakes*** (norma.boakes@stockton.edu), Stockton University, School of Education, 101 Vera King Farris Drive, Galloway, NJ 08205. *My Journey from Classroom Teacher to University Professor in a Preservice Teacher Program: Using Origami as a Tool for Improving Core Math Understanding in Local and Overseas Classrooms.*

This presentation will focus on my extensive experiences using Origami as a teaching tool in math since the late 90s. K-12 experience stems from initial work as a high school teacher and with middle school age children as part of my doctoral studies. Research conducted on Origami in the classroom showed promise with Origami offering a way to make math concepts and understandings tangible. Work in this realm soon expanded to training other K-12 teachers on the use of Origami in the math classroom and visiting local school programs including honors and STEM. Successes in the K-12 environment led to the creation of a university undergraduate course on Origami and its link to math and art. Here too Origami had a positive influence on math understandings. These scholarly pursuits on Origami's impact lead further to a unique opportunity to bring the Origami-based approach to the country of Lesotho. Though far from the US classroom, K-12 Lesotho teachers experience the same struggles as US teachers seeking more innovative techniques for engaging learners meaningfully in math. The results of my work over four years with Lesotho includes a training program that has produced resource teachers proficient in the use of Origami mathematics and its implementation in K-12 classrooms. (Received September 07, 2015)

1116-M5-742 **Charlene Morrow*** (cmorrow@mtholyoke.edu) and **James Morrow** (jmorrow@mtholyoke.edu). *Geometry Meets Algebra in Making Simple Origami Cubes and a Carrying Box for Them.*

We will describe a set of origami models that motivate exploration of geometric ideas, mathematical language, and connections between algebra and geometry. These exercises were developed for an Origami and Mathematics course in which students ranged from pre-service teachers to mathematics majors to art majors. These exercises deepened students' ability to draw on ideas they probably had already learned, but were not easily called up in a broader problem-solving context. Our emphasis was not on following a set of directions to make beautiful paper objects, but rather, having made these objects, studying the inherent geometry that can be seen. Students were first taught to make two differently sized origami cubes each folded from six sheets of the same size paper. Students then investigated sizing an origami box to hold a set of three cubes based on the edge length of the cubes. Finally, for each of the two different kinds of cubes, students were asked to form an expression for the paper size needed for a three-cube-box based both on the paper size used for each cube and on the folding sequence used to make the cubes. Learning objectives, connections to core curriculum standards, and sample student outcomes will be discussed. (Received September 11, 2015)

1116-M5-934 **Christi L. Wilkins*** (christi@dramaticresults.org), 3310 Lime Avenue, Signal Hill, CA 90755. *Dramatic Results uses research-based, innovative strategies to engage underserved youth from Long Beach USD in Core mathematical thinking using origami to achieve measurable and reproducible results.*

What do the Mars Rover, heart valves, automobile air bags, robots and Japan's space sail have in common? Origami - the ancient art of paper folding. "With origami, the math goes through your head to your hands to the art you are creating. I love making origami." This fifth grader is one of 1,250 inner-city students who have demonstrated 25+ point gains in math after experiencing Dramatic Results' InCreasing Math program. Delivered in-class as a regular part of students' instructional day, this origami-integrated program uses research-based, high quality instructional techniques to model strategies for the classroom teacher that can be applied across the school day. The curriculum exemplifies a participatory approach, using the Engineering Design Process and emphasizing Math Practices, to help students uncover their potential and creativity, building persistence and resilience in their math performance.

With just 10 hours of direct contact, internal evaluation shows a statistically significant increase in mathematical skills and processes, knowledge of engineering, artistic expression, persistence, creativity, and problem-solving. DR makes learning relevant, integrating the traditional art of origami to inspire technological innovations. (Received September 15, 2015)

1116-M5-969 **Patsy Wang-Iverson*** (pwangiverson@gmail.com). *Can Origami Help Improve Student Learning of Mathematics?*

Individual teachers have incorporated origami into the classroom over the years, but a search for the word in the Common Core State Standards yields no results. Thus, origami does not appear to be generally recognized and accepted as a vehicle for facilitating student learning of mathematics, although Illustrative Mathematics offers some lesson plans that do include origami. Studies also have been conducted on the 'effectiveness' of origami. However, they did not focus on mathematics content knowledge. In this presentation, we will examine some items from TIMSS (Trends in International Mathematics and Science Study) 2011 and discuss ways in which origami might have helped improve student performance and understanding of the mathematics concepts.We will conclude with a discussion of how origami is facilitating cutting-edge STEM research. (Received September 15, 2015)

1116-M5-2690 **Rona Gurkewitz*** (gurkewitzr@wcsu.edu), WCSU, 181 White Street, Danbury, CT 06810. *Three Theorems Accessible to Middle and High School Students Used in Folding a Simple Modular Origami Book.*

Mathematical theorems are used to design amd fold evem simple origami models. In the folding of a Simple Modular Accordion Folded Book of my design, three theorems arising from practical and aesthetic considerations are used. Furthermore, these theorems are accessible to middle and high school students. The first theorem involves folding a square or rectangle in half using opposite edges and avoiding a center crease or pinch. The second is Fold two folds spaced equally around the what would be the center line of a rectangle, without folding a center crease. The third involves a formula fpr the number of pieces of paper needed to achieve a book of a certain number of pages. (Received September 22, 2015)

1116-M5-2863 **Robert Orndorff*** (orndorff@uw.edu), **Debby Halperin** and **Mary Ann Crawford**. *Seattle Public Schools STEM Paper Folding Program.*

We started our paper folding program nine years ago. Every year, we work with three elementary school classes. Each class does paper folding once per week for one year.

Our principal aims comprise the following four aspects of early STEM education: ability, engagement, confidence and plans. We also address other objectives, e.g., looking at things deeply; failing constructively; asking one's own questions; nurturing creativity.

The program has been a success: it is popular with teachers, students, parents and the district math office; one of us has twice been a finalist for the national presidential award for math teaching; extracurricular programs are well attended; we were asked to present at the Northwest Mathematics Interaction meeting for math teachers.

In light of our aims, including the Common Core State Standards: How do we select projects? Which kinds of projects work? In what order do we do them? How do projects target specific goals? What behaviors and habits do we encourage? How do we adjust for student age? In this talk, we will address these and other things.

Our premise is that this program, taught by a math and origami expert in collaboration with teachers who value the connection between math and paper folding, will contribute to the above aims. (Received September 22, 2015)

1116-M5-2990 **Celina Gonzalez*** (cegonzalez@hightechhigh.org), University of San Diego/HighTechHigh(HTeNC),1480 West San Marcos Blvd.,San Marcos, CA, **Perla Myers** (pmyers@sandiego.edu), University of San Diego, and **Jeffrey Feitelberg** (jfeitelberg@hightechhigh.org), HighTechHigh (HTeNC). *Project Mathigami: engaging K-12 students in mathematics through Origami.*

Project Mathigami aims to give children, college students and educators positive experiences in mathematics to ignite their curiosity and stimulate them to create and explore meaningful mathematical questions. We focus on supporting students and educators as they develop the Standards for Mathematical Practices recommended by the Common Core and embrace the iterative process of exploration of mathematical concepts through failure, reflection and revision. Supported by a grant from the Wong Foundation, we invited a group of K-12 classroom teachers to work on mathematical explorations based on origami models alongside college students throughout the year. Each teaching team consists of one teacher and one to two college students from a wide range of fields including mathematics, computer science, engineering, art, biology, and education. Teaching teams attend Mathigami workshops together and plan, develop lessons, and then co-teach the K-12 students. In this presentation we will share some examples of lessons focused on fractions and proportional reasoning, through explorations based on the Platonic solids. We will also share our process and the preliminary results of our work. (Received October 05, 2015)

Preparation, Placement, and Support of Elementary Mathematics Specialists

1116-N1-249 **Cheryll Elizabeth Crowe*** (cheryll.crowe@asbury.edu). *TPACK & Training Teachers: Preparing Pre-Service Elementary Math Specialists.*

This presentation will outline the mathematics preparation for an elementary math specialist degree at a liberal arts university. Using the TPACK framework, this program emphasizes the teaching and learning of mathematics content through the integration of pedagogy and technology. Participants will gain insight into the program components (a sequence of six mathematics courses) which include embedded clinical experiences and an action research project in the capstone course. (Received August 18, 2015)

1116-N1-1468 **Victoria Kofman*** (drkofman@comcast.net), Stella Academy, 1358 Busch parkway, Buffalo Grove, IL 60089, and **Sayonita Ghosh Hajra**. *A Snapshot of Pre-service Teachers' Use of Visual Representation for Solving Word Problems.*

American students mostly present pictorial representations that retell situations, although students in other countries, e.g., Russia and Singapore, use pictorial representations that lack details, but present the word problems in a schematic way. Here, we present our findings from a pre-assessment on word problems with pre-service teachers, who were enrolled in a mathematics content course for elementary school teachers. We found most of the pre-service teachers, when asked to model to explain word problems, used free style situational pictures retelling the text. When dealing with small, three digit numbers, students still used squares as a one, resulting in time consuming illustrations. None of the pre-service teachers illustrated their solutions for more challenging 2-3 step problems where three digit numbers greater than 200 were involved. We concluded teaching pre-service teachers how to use visual models to solve challenging problems is a must in a mathematics course for pre-service teachers. (Received September 20, 2015)

1116-N1-2338 **Aimee J. Ellington*** (ajellington@vcu.edu), 1015 Floyd Avenue, Richmond, VA 23284-2014, **Joy W. Whitenack** (jwwhitenack@vcu.edu), 1015 Floyd Avenue, Richmond, VA 23284-2014, and **David J. Edwards** (dedwards7@vcu.edu), 1015 Floyd Avenue, Richmond, VA 23284-2014. *Virginia's K-8 Mathematics Specialists: How They Are Prepared to be Mathematics Leaders and Their Impact on Students and Teachers.*

In this presentation, quantitative and qualitative results from four large scale NSF funded grant projects on the preparation and placement of mathematics specialists in Virginia's elementary and middle schools will be presented. Virginia's program to prepare practicing teachers to serve in this coaching-based role will be described. In particular, what we have learned a successful program must include. In addition to presenting findings on the impact of mathematics specialists on student achievement, we will also share results related to (1) what specialists learned through the preparation program, (2) specialists' influence on teachers' beliefs about how mathematics should be taught, (3) the meaningful ways specialists spend their time in the school buildings, and (4) proven methods specialists use to help teachers make practical and useful shifts in their pedagogical practices. (Received September 22, 2015)

1116-N1-2378 **Laurie Burton** and **Cheryl Beaver*** (beaverc@wou.edu). *The Elementary Mathematics Instructional Leaders (EMIL) program: Preparing community leaders.*

We will share the structure and design of our Elementary Mathematics Instructional Leader (EMIL) graduate program for inservice teachers and describe the progress and successes of our DEMILO three-year grant training 60 inservice teachers in Oregon to be Elementary Mathematics specialists. Our graduates are teacher leaders and coaches who are responsible for supporting effective mathematics instruction and student learning at the classroom, school, district, or state levels. (Received September 22, 2015)

1116-N1-2857 **Bernadette Mullins*** (bmullins@bsc.edu), Department of Mathematics, Birmingham-Southern College, Birmingham, AL 35222. *Supporting In-service Elementary Mathematics Teachers in Implementing Inquiry-Based Instruction and the CCSS for Mathematical Practice.* Preliminary report.

Many in-service elementary teachers did not experience inquiry-based instruction as learners of mathematics. We describe a summer professional development workshop that immerses teachers in a learning environment focused on inquiry and the Common Core State Standards for Mathematical Practice and supports their efforts to implement it in their own classrooms. Our results include data from a rubric-scored pre-post assessment. (Received September 22, 2015)

Professional Development for Mathematicians: A Session for MAA PREP Organizers and Participants

1116-N5-547 **Betsy G Yanik*** (eyanik@emporia.edu), Department of Mathematics and Economics, Box, Emporia State University, Emporia, KS 66801. *A MAA PREP workshop on Preparing Departmental Reviewers.*

A MAA Prep workshop was held in Washington, DC this past summer. The purpose of this Pre-Mathfest event was to assist those who were nominated as outstanding candidates for department reviewers. This workshop was organized under the auspices of the MAA Committee on Departmental Review. My talk will summarize the major components of this program. (Received September 06, 2015)

1116-N5-1443 **Tevian Dray*** (tevian@math.oregonstate.edu), Department of Mathematics, Oregon State University, Corvallis, OR 97331, and **Corinne A. Manogue** (corinne@physics.oregonstate.edu), Department of Physics, Oregon State University, Corvallis, OR 97331. *A Tale of Two Workshops.*

We organized a very successful PREP workshop in 2004 — and tried again in 2007 but failed. What did we do right? What did we do wrong? What did we learn? This talk presents an informal summary of our experiences organizing several workshops, including these two. (Received September 19, 2015)

1116-N5-1499 **Qiang Shi*** (qshi@emporia.edu). *Using the MAA PREP Program to Enhance Teaching and Research.*

In this presentation, I will share my experience as a participant in several MAA PREP workshops. My first PREP workshop was the Wavelets and Applications workshop at the University of St. Thomas in 2007. In 2009, I attended the Mathematical Modeling in Population Biology and Epidemiology workshop at Texas Tech University. Last year I tried my first online PREP workshop - Authoring Effective Homework Problems with

WeBWorK. From my experience, I believe the MAA PREP program provides high-quality professional development opportunities for its participants. These workshops have helped me advance my teaching and scholarship. Using the material that I learned in PREP workshops, I have developed a new course and directed three undergraduate research projects. These projects will be shared at my presentation. (Received September 20, 2015)

1116-N5-1743 **John Travis*** (travis@mc.edu), Box 4025, Mathematics, Mississippi College, Clinton, MS 39058, and **Karl-Dieter Crisman**. *You should try running an online workshop!*

Do you have a teaching idea to share with others? Unsure about the logistics of bringing people to you to share it? Consider hosting an online workshop to disseminate your strategies and resources! Based on our experience attending and organizing many online PREP workshops, we'll introduce some basic dos and don'ts of presenting a workshop "in the cloud". (Received September 21, 2015)

1116-N5-2493 **Karen Bliss*** (blisskm@vmi.edu) and **Jessica Libertini**. *Setting a Pace for Success in Faculty Development.*

In July 2015, we ran an MAA PREP workshop with the goal of giving faculty the training, guidance, and community support needed to allow them to bring a modeling-based approach into their differential equations classes. Leveraging a wide range of prior faculty development activities, both as instructors and as participants, the organizers made an intentional decision to greatly relax the pace of the workshop in the hopes of fostering internalization of ideas as well as community cohesion amongst the participants. The workshop schedule included time for participants to rewrite modeling scenarios to add their own interests, angles, and voice to classroom materials. Based on formal survey feedback from the participants, as well as some continued informal communication with participants, we believe that this approach increased the impact of our workshop. (Received September 22, 2015)

1116-N5-2813 **Stan Yoshinobu*** (styoshin@calpoly.edu) and **Matthew G Jones**. *The Inquiry-Based Learning Workshop Model for Professional Development.*

Inquiry-Based Learning (IBL) is a method of teaching marked by deep engagement of students in rich mathematical tasks. The version of the IBL Workshops we discuss is the iteration that has been a part of the MAA PREP from 2013 to 2015. As evidence has gathered about the effectiveness of IBL, the authors have spent more than a decade promoting uptake of IBL methods by mathematics instructors, with the resulting system of professional development for instructors resulting in better than 75% uptake by participating instructors. In this session, we briefly describe IBL and evidence for IBL, and then proceed to explain our system of instructor professional development and the evidence for its effectiveness. We include a broad outline of a typical 4-day workshop, processes used in session strands and the goals of the strands, and our multi-faceted approach to follow-up. (Received September 22, 2015)

Proofs and Mathematical Reasoning in the First Two Years of College

1116-P1-373 **Kathleen M. Shannon*** (kmshannon@salisbury.edu). *Freshman-Level Discrete Mathematics as an Introduction to Proof.* Preliminary report.

In the 1980's, there was a push to introduce students to discrete mathematics in parallel with the Calculus. Proof and the language of proof fit neatly into a treatment of discrete mathematics, and at Salisbury University we have had, for over twenty-five years, a required freshman-sophomore-level Discrete Mathematics course, which serves both mathematics and computer science majors and which serves as an introduction to proof for the mathematics majors. We have had students transfer from community colleges with credit for Discrete Mathematics, at least one of whom used our syllabus and text. In this paper, I will describe the syllabus for and content of our course, the in-house text written specifically for the course, student reactions, and outcomes. I will also make an argument for discrete mathematics as a vehicle to introduce students to proof and to get them thinking more broadly about mathematics as a discipline early in their careers. (Received August 28, 2015)

1116-P1-909 **Karin R Saoub*** (saoub@roanoke.edu), 221 College Lane, Salem, VA 24153. *Bridging the Gap – Inserting a Transitions Course between an Introductory Proofs Course and Upper-level Theoretical Courses.*

Most students take an introduction to proofs course early and rigorous pure mathematics courses towards the end of their college career. This time gap and lack of practice in proof writing often leads to frustration for both the student and professor and the need to reteach proof techniques. To combat this, Roanoke College created mid-level proofs courses designed to transition students more effectively from Discrete Mathematics to Real Analysis and Abstract Algebra. This talk will discuss the format of these courses and preliminary results on student learning and outcomes. Early data and empirical thoughts will be included. (Received September 15, 2015)

1116-P1-1074 **B. Dean Gooch*** (dgooch@santarosa.edu), Dean Gooch, Mathematics/Shuhaw Hall, Santa Rosa Junior College, 1501 Mendocino Avenue, Santa Rosa, CA 95401. *Teaching Mathematical Reasoning and Proofs in the Two-Year College Setting.*

I teach at a two-year college in Northern California. I have seen that more and more, my students who wish to major in mathematics need a solid course in mathematical reasoning and proofs to prepare them for upper division mathematics. I have crafted such a course and will talk about the very preliminary results so far. I will also talk about the problems with students taking only a less rigorous discrete mathematics course and what kind of experiences some of these students have had at their transfer institutions. I posit that the mathematical reasoning and proofs course is needed as a means of recruiting more students into mathematics. I will also discuss the difficulties with introducing such a course to a two-year college environment in which such courses are virtually unknown and the some of the problems with transferability to four-year institutions. (Received September 16, 2015)

1116-P1-1286 **Ahmed A Benkhalti*** (benkhaaa@nmsu.edu), **John Selden** and **Annie Selden**. *Proof Frameworks – A Way to Get Started on Writing Proofs.*

Many mathematics departments have instituted transition-to-proof courses for second semester sophomores to help them learn how to create proofs in order to prepare them for proof-based courses in their junior and senior years. It is our understanding that now many community colleges do not offer such courses, but may want to begin doing so. We have developed a way of getting students, who often stare at a blank piece of paper not knowing what to do, started on proof writing. This is the technique of writing proof frameworks, based on the logical structure of the statement of the theorem and associated definitions. Often there is both a first-level and a second-level of a proof framework. We will discuss how we came to the idea of proof frameworks and demonstrate the writing of several proof frameworks. (Received September 18, 2015)

1116-P1-1323 **James Sandefur*** (sandefur@georgetown.edu), Department of Mathematics and Statistics, Georgetown University, 37 & O St. NW, Washington, DC 20057, and **Kay Somers** (somersk@moravian.edu). *Using Videocases to Focus Student Thinking (Inside and) Outside of Class.*

The authors, to better understand where their introduction to proof students' difficulties lie, have been creating videos of pairs of their own students working together to write proofs. Through this work, we have determined that there are often three steps in the proof writing process: discover a key idea about why the statement is true or false; find some, often algebraic, techniques to convert the idea into a convincing argument; and convert this argument into a well-written proof. The students in our videos frequently discover a key idea of why the statement is true and some algebraic tools that convert these ideas into a (sometimes sketchy) argument, but they do not, generally, produce a well-written proof. In this talk we will illustrate one way we have used our videos to help our current students reflect on their own proof-writing. In this method, we show a video in class, discuss the "proof" and, as a class or in groups, work on producing well-written proofs. As a follow-up, students are also assigned to watch additional relevant videos outside of class, answer questions and write about the positives and negatives of the students' work in the video, and produce a proof. Attendees can have free access to the more than 40 videos we have edited. (Received September 18, 2015)

1116-P1-1619 **Houssein El Turkey*** (helturkey@newhaven.edu), **Gail Tang**, **Milos Savic**, **Gulden Karakok**, **Emilie Naccarato** and **David Plaxco**. *Addressing Creativity in an Introductory Proof Course.*

To help students overcome some of the difficulties in learning how to construct proofs, we implemented a formative assessment instrument called the Creativity-in-Progress Rubric (CPR) on Proving. This formative assessment tool was created to foster students' mathematical creativity as well as to enhance their proving skills. The CPR has two main categories with subcategories: Making Connections (Between Definitions/Theorems, Between Representations, Between Examples) and Taking Risks (Tools/Tricks, Flexibility, Perseverance, Posing Questions, Evaluation of the Proof Attempt). In this presentation, we will share the design of an inquiry-based learning (IBL) introductory proofs course, describe the CPR, and explain the ways the CPR was implemented in class. We will also report on results from a qualitative study conducted with students who took the IBL course.

The interviews focused on their perspectives of the CPR and how they used it on their proving. Preliminary analysis shows that student use of the CPR aided them when they were "stuck" on a proof, and that the CPR was useful in helping them make connections in order to prove a theorem. (Received September 20, 2015)

1116-P1-2010 **Wei-Kai Lai*** (`laiw@mailbox.sc.edu`), 807 Hampton St., Walterboro, SC 29488. *Proof-writing before Calculus, a Salkehatchie experience.* Preliminary report.

As one of the regional campuses of the University of South Carolina, Salkehatchie campus offers only first two year Math courses to students from all majors. To better equip students in STEM majors, we incorporate many proof-writing practices in Precalculus, Calculus, and Independent Study. Even though these practices do not weight much in their final grade, and many of them are used as bonus-point problems, students still get a taste of how to compose these arguments. In this talk I will share some sample problems we used in classes, mainly Precalculus, for students to practice proof-writing. Suggestions and experience from the audience are also welcome. (Received September 21, 2015)

1116-P1-2782 **Ross Sweet*** (`rsweet@math.northwestern.edu`), 2033 Sheridan Road, Evanston, IL 60208, and **Matthew Graham**. *Transitioning from Lecture to Active Learning in an Introduction to Proofs Course.* Preliminary report.

At Northwestern University, the introduction to proofs course is generally taken by students in between the calculus sequence and upper-level courses. Traditionally, this course has been taught in the lecture model, combined with homework and in-class exams. This model tends to limit the number of examples and problems students are able to work. Our philosophy in approaching this course was to invert the course and create an active learning environment during lecture time. This model dramatically increased the number of problems students were exposed to during the course. We will discuss the process of transitioning from a lecture model to an active learning inverted model, student outcomes with survey data, as well as identify novel challenges that this model incurs. (Received September 22, 2015)

1116-P1-2785 **Matthew D. Graham*** (`mdgraham@math.northwestern.edu`). *Promoting Out-of-class Student Engagement in an Introduction to Proofs Course.* Preliminary report.

Having previously converted a standard lecture course into an inverted active learning course for the introduction to proofs course at Northwestern University, we wanted to refine our structure to emphasize the communications skills (written, formal presentation, and casual math communication skills) of our students while still exposing our students to a much larger than average number of problems. To do this we assigned two in-class presentations. The first being a partner presentation and the second a solo presentation. This change takes up valuable class time. To still expose our students to the large number of problems we needed to maximize out-of-class engagement. We discuss the structural methods and technology that we used in our attempt to achieve these goals. Additionally, we present empirical and anecdotal data gathered from anonymous surveys, teaching evaluations, and observations in the classroom and office hours. (Received September 22, 2015)

Quantitative Literacy in the K–16 Curriculum

1116-P5-485 **Olaseni T. Fadipe*** (`fadip1ot@cmich.edu`), Mathematics Department, Central Michigan University, Pearce 214, Mount Pleasant, MI 48859. *The Development of Quantitative Literacy (QL) in College Students.*

The ability to use basic mathematics to make sense of numerical information found around us is called Quantitative Literacy (QL). The need for quantitatively literate citizens is now frequently discussed not only amongst mathematicians and the academic community but also amongst people in government and industry. Increasingly, QL courses are now being taught at many universities to meet this need. In this presentation, I will discuss the outcome of a study that examined the QL skills of college students with regards to some basic mathematics concepts. 36 students were asked to complete pre- and post-tasks on percentages, large numbers, and graphs. Results show that students did better in large numbers and graphs tasks than they did in percentages tasks. For example, more than half of the students failed to realize that when you decrease a number by a percentage and then increase the reduced number by the same percentage, the new number is not the same as the original number. Two students were also interviewed and asked to complete a financial decision-making task. Their attempts of this task suggest that students could have difficulty differentiating between a percent bonus and a percent increase. I will conclude my talk by discussing the teaching implications of this work. (Received September 04, 2015)

1116-P5-795 **Ksenija Simic-Muller*** (simicmka@plu.edu), Pacific Lutheran University, Mathematics Department, 1010 122nd St S, Tacoma, WA 98447. *From quantitative literacy to basic modeling in a summer bridge program.*

This summer I taught a quantitative literacy mathematics course in a summer bridge program. The students, while having taken a variety of mathematics courses in high school, including calculus, had placed in the lowest level mathematics class at my institution, and had weak mathematical preparation, even having trouble reading and writing large numbers. The curriculum in the course especially focused on issues of social justice. The course culminated in a final project, in which most students used basic mathematical modeling to make predictions about future graduation rates, world population, and the end of oil reserves, among others. I found that the focus on critical reasoning rather than on formulas and equations, the use of technology to assist in problem solving, as well as the use of contexts that were familiar and relevant, leveled the playing field and provided all students enrolled in the class with an opportunity to do mathematics and be mathematicians. (Received September 13, 2015)

1116-P5-1104 **Lina Wu*** (lwu@bmcc.cuny.edu), 529 West 42nd Street Apt. 5K, New York, NY 10036, and **Wenyi Lu**. *Enhancing Students' Quantitative Literacy and Reasoning Skills in Statistical Thinking by Projects.* Preliminary report.

The presenter is interested in incorporating projects in teaching to enhance students' ability of quantitative literacy as well as quantitative reasoning skills in statistics. During the sequence of pilot statistics courses from 2012 to 2015 at Borough of Manhattan Community College-The City University of New York, the presenter designed a series of projects in statistics especially for the subject of hypothesis testing to facilitate students' learning. By working on projects in the pilot courses, students would be expected to improve their decision-making skills based on data as evidence when they are surrounded by numerical information in the current data-driven society. This new approach of teaching will closely correlate learning of statistical techniques with practicing of real-life projects. It can bring interests and excitements to ignite students' learning desires. Results of students' performance in pre-tests and post-tests will be compared and analyzed at the end of this presentation. This sequence of pilot courses from 2012 to 2015 was supported by the program of "Quantitative Reasoning across Curriculum" at Borough of Manhattan Community College joint with CUNY Graduate Center. (Received September 17, 2015)

1116-P5-1150 **Kira Hylton Hamman*** (kira@psu.edu). *From the Algebra Project to the Common Core: Quantitative Literacy and Social Justice.*

Quantitative literacy and social justice are inextricably linked. Bob Moses recognized this is 1982, when he used the MacArthur fellowship he had just won to launch the Algebra Project. Two decades later, he explained the success of the project in his book Radical Equations, the first chapter of which is tellingly titled "Algebra and Civil Rights?" In the same two decades, a parallel movement emerged in higher education linking quantitative (il)literacy to the (ill) health of our democracy and was brilliantly summarized in Lynn Steen's 2001 book Mathematics and Democracy. In this talk we discuss the relationship between these two movements and their relevance to the current state of K-16 quantitative literacy, as embodied in the Common Core State Standards for Mathematics. (Received September 17, 2015)

1116-P5-1178 **Thomas E. Leathrum*** (leathrum@jsu.edu), Dept. of Math, Computing, and Info. Sciences, Jacksonville State Univ., 700 Pelham Road North, Jacksonville, AL 36265. *Personal Finance as a Practical Approach to Mathematical Literacy in College.*

Our students not pursuing majors in a STEM discipline have been seeking alternatives to the Precalculus sequence courses. Textbooks for such courses often include a chapter on mathematics of finance with topics such as compound interest and annuities, useful for students but often out of context for these courses. Another department asked for a course covering practical uses of percentages with an emphasis on applications relevant to consumers or employees. Seeing an opportunity to both address this request and allow the other courses to better focus their material, we created a new course, "Mathematics of Personal Finance." Applications covered include markups and markdowns, single and chain discounts, simple interest, revolving credit accounts, compound interest, annuities, installment loans and mortgages, amortization, and the costs of home ownership. The development of formulas for these applications involves some interesting mathematical tools such as exponentials and partial geometric sums. This provides a practical approach to quantitative literacy in a college course for non-STEM students, and connects well with topics in the high school Common Core math curriculum standards. (Received September 17, 2015)

1116-P5-1937 **Lindsay Orlando*** (lorlando@austincc.edu), Austin Community College, Highland Campus, 6101 Airport Blvd, Austin, TX 78752, and **Mary Parker** and **Hunter Ellinger**. *Statistical Visualization Applets for the Collegiate QL Course.*

Statistical topics are often hard to for students to conceptualize and time-consuming to create by hand. In this talk I will present how several visualization Applets (designed and written by Dr. Mary Parker and Hunter Ellinger at Austin Community College) can be used in a Quantitative Literacy course that includes basic statistical content to enhance student understanding of how to create and interpret histograms, various plot types, correlation, and more. These open-source Applets and their instructions can be copied to an instructor's own webpage and modified. (Received September 21, 2015)

Recreational Mathematics: Puzzles, Card Tricks, Games, Game Shows, and Gambling

1116-Q1-40 **Jay Malmstrom*** (jmalmstrom@occc.edu), OCCC, Dept of Mathematics, 7777 S May Ave, Oklahoma City, OK 73159. *Odd or Even: Dominoes, Graphs, and the "Missing Link.".*

A popular self working magic trick involves having an individual lay out a set of dominoes in a single line, while your back is turned and then, without looking, revealing the numbers on the end of the line. The trick, and the conditions under which it works, can be used to demonstrate concepts in graph theory to students in a general education Mathematics class. (Received June 12, 2015)

1116-Q1-174 **Mark Bollman*** (mbollman@albion.edu), Dept. of Mathematics and Computer Science, Albion College, Albion, MI 49224. *Simple Matching Game or Clever Counter Trap? The Story of Pell (c. 1977-1982).*

Pell was a short-lived casino game that had a brief run in 1982 at Sam's Town in Las Vegas. The card game was easy to understand and to play, and offered a number of wagers with reasonable house advantages. Whether the inventor knew it or not, Pell was susceptible to card counting, and a card-counting team attacked the game during its trial, contributing to its short life. Some gaming experts suggested that Pell was deliberately designed to identify gamblers who were counting cards at blackjack. This talk will look at the mathematics behind Pell, examine the card-counting scheme that took it down, and consider a newer game, Top Rung, with many of the same game elements and challenges. (Received August 11, 2015)

1116-Q1-304 **Bruce Torrence*** (btorrenc@rmc.edu), Dept. of Mathematics, P.O. Box 5005, Ashland, VA 23005. *Fibonacci over Lucas; Lucas over Five Fibonacci - Winning Probabilities in a Game of Chance.*

Imagine that you are one of n people seated at a round table playing a game. A hundred dollar bill is placed in front of you, and the bill takes a random walk: With probability 1/3 it moves one place to the left; with probability 1/3 it moves one place to the right; and with probability 1/3 the game ends and the bill is given to the player seated at its current position. The bill starts in front of you, and keeps moving one player to the left or right until at some stage the game ends. What is the probability that you are the winner? Surprisingly, it will be shown that each player's likelihood of winning is a ratio involving a Fibonacci number and a Lucas number. (Received August 24, 2015)

1116-Q1-407 **Susanna Molitoris Miller*** (smolitor@kennesaw.edu), **Brian G. Kronenthal**, **Jathan W. Austin** and **Jonathon A. Miller**. *Mathematics in the Settlers of Catan.* Preliminary report.

The Settlers of Catan, a popular property-building and trading board game, can be used to explore a number of different mathematical areas relevant to undergraduate courses. Aspects of the game relevant to probability, combinatorics and graph theory will be discussed, as well as ways in which the game might be incorporated into introductory mathematics courses. (Received August 31, 2015)

1116-Q1-615 **Dibyajyoti Deb*** (dibyajyoti.deb@oit.edu), 3201 Campus Drive, Oregon Institute of Technology, Mail Stop 105, Klamath Falls, OR 97601. *Fun applications of Abstract Algebra: The 15 Puzzle.*

Abstract Algebra, at first glance seem to have very few applications in the real world, which deters undergraduate students from taking the class unless it is mandatory. In this talk we will look at ways in which we can make

Abstract Algebra fun and interesting for students. I will talk specifically about the 15 puzzle and how we can use simple Abstract Algebra to solve it. (Received September 09, 2015)

1116-Q1-951 **Aaron Montgomery*** (montgoaa@cwu.edu), Mathematics Department, Central Washington University, 400 East University Way, Ellensburg, WA 98926-7424. *What is left after everything is removed? Unexpected results from infinite processes.*

As filler in an undergraduate abstract algebra class, I tossed out a question that I had encountered in a high school math puzzler involving the final state of an infinite process. In the process, chips are added and removed from a bag and the question asks what remains at the end of all additions and removals. As the class discussed the solution, more questions arose than we could answer. The question sparked enough interest that an undergraduate and I decided to spend some time exploring the questions raised. Some of the early exploration involved enumeration and suggested basic computational techniques, but soon we found that the more interesting questions led through an introduction to cardinality theory and the point-set topology of the real line. As we discussed this topic with other faculty on campus, we discovered that the original question was unknown to the them. In the talk, I will present the original question and discuss some of our results. Hopefully, you will leave the talk with some new questions for your students to ponder. (Received September 15, 2015)

1116-Q1-1160 **Tom Edgar***, Mathematics Department, Pacific Lutheran University, Tacoma, WA 98447, and **Jessica Sklar**, Mathematics Department, Pacific Lutheran University, Tacoma, WA 98447. *Confused Electrician Games.* Preliminary report.

We define "Confused Electrician games," which generalize "Lights Out," a game popular in mathematics literature. In addition to "Lights Out," many more recent computer game puzzles can be modeled as Confused Electrician games. We provide examples of this, and explain how to solve such games using the Smith Normal Form of a matrix. We note that in many cases, using this method proves to be very efficient compared to another more obvious method. (Received September 17, 2015)

1116-Q1-1197 **Whitney George*** (wgeorge@uwlax.edu) and **Janine Janoski**. *The Hidden Mathematics of Super Tic-Tac-Toe.*

We all have played the beloved game tic-tac-toe. Now imagine in each square of the board, we draw a smaller tic-tac-toe board, making a 9×9 grid with 9 squares making a larger board. Now let Super Tic-Tac-Toe (STTT) be a game where each player's move dictates which larger square a player must make their next move. We will also play an impartial game of STTT where each player uses an "x".

In this talk we will explore the mathematical structure of impartial STTT. We define a set of actions on a game board which gives rise to a group-action on the game that creates equivalent games. We will discuss how the structure of this group-action forms a Dihedral group and how this can be extended to $n\times n$ super tic-tac-toe boards. (Received September 17, 2015)

1116-Q1-1284 **Robert W Vallin*** (robert.vallin@lamar.edu), Department of Mathematics, Lamar University, P.O. Box 10047, Beaumont, TX 77710. *Waiting for a Sequence in Roulette.*

In an experiment of flipping a coin three times, each of the eight possible outcomes is equally likely to occur. However the possible results of three tosses have different wait times for an outcome's first appearance in a string of coin flips. In this talk we apply this idea to a roulette wheel and analyze the wait time for three outcome choices (such as Red/Black/Red) to appear in a run of spins under different green square (0 and 00) interpretations. This is all related to Penney's Game, a non-transitive two-player game that first appeared in 1969. (Received September 18, 2015)

1116-Q1-1363 **Deborah E. Seacrest*** (debbie.seacrest@umwestern.edu) and **Tyler P. Seacrest** (tyler.seacrest@umwestern.edu). *On Prisoners, Hats, and Sperner Labelings.* Preliminary report.

Suppose n prisoners are given hats by a prison warden, and the hat labels range from 1 to s, with repetition permitted. Each prisoner can see the other hats but not their own. The goal of the prisoners is for all n prisoners to simultaneously shout the same number, and for that number to be on at least one of the hats. We show that the prisoners have a strategy that gives a probability of success at least $\frac{n}{n+s-1}$, and that this is best possible. The proof uses Sperner labelings to demonstrate optimality. (Received September 18, 2015)

1116-Q1-1632 **Brendan W Sullivan*** (sullivanb@emmanuel.edu), Emmanuel College, 400 The Fenway, Boston, MA 02115, and **Nikolas Townsend** and **Mikayla Werzanski**. *Cops and Robbers meets Chess.*

In the game of Cops and Robbers, a team of Cops pursues an evasive Robber. The sides alternate turns, with legal moves specified by some underlying graph of nodes and edges. The Cops win if there exists a strategy whereby they capture the Robber in finite time; otherwise, the Robber wins by indefinitely escaping. In general, one seeks the "Cop number" of a graph, the minimum number of Cops required to guarantee victory.

Here, we present results about this game when the Cops and Robber are allowed to move like specified chess pieces on an $n \times n$ board. We investigated Bishops, Rooks, and Queens. More specifically, we analyzed differences between the standard game and the so-called "Lazy Cops" variant, wherein only *one Cop may move* when it is the Cops' turn. We show that the Cop number for Bishops and Rooks is 2 for any n, whereas n Lazy Cops are required. We demonstrate a similar relationship for Queens: For ordinary Cops, 3 suffice as long as $n \leq 7$, and 4 suffice for any n. (We also show that 4 are *required* as long as $n \geq 19$.) Meanwhile, the Lazy Cop number grows with n, bounded between $n/3$ and $n/2$. We conclude by posing some related conjectures and open problems. (Received September 20, 2015)

1116-Q1-1904 **Ward Heilman*** (wheilman@bridgew.edu), **Leonard Sprague** and **Nicholas Pasciuto**. *Grime Dice and the Archbishop.* Preliminary report.

We discuss investigations into two unique problems. The first uses Grime dice as a starting point to study non-transitive dice in general. In the other, world chess champion José Capablanca's new piece, the Archbishop, presents new twists on ancient chess questions. (Received September 21, 2015)

1116-Q1-1955 **Oscar Levin*** (oscar.levin@unco.edu), School of Mathematical Sciences, University of Northern Colorado, Greeley, CO 80639. *Knights and Knaves in the Classroom.*

Knights and Knaves puzzles ask the reader to draw conclusions from a number of statements without knowing the truth value of each statement. One would hope that these logic puzzles would make a fantastic introduction to logic for students in a undergraduate discrete math or bridge course. However, while most examples of puzzles of this type do give students practice with logical reasoning, they do little to illustrate the use of connectives or quantifiers. In this talk, I will attempt to fill this void with a few original puzzles designed specifically to introduce students to topics in elementary logic. (Received September 21, 2015)

1116-Q1-1984 **Darren Glass**, **S K Lucas** and **Jonathan Needleman*** (needlejs@lemoyne.edu). *Chuteless and Ladderless.* Preliminary report.

Chutes and ladders is a game, that after while, many players just want to end! Previous papers on the subject have used computational methods to study the average length of the game for common layouts of chutes and ladders. In this talk we will give preliminary results toward understanding optimal placement of chutes and ladders, subject to making the game end quickly as possible. We begin with boards with no chutes or ladders, and find analytic approximations of computational results. If time permits we then use these results to understand optimal placement of a single chute and ladder. (Received September 21, 2015)

1116-Q1-2278 **Tong Liu*** (1808772401@qq.com), Tsinghua University, Beijing, Peoples Rep of China. *Discussion on some combinatorial problems in "2048" Game.* Preliminary report.

This research deals with some combinatorial problems in a popular mobile game "2048". Using two theorems about the number of moves and the score in "2048" Game, we reach more precise conclusion on the problems which are frequently discussed by the "2048" players. (Received September 22, 2015)

1116-Q1-2756 **Benjamin Thirey*** (benjamin.thirey@usma.edu), Department of Mathematical Sciences, 601 Swift Road, West Point, NY 10996. *Just One More Roll: An Analysis of Farkle Strategies.*

Farkle is a folk game played with dice and provides an excellent model for probability and combinatorics. The methods of scoring are varied, with different scores accumulating to different combinations of the dice. In addition, a number of various strategies have been put forth regarding the decisions that a player has to make: which dice to count for score and when to stop rolling the dice. Various stopping and scoring criteria are examined and compared to determine the best strategy when playing. (Received September 22, 2015)

Research in Undergraduate Mathematics Education, I

1116-Q5-91 **Kevin C. Moore*** (kvcmoore@uga.edu), 105 Aderhold Hall, Dept. of Mathematics and Science Education, UGA, Athens, GA 30602. *Graphing habits and students' thinking about graphs emergently.*

Numerous researchers have argued that thinking about graphs as representing covariational relationships–how two quantities change in tandem–is a productive way of thinking for undergraduate mathematics studies. These same researchers have illustrated that students experience sustained difficulties thinking about graphs in terms of covarying quantities. In this paper, I report on clinical interviews designed to gain insights into undergraduate students' propensity and capacity to think about graphs as emergent traces of covariation. Contributing to the extant literature base, I describe students' ways of thinking that were not productive for graphically representing covariational relationships that constitute some phenomenon (e.g., a group of individuals taking a trip). In addition to detailing students' ways of thinking, I explain the extent that students experienced perturbations as they attempted to graph relationships that they perceived incompatible with these ways of thinking. For instance, students encountered difficulties graphing relationships that did not "start" along the vertical axis. These findings clarify tacit features of curriculum and instruction that potentially constrain students' opportunities to understand graphs as emergent traces of covariation. (Received July 21, 2015)

1116-Q5-421 **Jessica Ellis** and **Rebecca Cooper***, cooperbecca314@yahoo.com. *Gender, switching, and student perceptions of Calculus I.*

We analyze survey data to explore how students' reported perceptions of their Calculus I experiences relate to their gender and persistence in calculus. We draw from student free-responses from universities involved in a comprehensive US national study of Calculus I. We perform a thematic analysis on the data, identifying quantitative patterns within themes and analyzed student responses to better understand these patterns. Our analyses indicate that female students report negative affect towards themselves more often than males, and that female students discuss their high school preparation differently than males. We discuss how these potential factors may influence student persistence in calculus. (Received August 31, 2015)

1116-Q5-532 **Kathleen Melhuish***, kmelhuish@teachersdg.org. *The State of Student Understanding in Introductory Group Theory: Results from the Group Concept Inventory.*

The Group Concept Inventory (GCI) was developed to assess student understanding of key introductory level group theory topics such as subgroups, quotient groups, and isomorphism. A concept inventory is a multiple-choice test that aimed to assess students' conceptual coherence in a given subject area. The GCI was designed with the goal of maximize validity through incorporating textbook analysis, expert consensus protocols and evaluations, and extensive field-testing with students. Each multiple-choice question began as an open-ended question allowing for genuine student responses to become the options in the closed-form version. Through three rounds of field testing (one open-ended and two closed-form), over 800 students, representing all undergraduate institution types, responded to a set of 17 group theory questions. Thirty of these students were also interviewed in order to establish validity for answer-choice interpretations. In this report, I will present several questions from the GCI along with corresponding national results, student interview excerpts, and discussion of how this instrument could be leveraged by instructors and researchers. (Received September 05, 2015)

1116-Q5-711 **Robert Moore** and **Martha Byrne***, Earlham College, Drawer 138, 801 National Rd W, Richmond, IN 47374, and **Tim Fukawa-Connelly** and **Sarah Hanusch**. *Interpreting proof feedback: Do our students know what we're saying?*

Instructors often write feedback on students' proofs even when there is no expectation for the students to revise and resubmit the work. To learn how students interpret such feedback, we interviewed eight advanced mathematics undergraduates and asked them to respond to professor comments on three or four written proofs. The participants were asked to interpret and justify each comment and then write a revised version of each proof. Using the theoretical frameworks of communities of practice and legitimate peripheral participation, we analyzed the interviews and written data, compared the students' interpretations of the comments to expert consensus, and identified patterns and commonalities in their responses and actions. A noteworthy finding was that even though students were able to identify and correctly implement the professor's recommended changes, they sometimes misinterpreted the professor's intentions. (Received September 10, 2015)

1116-Q5-788 **Kedar Mani Nepal*** (nepal_k@mercer.edu), 1501 Mercer University Drive, Mathematics Department, Macon, GA 31207. *Why Students Cannot Solve Mathematical Problems: An Exploration of College Students' Problem Solving Processes by Analyzing the Execution Behaviors of their own Global Plans for Solving the Problems.* Preliminary report.

This qualitative study investigates undergraduate students' mathematical problem solving behaviors by analyzing execution behaviors of their global plans for solving problems. The primary purpose of this study is to explore why many students cannot execute or communicate their understandings in writing even when they demonstrate clear understandings of underlying concepts during their interactions with the teachers and peers. Students in three courses (Calculus I, Calculus II, and Intro. to Diff. Equations) were asked to write their global plans before they started to solve problems in their in-class quizzes and exams. Many categories of student errors were identified in their solutions, and the extent to which those errors affected problem solving efforts was studied. Even though most students had clear and valid global plans for solving the problems, they could not execute their plans successfully in more than 50% of their responses due to algebraic and computational errors, and also errors due to carelessness. These student errors had stronger effects in hindering their effort to successfully solve the problems than the ones due to lack of conceptual understandings. This study is based on Garofalo and Lester's (1985), and Schoenfeld's (2011) problem-solving frameworks. (Received September 12, 2015)

1116-Q5-877 **Anneliese H. Spaeth*** (aspaeth@hawks.huntingdon.edu), Huntingdon College, Department of Mathematics, 1500 E. Fairview Ave, Montgomery, AL 36106, and **Tara C. Davis** (tdavis@hpu.edu), Hawai'i Pacific University, Department of Mathematics, 1164 Bishop Street, Honolulu, HI 96813. *Using Reading Journals in Calculus.* Preliminary report.

In parallel studies during the Fall 2015 semester, we examined the effects of assigning reading journals in a first semester calculus course. At the beginning of the semester, students were given instructions about how to read the textbook. On alternating weeks, students were asked to complete journal assignments - these included taking reading notes, responding to a prompt question, and reflecting upon any confusing portions of the reading. A comparison between student quiz scores from weeks during which journals were assigned and quiz scores from weeks during which no journals were assigned will be given, and implications for teaching will be discussed. (Received September 14, 2015)

1116-Q5-907 **Lori Carmack*** (lacarmack@salisbury.edu), Dept. of Mathematics and Computer Science, Salisbury University, 1101 Camden Avenue, Salisbury, MD 21804. *Assigning Homework via Interleaved Practice.* Preliminary report.

The study of learning and memory is an active area of research among cognitive scientists. In terms of retention and performance, many recent studies favor the concept of interleaved practice (working on several related tasks during a single practice session) over blocked practice (working on only one task during a single practice session). Results of studies are compelling. In two of my Fall 2015 courses, I formally conducted a study to investigate whether assigning homework sets that are generated using the notion of interleaved practice (the assignments consist of problems from many different sections of the text as opposed to just one section) has an impact on student learning and retention. Participating students were randomly assigned interleaved homework for roughly one half of the semester, and traditional homework for the other half. In this paper, I will discuss results of several studies on interleaved practice, then present the details of my investigation, including data analysis of exam and homework performance. (Received September 15, 2015)

1116-Q5-914 **Aaron Brakoniecki*** (brak@bu.edu). *The Development of Beginning Teachers' Understanding of Pythagorean Theorem from Two Internet-Based Activities.*

Teacher preparation programs' limited time with their beginning teachers make it impossible to cover all of the mathematical knowledge they will need in their career. When these teachers inevitably encounter unfamiliar content in their schools, they need to have tools available with which they can investigate this content. Many will (and already do) use the Internet as a resource to help with their understanding of mathematics.

Seven beginning teachers participated in a study where they attempted to use the Internet to help them better understand the content of the Pythagorean Theorem. Over the course of two activities, they searched for and used internet resources in an attempt to better understand how to prove the Pythagorean Theorem and its converse. Before, between, and after these two activities, the beginning teachers created concept maps that represented their understanding of the content. These concept maps were analyzed for content, structure, and the form and quality of mathematical connections that appeared in these concept maps. This presentation describes the ways in which the beginning teachers' concept maps changed over the course of the activity. Additionally this presentations describes two groupings that the participants fell into based on their concept maps. (Received September 15, 2015)

1116-Q5-1001 **Joseph F. Wagner*** (wagner@xavier.edu), Department of Mathematics, Xavier University, 3800 Victory Parkway, Cincinnati, OH 45207. *Students' obstacles to making sense of the definite integral.*

Students use a variety of resources to make sense of integration, and interpreting the definite integral as a sum of products (rooted in the concept of a Riemann sum) is particularly useful in many physical contexts. This study of beginning and upper-level undergraduate physics students examines some obstacles students encounter when trying to make sense of integration, as well as some discomforts and skepticism some students maintain even after constructing useful conceptions of the integral. In particular, many students attempt to explain what integration does by trying to interpret the algebraic manipulations and computations involved in finding antiderivatives. This tendency, perhaps arising from their past experience of making sense of algebraic expressions and equations, suggests a reluctance to use their understanding of "what a Riemann sum does" to interpret "what an integral does." (Received September 15, 2015)

1116-Q5-1069 **Zackery K. Reed*** (reedzac@math.oregonstate.edu), 360 Kidder Hall, Department of Mathematics, Oregon State University, Corvallis, OR 97331, and **Elise Lockwood** (lockwoel@math.oregonstate.edu), 338 Kidder Hall, Department of Mathematics, Oregon State University, Corvallis, OR 97331. *Examining Student Generalizing Activity in an Accessible Combinatorial Task.*

Generalizing is one of the most fundamental practices with which mathematics students engage. Although generalization among young students has been under much investigation, there is more to learn about generalization in more advanced, specifically undergraduate, contexts. Problems in combinatorics provide a useful context in which to explore generalization because they are challenging but accessible, and they require deep mathematical thought. While research has been conducted on students' combinatorial reasoning, there has not been work that has explicitly investigated the role of generalization in the context of solving counting problems. To study generalization in this context, we conducted individual interviews with undergraduates who had not previously taken discrete mathematics. In this talk, we present multiple kinds of generalizing activities that emerged as students completed counting tasks involving passwords. The nature of the students' generalizing activity varied from simply observing numerical patterns to creating and leveraging abstract outcomes with a general structure, and we present different cases to demonstrate this variety. We also discuss the relationship between generalizing activity and the depth and nature of students' combinatorial reasoning. (Received September 16, 2015)

1116-Q5-1084 **Elise Lockwood*** (lockwoel@math.oregonstate.edu), 338 Kidder Hall, Department of Mathematics, Oregon State University, Corvallis, OR 97331, and **Branwen Schaub** (schaub16@up.edu). *Student Interpretations of Textbook Statements of the Multiplication Principle.*

The multiplication principle (MP) is a foundational aspect of students' combinatorial activity, called by some the "fundamental principle of counting." Although it is an important idea in enumerative combinatorics, discrete mathematics and combinatorics textbooks vary widely in how exactly they state the MP, and students are not always attuned to mathematical details of the MP. Little has been studied about ways in which students think about and make meaning of this important principle. In order to investigate student reasoning about the MP, we had a pair of students reinvent a statement of the MP, and we then had them interpret a handful of textbook statements. In this talk, we share results from the students' reinvention, particularly focusing on their understanding of mathematical subtleties of the MP that appear in the textbook statements. These findings shed light on student understanding of the MP, and we discuss hypotheses about what aspects of the reinvention contributed to the students' being attuned to particularly subtle and complex mathematical issues. We conclude with implications for the teaching and learning of the MP and directions for future research. (Received September 16, 2015)

1116-Q5-1332 **Michael A Tallman*** (michael.tallman@okstate.edu), 3523 Bristol Road Ave, Stillwater, OK 74074. *Instructional Coherence and Quantitative Reasoning.*

In this talk I report findings from a study that explored the effect of a secondary mathematics teacher's level of attention to quantitative reasoning on the quality and coherence of the ways of understanding his instruction supported. I analyzed 37 videos of an experienced secondary mathematics teacher's instruction of trigonometric functions. Specifically, I characterized the extent to which the teacher's instruction attended to supporting students in reasoning quantitatively and examined the consequences of this attention (or lack thereof) on the quality and coherence of the mathematical meanings the teacher afforded his students the opportunity to construct. My analysis revealed that the incoherencies in the teacher's instruction were occasioned by his inattention to supporting students in reasoning quantitatively. My results suggest that pre-service teacher preparation programs and in-service professional development initiatives should engage teachers in experiences that advance their ability to reason quantitatively, as well as support them in leveraging quantitative reasoning in their teaching of specific mathematics concepts. (Received September 18, 2015)

1116-Q5-1357 **Kathleen Clark***, School of Teacher Education, 1114 West Call Street, Tallahassee, FL 32308, **Ingo Witzke**, Emmy-Noether-Campus, Walter-Flex-Str. 3, 57068 Siegen, Germany, **Horst Struve**, Seminar für Mathematik und ihre Didaktik, Gronewaldstraße 2, D-50931 Cologne, Germany, and **Gero Stoffels**, Emmy-Noether-Campus, Walter-Flex-Str. 3, 57068 Siegen, Germany. *Initial results from an undergraduate seminar designed to address the problem of transition from school to university mathematics.* Preliminary report.

In spring 2015 the authors taught an intensive seminar for undergraduate students preparing to teach secondary mathematics, which addressed the transition problem from school to university mathematics by making students aware of concept-changes in mathematical history. In this presentation the authors will first briefly introduce a theoretical framework, which relied on the thesis that broaching the issue of differing natures of school and university mathematics will support students in overcoming the transition problem. The focus of the presentation is to share results of qualitative analysis of several data sources collected during and after the seminar, including surveys, participant interviews, and participant essays. The data analysis and construction of six case studies (developed from the 20 seminar participants) revealed that students who were able to actively reflect on their own beliefs might be more likely to succeed in bridging the gap between school and university mathematics. We conclude with implications for mathematics teacher preparation programs with an emphasis on particular uses of history of mathematics within mathematics teacher preparation programs. (Received September 18, 2015)

1116-Q5-1420 **Sayonita Ghosh Hajra*** (sayonita@math.utah.edu), 155 S. 1400 E., Salt Lake City, UT 84112, and **Victoria Kofman**. *Assessing mental math knowledge of prospective elementary pre-service teachers.*

One of the Standards for Mathematical Practice of Common Core State Standards is "Make sense of problems and persevere in solving them." This requires students to 'plan a solution pathway.' We studied pretests from 17 prospective pre-service elementary teachers enrolled in a mathematics course at a western public university in the United States of America. The goal was to estimate their abilities to 'plan a solution pathway' when solving one-step number problems with positive integers. Our findings suggest most of the pre-service teachers, before taking required mathematics courses towards certification/ licensure, do not look for alternative strategies. Instead, they use standard column approaches when presented with one-step number problems, which can be solved by using the ideas of mental math. We found although some pre-service teachers knew about mental math strategies, their knowledge was below the level of application. Also, we observed that many pre-service teachers do not internalize the idea of place value and, as a result, cannot transfer their mental math knowledge towards larger numbers. We will discuss how we can improve mental math strategies of pre-service teachers by applying a developed remediation approach adapted to the needs of university level students. (Received September 20, 2015)

1116-Q5-1627 **Sepideh Stewart*** (sstewart@math.ou.edu), 601 Elm Ave, Norman, OK 73019, and **Stacy Reeder** (reeder@ou.edu), 820 Van Vleet Oval, Norman, OK 73019. *Investigating calculus students' struggles with algebra.* Preliminary report.

For several years, the US has been steadily falling behind many other industrialized nations in terms of the production of STEM graduates. Students who lack a solid understanding of high school Algebra tend to struggle in college level courses and may subsequently be deterred from pursuing STEM field degrees. College instructors within STEM fields may rightfully view the mathematics that follows the initial step(s) in their higher level courses as "just Algebra", but in reality, this missing foundation may be the downfall for many college students. In this research, a team of mathematics educators, mathematicians, teacher trainers, high school teachers, cognitive psychologists and mathematics graduate students are committed to bring the matter under scrutiny. The purpose of this project is to identify common algebraic errors students make in college level mathematics courses that plague their ability to succeed in higher level mathematics. The identification of these common errors will aid in the creation of a model for intervention. The findings of this investigation will inform university level mathematics instructors on ways to support student algebraic understanding for success in courses such as Calculus. (Received September 20, 2015)

1116-Q5-1680 **Tamara Lefcourt Ruby*** (lefcourt@ictl.org), Efrata College of Education, Ben Yefune Street, #17, Jerusalem, Israel. *Changing personal epistemologies of mathematics across cohorts of pre-service secondary mathematics teachers.*

Beliefs about knowledge and knowing (personal epistemologies) have been studied for many groups of students, including math students, but there is limited research on the personal epistemologies of math education students. This study examines personal epistemologies of mathematics of pre-service secondary mathematics teachers in a three-year program.

Qualitative categorical analysis highlights two aspects of personal epistemology: source of and justification for knowledge. Results suggest a transition over time-from justifying mathematical knowledge from learning outcomes to justification based on teaching success. In addition, a shift from external to internal attributions of knowledge source was seen. Few students related to post-secondary, academic mathematics, despite the program's emphasis on academic level mathematics; participants focused on "school mathematics."

The shift in personal epistemologies across cohorts suggests that self-identities of math education students evolve from learners to teachers. Participants did not self-identify as mathematicians; they did not see themselves as "consumers" of academic mathematics. This raises questions about how to include math education students and teachers of mathematics in the wider community of mathematicians. (Received September 21, 2015)

1116-Q5-1847 **Harrison E. Stalvey*** (hstalvey1@gsu.edu) and **Draga Vidakovic**. *Water coolers and parametrizations.*

This report is on a portion of an investigation of fifteen second-semester calculus students' understanding of the concept of parametric function. In particular, we will present an adaptation of the popular bottle problem in which we asked students, during an interview, to sketch relationships between the volume and height of water in two identical coolers that are being emptied at different rates. By investigating students' reasoning about a relationship between variables in a real-world problem, we hoped to gain insight into how students reason about parametrization. We will present our results in terms of APOS theory and make connections to existing literature on covariation. Our findings indicate that conceiving an invariant relationship described by two parametrizations is nontrivial and involves various complementary ways of reasoning. (Received September 21, 2015)

1116-Q5-1988 **Aditya P Adiredja*** (adiredja@math.arizona.edu), ENR2 Rm S317, 1064 E. Lowell St., Tucson, AZ 85719. *Using the Pancake Story to Make Sense of the Epsilon Delta Definition.*

The well-documented students' difficulty with the formal definition of a limit has instigated debates about its introduction in first semester calculus. This study explores the utility of an instructional analogy, the Pancake Story in assisting students to make sense of the temporal order of ϵ and δ in the definition: the stipulation that for any given $\epsilon > 0$ there exists a $\delta > 0$. The Pancake Story was designed to leverage the intuitive notion of quality control in learning the formal definition. Eighteen first and second year university students participated in a semi-structured interview about the definition. Students responded to questions about the temporal order before and after discussing the story. The results show a large shift in the number of students who responded with "epsilon first." This pattern was not found with the comparison group who read about the temporal order in a textbook. The analysis also compared common justifications for the temporal order before and after engaging with the story. The study argues that the notion of quality control serves as an accessible entry into understanding the formal definition. The findings also show that formal mathematics can be productively built upon students' intuitive knowledge. (Received September 21, 2015)

1116-Q5-2077 **May Chaar***, mchaar@framingham.edu. *Secondary Preservice, In-Service, and Student Teachers' Noticing of Mathematical Work and Thinking in Trigonometry.*

Recognizing and responding to students' work and thinking are central to reform-minded mathematics teaching; in particular, recent educational reforms advocate for instruction that builds on students' thinking, requiring teachers' continual assessment of students' verbal and written strategies. Despite its significance however, little is known about how secondary mathematics teachers analyze and respond to students' work and thinking. This study aimed to help explain how teachers carry out this work. In particular, it sought to explain what types of knowledge and other resources enable or inhibit teachers' in-depth analysis of students' work and thinking while more generally describing the ways in which preservice, in-service, and student teachers attend to, interpret, and respond to students' work and thinking in trigonometry. These findings serve to inform efforts to improve these skills in teacher preparation programs. This study also provides insight into secondary mathematics teachers' understandings of various concepts in trigonometry and characterizes how and to what extent teachers' previously held mathematical conceptions were challenged as they attempted to make sense of solutions. (Received September 21, 2015)

1116-Q5-2097 **Jeffrey D Pair*** (jeffrey.pair@mtsu.edu). *Experiencing the Roles of Proof.*

Proof serves many roles for the mathematics community. Scholars have noted that proof supports mathematicians in verifying, discovering, communicating, etc... (de Villiers, 1990). How can mathematics classrooms be structured so that students experience the various roles of proof? As part of a qualitative study, we investigated written reflections on an end-of-semester assignment from undergraduates in an inquiry-based transition-to-proof course. Students reflected on instances during the course when they engaged in different roles of proof. This presentation will serve to highlight the results of this work by describing activities that engaged students in verification, communication, and discovery. For instance, students described how considering the truth of classmate's conjectures supported them in using proof as a means to gain conviction in a mathematical claim. Instructions asking students to "prove, disprove, or salvage" a mathematical claim supported them in making mathematical discoveries. Students described how two instructional activities, a group proof activity and a critiquing activity, provided them opportunities to experience proof as communication. References: de Villiers, M. D. (1990). The role and function of proof in mathematics. Pythagoras, 24, 17–24. (Received September 21, 2015)

1116-Q5-2144 **Gizem Karaali*** (gizem.karaali@pomona.edu), Pomona College Dept of Mathematics, 610 N. College Avenue, Claremont, CA 91711. *Defining Quantitative Literacy Through College-Level Textbooks: A Preliminary Report.* Preliminary report.

Scholarship in the interdisciplinary world of quantitative literacy (QL) is thriving. Colleges and universities across North America are moving toward requiring courses in quantitative literacy in place of mathematics as part of their General Education plans. In the midst of such productive action, the term quantitative literacy itself still is not curricularly proscribed. This project attempts to seek out common threads and analyze discrepancies in the QL curricula proposed by eight different textbooks and content-providers. Following the framework developed originally in (Harel 1987) we investigate sequencing of content, levels of generality, emphasized applications, introductory material, as well as explicitly stated learning outcomes. (Received September 22, 2015)

1116-Q5-2294 **Susan D Nickerson*** (snickerson@mail.sdsu.edu), 5500 Campanile Drive, Department of Mathematics and Statistics, San Diego, CA 92182-7720, and **Katie Bjorkman**, **Sei Jin Ko**, **David Marx** and **Christina Wu**. *If I Can, So Can You: Peer Role Models Improve Self-Perception of Mathematical Ability for Women.*

Student persistence in the STEM disciplines continues to be a national problem, especially for women and underrepresented minorities. We present the results of an ongoing study involving the use of peer role models to reduce stereotype threat and increase minority women's persistence in the calculus sequence. Half of the first-semester calculus break-out sections were visited twice by female peer role models (treatment condition) whereas the other half were not visited by peer role models (control condition). At the start and end of the semester we collected data on student beliefs, attitudes, and behaviors, such as belongingness in the mathematics department, personal mathematical ability, attitude toward mathematics, and intention to continue in the calculus sequence. In the control condition, female students' beliefs about their math ability were highly significantly lower than male students. Whereas, in the treated condition, female students' beliefs about their math ability were just as high as that of male students. This finding shows promising evidence that exposure to a female peer role model may improve women's mathematics experiences. (Received September 22, 2015)

1116-Q5-2384 **William L Hall*** (wlhall@ncsu.edu), 502P Poe Hall, 2810 Stinson Dr., Raleigh, NC 27695. *An investigation into learning about integrals as participation in different professional communities.*

Introductory calculus at the undergraduate level is largely a service course to a variety of academic majors. This is true primarily because most students intending to major in mathematics arrive to college with calculus credit and rarely end up taking Calculus I (Bressoud, Carlson, Mesa, & Rasmussen, 2013). While there has been a good deal of cognitive research into how students understand the calculus concepts of limit, derivative, and integral, there has been very little research into how these calculus concepts are understood in the various professions that require students to take Calculus I in college. In this report, I share the results of both a national survey and clinical interviews concerning how three such communities think about and use integrals in the authentic practice of their field. The three communities I investigated were engineering, biological and life sciences, and business and were made up of undergraduate students, faculty members, and practicing professionals from across the country. Findings include summaries of the ways in which the different communities describe the integral and the contexts and applications the members indicated were most useful in their field. Implications for the future of undergraduate calculus instruction are discussed. (Received September 22, 2015)

1116-Q5-2395 **William L Hall*** (wlhall@ncsu.edu), **Karen A Keene** and **Nicholas C Fortune**. *Measuring student conceptual understanding: The case of Euler's method.*

In this study, we report on early work for a differential equations concept inventory, which is being developed for an NSF-funded project to support mathematics instructors as they implement inquiry-oriented curricula. The goal is to assess student learning of differential equations. Preliminary results show that the iterative method of developing and field testing items, conducting student interviews, and modification may prove successful to complete a valid concept inventory. The field testing and piloting of questions concerning Euler's method show that students do respond as the research suggests but that Euler's method can be recreated by students and the correct response can be "figured out." (Received September 22, 2015)

1116-Q5-2444 **George Kuster*** (gkuster@vt.edu) and **Estrella Johnson** (strej@vt.edu). *Toward a measure of Inquiry-Oriented instruction.*

Research has shown that inquiry-oriented curricular materials present instructors with a number of challenges regarding implementation. In inquiry-oriented instruction the tasks, the students and the teacher work together to support the classroom participants in advancing the mathematical agenda. Instructors utilize carefully designed tasks to engage students in meaningful mathematical activity and generate student thinking which is then leveraged by the instructor and subsequent tasks to support student development of more sophisticated ways of reasoning and understanding. By analyzing video data from the implementation of three inquiry-oriented curricula materials and by drawing on the K-16 research literature, we have identified and characterized four instructional components that are central to successfully implementing inquiry-oriented instruction. These components have been further delineated into instructional practices that will comprise an instrument for measuring inquiry-oriented instruction. (Received September 22, 2015)

1116-Q5-2520 **Sarah A. Erickson*** (ericksos@oregonstate.edu), Kidder 330, Department of Mathematics, Oregon State University, Corvallis, OR 97331, and **Elise Lockwood** (lockwoel@math.oregonstate.edu), Kidder 338, Department of Mathematics, Oregon State University, Corvallis, OR 97331. *Listing as a Potential Connection between Sets of Outcomes and Counting Processes.*

Previous studies have been conducted that show the effectiveness of undergraduate students' listing behavior in the context of counting problems, and there has been work that emphasizes the relationship between the formulas, the counting processes, and the sets of outcomes that students navigate as they solve counting problems. However, there has been little work done that examines the ways in which students might explicitly relate their lists with specific counting processes to organize and enumerate outcomes in their lists. In an effort to better understand the role of listing in students' counting, we conducted individual, task-based interviews with 20 undergraduate students. In this talk, we focus on a particular counting problem that we gave to the students and for which we asked them to create a list of outcomes. We report on students' responses when asked to articulate relationships between their solutions and the complete lists of outcomes they created, and our findings suggest that students varied in their understanding of how counting processes and sets of outcomes were related. We present implications that this research may have for combinatorics educators and researchers, and we discuss possible directions for future research. (Received September 22, 2015)

1116-Q5-2669 **Emily Miller*** (ekm@illinois.edu) and **Casey George-Jackson** (casey.george-jackson@louisville.edu). *Success in doctoral mathematics: What do faculty members expect of their students in order for them to be successful and to what do they attribute their own success?*

Although gender disparities at the undergraduate level are narrowing, women and members of racial and ethnic minority groups continue to be underrepresented in doctoral mathematics. In order to better understand issues of persistence and retention for these groups of students, two studies were conducted. The first study examined mathematics faculty members' expectations of successful students, both generally and for members of underrepresented groups. Data were collected through online survey from faculty members involved in a nationwide mentoring program aimed at easing underrepresented students' transitions from undergraduate to graduate mathematics. The second study investigated the reflections and attributions for their own doctoral program success for current mathematics faculty members and compared theses responses for male and female respondents. Quantitative data were collected through online survey from a stratified, random sample of mathematics professors in the United States. Similar findings across the two studies include the importance of mentorship and advising, and intrinsic motivation. Comparisons such as these are used in order to provide recommendations for how best to support underrepresented students in attaining advanced degrees in mathematics. (Received September 22, 2015)

1116-Q5-2673 **Hortensia Soto-Johnson*** (hortensia.soto@unco.edu), Ross 2240C, School of Mathematical Sciences, Greeley, CO 80639, and **Brent Hancock** and **Michael Oehrtman**. *Mathematicians' Conceptual and Ideational Mathematics about Continuity of Complex-Valued Functions.*

Adopting Schiralli and Sinclair's notions of conceptual mathematics (CM) and ideational mathematics (IM), we investigated mathematicians' reasoning about continuity of complex-valued functions. There were four IM notions that the mathematicians used to convey the idea of continuity for complex-valued functions: control, topological features, preservation of closeness, and paths. The mathematicians' IM tended to be grounded in their embodied experiences and espoused for pedagogical reasons, in preparation for other actions, or to assist their own reasoning. Some of the mathematicians' IM metaphors conveyed a domain-first quality, which accounted for the domain of the function before mentioning any objects from the codomain. Given such metaphors did not capture the full structure of the epsilon-delta definition of continuity, the mathematicians transitioned to CM language in an effort to make their IM statements more rigorous. Our research suggests that while IM metaphors stemming from embodied experiences can serve as helpful tools for reasoning about continuity of complex-valued functions, one must be cognizant of ways in which the informal IM must be altered or extended to fully capture the CM. (Received September 22, 2015)

1116-Q5-2742 **Elena A. Cheser*** (cheser@hartford.edu), 200 Bloomfield Avenue, West Hartford, CT 06117. *The Hillyer College Summer Bridge-Math Program: A Case Study for Assessing and Improving Student Academic Performance.*

This study follows student performance in math from student entry into the Summer Bridge Program to the final grade of the first academic semester math course in Hillyer College. A model has been developed which maps and quantifies the critical path for academic success. Program effectiveness was assessed in two dimensions:(1)Bridge Program students: (a) determination of progress made during the Bridge Program; (b) determination of relationships between the first regular semester math course grade with "Delta" Math SAT scores;(2)Comparison of regular semester final grades. Results show that for students who complete the Summer Bridge Program: (1)the overall mean score on the post-Program assessment is statistically significantly greater than the pre-Program assessment mean score; (2) the degree of individual student improvement demonstrated over the Summer Bridge Program correlates significantly with individual first semester final grades in math; (3)the overall mean score of the first semester final grades in math for the Bridge cohort is statistically significantly greater than the mean score for non-Bridge students who completed the same first semester math course; the enhanced performance is equivalent to approximately a full letter grade. (Received September 22, 2015)

1116-Q5-2750 **Stephen Kenneth Liddle*** (sliddle@gmu.edu) and **Sheeva Doshireh** (shashasheevs@gmail.com). *Learning Assistants in Business Calculus Classes.*

The learning assistant program was created to integrate strong, knowledgeable students into classes to help college students not only learn the material, but deepen the understanding behind the subject material. Most students taking a mathematics class, especially Math 108, want to learn the steps and formulas without learning the intuition and reasoning behind those steps. Because of this, students tend to find mathematics out of their reach and not applicable to their lives. By integrating learning assistants, we hope to increase the understanding of the material and their interest in the class.

A great deal of quantitative data has been collected on the performance of student's grades with and without a learning assistant. However, We wanted to focus on the Math 108 student's views on whether or not Learning Assistants helped increase their grade and understanding of the course material. We will show that learning assistants benefit the student's grades, views on mathematics, and help deepen their understanding of the course material. (Received September 22, 2015)

1116-Q5-2796 **Kristen Lew*** (kristen.lew@gse.rutgers.edu) and **Juan Pablo Mejia-Ramos** (pablo.mejia@gse.rutgers.edu). *Investigating the genre of mathematical proof writing at the undergraduate level.*

We studied the genre of mathematical proof writing at the undergraduate level both qualitatively and quantitatively. Eight mathematicians and fifteen undergraduate students were asked in interviews (based on Herbst and Chazan's (2003) breaching experiments) to read seven partial proofs based on student-generated work and to identify and discuss uses of mathematical language that were out of the ordinary with respect to what they considered to be conventional mathematical proof writing. Results were analyzed using open-ended thematic analysis to find common explanations for why the writing was unconventional. We then sent an online survey to mathematicians and undergraduate students throughout the United States asking them to read the same partial proofs. Participants were asked if they agreed that passages were unconventional for the explanations found

in the qualitative study and to what degree the unconventional language use would affect the quality of the exposition of the proof. Results indicate mathematicians believe that mathematical language obeys the rules of natural language, whereas some students believe mathematical language and natural language are independent. (Received September 22, 2015)

1116-Q5-2933 **Guadalupe I Lozano*** (guada@math.arizona.edu). *A model for implementing interactive-engaged practices in calculus: effects on performance and conceptual learning.* Preliminary report.

Interventions for engaging undergraduates in the learning of concepts (not just skills) and the creation of instruments to evaluate the success of such interventions have received a fair amount of attention in various STEM disciplines, including undergraduate mathematics.

The Calculus Concept Inventory (CCI), for instance, has been used in a number US calculus classrooms specifically as a measure of conceptual calculus learning. Further, gains on this instrument are often analyzed as means to validate posited positive associations between conceptual learning and interactive-engaged (IE) classroom practices, a type of "flipped-classroom" instruction.

In this talk, I will provide some background on the problem of knowledge measurement, and discuss results from one of my studies exploring effects of IE supplemental instruction on undergraduate calculus learning, based on the use of Hierarchical Linear Models (HLM). (Received September 23, 2015)

1116-Q5-2943 **Juan Carlos Apitz*** (jc@jcapitz.com), Department of Mathematics and Statistics, California State University, Long Beach, 1250 Bellflower Blvd., Long Beach, CA 90840. *Classification and Prediction: What Admissions and Grades Data Tell Us About Who is Likely to Succeed in Undergraduate Mathematics Programs.* Preliminary report.

In this work we implement machine learning ideas in order to identify possible key success factors in students pursuing undergraduate degrees in mathematics at UCLA. The primary framework utilizes regularized logistic regression. The regularization is performed at two levels. We develop results based on L_1 norm and elastic net regularized logistic regression. The data examined consists of sixteen years worth of enrollment records from the mathematics department at University of California, Los Angeles (UCLA). The features contained in the data set consist of course grades along with ethnicity and gender profiles, majors, transfer status, and terms. The objective of the analysis is two fold. First we utilize dimensionality reduction to identify the key features of students achieving a certain grade threshold; second, we fit a classification model to identify students likely to perform well vs. students not expected to have strong outcomes.. The results are reported in probabilistic measures of performance. (Received September 23, 2015)

Research in Undergraduate Mathematics Education, II

1116-Q6-432 **Eyob Demeke*** (esg34@wildcats.unh.edu), 33 Academic Way, Durham, NH 03824, and **David Earls**, 33 Academic Way, Durham, NH 03824. *Why do mathematicians present proofs? A case study of introductory abstract algebra and real analysis course.* Preliminary report.

Proofs are essential to communicate mathematics in upper-level undergraduate courses. In an interview study with nine mathematicians, Weber (2012) describes five reasons for why mathematicians present proofs to their undergraduate students. Following Weber's (2012) study, we designed a mixed study to specifically examine what mathematicians say undergraduates should gain from the proofs they read or see during lecture in introductory abstract algebra and real analysis. Our findings suggest that: (i) A significant number of mathematicians said undergraduates should gain the skills needed to recognize various proof type and proving techniques, (ii) consistent with Weber's (2012) findings, only one mathematician said undergraduates should gain conviction from proofs, and finally (3) some mathematicians presented proof for reasons not described in Weber's (2012) study such as to help their students develop appreciation for rigor. (Received September 01, 2015)

1116-Q6-2247 **Wes Maciejewski*** (wes@mathwes.ca) and **Bill Barton**. *An Analysis of Undergraduate Students' Mathematical Foresight.* Preliminary report.

In a recent manuscript (Maciejewski and Barton, under review) we introduced mathematical foresight as a means of describing research mathematicians' initial approaches to novel mathematical situations. Mathematical foresight is the active process of imagining a possible resolution to a given mathematical situation and a solution path likely to lead to that resolution. This talk will present an analysis of undergraduate students' initial problem solving activity from the perspective of mathematical foresight. Through a qualitative analysis of student activity during the pre-planning phase of problem solving, we have developed a framework of student mathematical foresight. In this talk we first present our initial mathematical foresight framework, positioning it relative to extant constructs in the mathematics education literature. Second, we present our emerging framework of student mathematical foresight and discuss some of its limitations. We conclude with a number of directions for future research. (Received September 22, 2015)

1116-Q6-2470 **Jungeun Park*** (jungeunpark124@gmail.com), 15 Orchard Rd., Ewing Hall 501, University of Delaware, Newark, DE 19716. *Realizations of the Derivative in Three Widely Used Calculus Textbooks.*

This study analyzed realizations of the derivative in three widely used calculus textbooks based on the recent MAA calculus study using Sfard's communicational approach. The analysis of words and visuals in the textbooks focused on the limit process through which the derivative at a point was objectified, and words and visuals for the derivative process through which the derivative as a function was objectified. The analysis highlighted inconsistencies in realizations of the process and object, and an implicit treatment of the relations between different visuals. Specifically, although the initial and final objects (e.g., Difference Quotient and the derivative at a point) were mainly mediated with the same type of visuals (e.g., symbols, graphs), the limit process connecting these two objects was often mediated with a different type of visual or simply with words. Various graphs (zoomed-in graphs, secant segments, and secant lines) mediated the process, but their relations were not explicitly addressed. The analysis also highlighted that words were key in the process through which the derivative at a point was expanded to the derivative as a function. Symbols were frequently used in realization of both the limit process and the derivative process without any other mediators. (Received September 22, 2015)

1116-Q6-2674 **Mariana Levin*** (mariana.levin@wmich.edu), Department of Mathematics, Western Michigan University, 1903 W. Michigan Avenue, Kalamazoo, MI 49008, and **John P. Smith III**, **Aaron Levin**, **V. Rani Satyam** and **Younggon Bae**. *The Transition to Proof in Collegiate Mathematics: Examining A Hybrid Lecture/Laboratory Approach at a Large Public Research University.* Preliminary report.

Many undergraduate students majoring in mathematics experience difficulty in learning to prove mathematical propositions. In addition to the substantial differences in the "didactical contract" between computation-heavy lower division classes and proof-intensive upper division courses, students encounter myriad difficulties of a more fine-grained nature, including the use of logic and definitions, the ability to generate and use examples and counterexamples effectively, difficulty understanding the concepts and theorems themselves, and the ability to evaluate arguments created by others. In short, the transition to proof is complex and challenging. Mathematics departments have recognized this problem and experimented with different curricular and instructional approaches to supporting students' entry into proof, including courses dedicated to this transition. This talk will focus on observational data from a hybrid lecture/laboratory "transitions" course at a large public research university, emphasizing the design principles that characterize how the course attempted to shift students' didactical contract. Preliminary student interview data concerning the transitions experienced in the course will be discussed. (Received September 22, 2015)

1116-Q6-2736 **Hyunkyoung Yoon*** (hyoon14@asu.edu), 1720 E. Braodway Road APT1159, Tempe, AZ 85282, and **Patrick W Thompson**. *Teachers' meanings for function notation in U.S.A. and Korea.*

This study investigates teachers' meanings for function notation in U.S.A. and Korea. Research has focused on students' or teachers' difficulties of functions, but this study focuses on teachers' ways of thinking about function notation. We believe that teachers convey their meanings to students and teachers who have productive meanings helps students develop coherent meanings for future learning. Project ASPIRE administered a diagnostic instrument to 252 U.S. high school teachers and 264 Korean high school teachers. This study reports our analysis of teachers' meanings for function notation as a means to examine teachers' understanding of functions. The analyses suggest that Korean teachers' meanings for function notation are stronger that U.S. teachers' meanings. However, a considerable number of teachers in both countries demonstrated unproductive meanings for function notation. This presentation will discuss different spectra of teachers' meanings for function notation in the two countries. (Received September 22, 2015)

1116-Q6-2748 **George Kuster*** (gkuster@vt.edu). *An investigation of student resources for function and rate of change in differential equations.*

Research on student learning indicates that student understanding of function and rate of change play an important role in the development of their understanding of differential equations. Few studies however, have focused on how students' understanding of function and rate of change evolve and interact over time as students learn differential equations. I will present findings from a larger research project, which utilized the perspective of Knowledge in Pieces (diSessa, 1993), to explore the resources relating to function and rate of change that students use to solve differential equations tasks. More specifically I will discuss how the sets of resources students used to solve certain problems changed over time and the implications these changes had concerning their understanding of function and rate of change with regard to differential equations. (Received September 22, 2015)

Revitalizing Complex Analysis

1116-R1-149 **Yves Nievergelt*** (ynievergelt@ewu.edu), Eastern Washington University, Department of Mathematics, 216 Kingston Hall, Cheney, WA 99004-2418. *Complex Arithmetic Boot Camp.*

Connections between complex arithmetic and other applied or theoretical fields help draw students' attention to complex analysis from the start.

An in-class exercise asks students to find a formula that involves not four but only three real multiplications to multiply two complex numbers. In such an exercise, students' activities are related to two yet unsolved problems: the search for a faster multiplication and inversion of matrices, and a proof that Gaussian elimination with partial pivoting is probabilistically backward stable, for which Lloyd N. Trefethen (The Smart Money's on Numerical Analysts, *SIAM News*, November 2012) offers \$100 and \$1000 rewards.

After more preparation with complex division, square roots, and cube roots, a small project asks students to supply and verify omitted arithmetic steps in Isaac Sofair's quartic "Improved Method for Calculating Exact Geodetic Latitude and Altitude" (*J. Guidance, Control, and Dynamics*, July–August 1997), which is used by NASA (Karlgaard et al., *J. Spacecraft and Rockets*, May 2013, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110011138.pdf).

More activities and applications are in UMAP Modules 743, 805, 806, 807. (Received August 07, 2015)

1116-R1-224 **Stephan Ramon Garcia*** (stephan.garcia@pomona.edu), Department of Mathematics, Pomona College, 610 N College Ave, Claremont, CA 91711. *Advanced linear algebra: a call for the early introduction of complex numbers.*

A second course in linear algebra, which goes beyond the traditional lower-level curriculum is increasingly important for students of the mathematical sciences. Although many applications involve only real numbers, a solid understanding of complex arithmetic often sheds significant light. Many instructors are unaware of the opportunities afforded by the early introduction of complex arithmetic. Most elementary properties of complex numbers have immediate matrix analogues and many important theorems can be deduced, or at least postulated, from the basics of complex arithmetic alone. (Received August 15, 2015)

1116-R1-498 **Martin E Flashman*** (flashman@humboldt.edu). *Visualizing Complex Variable Functions with Mapping Diagrams: Linear Fractional Transformations.* Preliminary report.

Crucial to understanding much about complex variable functions is a sound comprehension of core linear fractional transformations. In a recent undergraduate complex variables course the author used GeoGebra 5.0 to create mapping diagrams for these functions in a three dimensional setting. The diagrams are modeled after mapping diagrams for real variable functions. Several visual features of these functions and their complex integrals will be illustrated that can add to the understanding of these core functions. The diagrams will be available for use over the internet. (Received September 04, 2015)

1116-R1-885 **Barbara A. Shipman*** (bshipman@uta.edu), **Patrick D. Shipman** and **Stephen P. Shipman**. *Orthogonal Systems in the Euclidean and Lorentzian Complex Planes.*

A standard course on complex analysis includes a study of conformal mappings of the complex plane to itself. The real and imaginary parts of such a mapping are conjugate harmonic functions; they satisfy the Laplace equation and the Cauchy-Riemann equations. Students see that conformal mappings send curves that intersect orthogonally into curves that again intersect orthogonally. Here orthogonality is measured with respect to the standard Euclidean dot product. Less familiar to undergraduates is the Lorentz inner product on the complex plane. Systems of curves that intersect Lorentz-orthogonally no longer look, in general, orthogonal in the Euclidean sense. But their geometry is surprisingly beautiful, and elegant in its formulation. Such systems arise from Lorentz-conformal transformations, whose real and imaginary parts satisfy the wave equation and a Lorentzian analog of the Cauchy-Riemann equations. From these simple equations, one obtains beautiful and varied Lorentz-orthogonal systems with different symmetries and structures. This work, joint with P. Shipman and S. Shipman, will bring to any course on complex analysis a new perspective on the geometry of complex functions, and one that has interesting connections in physics as well. (Received September 15, 2015)

1116-R1-1300 **Michael Brilleslyper*** (mike.brilleslyper@usafa.edu), Department of Mathematical Sciences, USAF Academy, CO 80840, and **Beth Schaubroeck**. *Zeros of Trinomials: Visualization and Location.* Preliminary report.

Modern technology affords the ability to visualize roots of polynomials in the complex plane. The geometry associated with certain sets of roots provides several interesting phenomena and connections to basic number theory. We investigate the 2-parameter family of trinomials given by $p(z) = z^n + z^k - 1$. We explore when this family has zeros on the unit circle and also provide a conjecture for the number of roots inside the unit circle in terms of n and k. In the case $k = 1$, we provide a sketch of the proof, which depends heavily on an application of Rouché's Theorem. This material and associated open problems are suitable for undergraduate research. (Received September 18, 2015)

1116-R1-1852 **William M. Kinney*** (bkinney@bethel.edu), Bethel University, Mathematics and Computer Science Department, P.O. 95, St. Paul, MN 55112. *The Complex Moduli Project and Mathematica-Based Modules in Complex Analysis.* Preliminary report.

The Complex Moduli Project (semi-pun intended) is a website under construction whose purpose is to house materials for educational modules in complex analysis. Educational modules can take a variety of forms, from thirty-minute learning activities to semester-long projects. In any form, it is important to relate educational modules to the rest of the course content, and to include background information and goals. Personally, I am creating Mathematica-based modules to help students learn how to use Mathematica as a tool for exploration in complex analysis. I will show the website and some of these modules in my talk. I welcome collaborators on the website. (Received September 21, 2015)

1116-R1-2363 **Russell W Howell*** (howell@westmont.edu), Department of Mathematics, Westmont College, 955 La Paz Road, Santa Barbara, CA 93108. *Rouchés Theorem: Projects and Pedagogy.* Preliminary report.

It is well known that Rouché's Theorem is a powerful tool in complex analysis, and that it has interesting applications within the field of mathematics, such as using it to provide a simple proof for the fundamental theorem of algebra. Less well known is a simple proof—accessible to undergraduates—of a generalized version of the theorem, and much less than that any applications of the theorem to areas beyond pure mathematics. This talk addresses the latter two issues, and suggests a realistic path that a first course in undergraduate complex analysis might take to allow time for such explorations by means of class projects. (Received September 22, 2015)

1116-R1-2494 **Robert Sachs*** (rsachs@gmu.edu). *Planting Seeds: Complex Analysis Topics in the Calculus Sequence.*

Many students have essentially no exposure to complex algebra and analysis early in their college mathematics career. As a means towards sparking increased interest in a complex analysis course, several opportunities for a complex analysis slant on traditional calculus topics will be described. (Received September 22, 2015)

1116-R1-2844 **Paul Zorn*** (zorn@stolaf.edu), MSCS Department, St Olaf College, Northfield, MN 55057. *Animating maximum and minimum principles in complex analysis.*

The maximum modulus principle for analytic functions, and related maximum and minimum principles for harmonic functions, can be challenging to envision geometrically. As a result the statements of these principles, let alone their proofs, can be difficult for students to comprehend. Using animated graphics produced by Mathematica or similar software, one can see maximum and minimum principles for analytic and harmonic functions in action for functions defined on the unit disk and on other familiar plane domains. Combining such views with geometric mapping properties of non-constant analytic functions, also readily illustrated graphically, helps explain from first principles why the maximum modulus principle holds. The speaker will illustrate these methods and views. (Received September 22, 2015)

The Scholarship of Teaching and Learning in Collegiate Mathematics

1116-R5-36 **Pangyen B Weng*** (pangyen.weng@metrostate.edu), 700 E 7th St, St. Paul, MN 55113.
Flipping the Discrete Mathematics Classroom with Interactive e-Textbooks. Preliminary report.

At Metropolitan State University, discrete mathematics is offered to students in computer science or math teaching, and the prerequisite is college algebra. Because of the diverse student needs and preparations, the math department and its instructors constantly face challenges in choosing textbook and defining expectations. In this presentation, the author talks about his experiment of using zyBook for Discrete Math, an interactive e-textbook, in a flipped classroom. He will demonstrate how zyBooks work, describe his design of flipped instruction, and show the positive student responses and improved learning outcomes measured from the experiment. He concludes the presentation with advice for those who wish to try zyBooks or use flipped instruction in similar courses. (Received June 09, 2015)

1116-R5-161 **Hilary T Freeman*** (freeman@math.colostate.edu) and **Mary E Pilgrim**. *Engaged Learning Through Writing: A Faculty Development Project.*

Beginning in the fall 2014 semester, we were provided with funding to develop a Writing to Learn (WTL) program in the College of Natural Sciences at Colorado State University. The first year of the program was devoted to developing faculty understanding of WTL, to the development of WTL activities, and to exploring the importance and best approaches to giving meaningful feedback. The ultimate goal of the program is to address the student experience in gateway courses across the College of Natural Sciences. The first year of the program was focused not only on the mechanics of writing for engagement but also on faculty identification of the central disappointments with student math understanding that our WTL program hopes to address. Preliminary results indicate that students who participate in writing activities that are incorporated in the classroom as well as outside of the classroom perform better on exam questions.

In this presentation we will provide the framework of the WTL program, provide prompts that emerged from our processes, share sample student responses, and provide preliminary results. We will also discuss current WTL projects, connecting to GTA training, and contending with efficient feedback strategies. (Received August 10, 2015)

1116-R5-367 **Victor I Piercey*** (piercev1@ferris.edu), Ferris State University, Department of Mathematics, 820 Campus Drive, ASC 2021, Big Rapids, MI 49307, and **Andrew Peterson**. *Using Games to Teach Freshmen to Handle Mathematical and Professional Complications.* Preliminary report.

Many mathematical problems that working professionals face are inherently complicated. Freshmen in general education courses find these complications challenging. Can games be used to teach students how to handle complications in their mathematical and professional work? Many games are complicated, but often the players' internal motivation sustains them through the learning curve. We introduced a module into a quantitative reasoning course for business students in which the learners played unfamiliar and complicated board games and reflected on their learning process. They were then tasked with applying what they learned to complete an IRS 1040 tax return. This is a complicated task that requires more external than internal motivation, especially in a classroom setting. We use student work and classroom observations to assess the extent to which lessons learned from reflecting on the games transferred to the tax return assignment. We will conclude with plans for future studies regarding this module. (Received August 28, 2015)

1116-R5-370 **Jessica Gehrtz*** (gehrtz@math.colostate.edu) and **Mary E. Pilgrim** (pilgrim@math.colostate.edu). *Increasing Student Engagement in Learning Calculus Through PBL, Oral Assessments, and Writing.*

Evidence-based research in education supports the use of classroom methods that encourage student engagement in learning. Providing an environment that prompts students to analyze their own learning promotes the development of metacognitive skills, and has been shown to enhance learning. This is particularly important in mathematics courses, since a robust understanding of mathematics underpins success in other STEM disciplines, and is therefore essential for supporting increased persistence in STEM fields. Regrettably, mathematics courses are often taught in traditional, non-engaging, teacher-centered ways, especially at large institutions where many thousands of students enroll in these courses each year.

To address this problem, we have designed a model that incorporates problem-based learning, oral assessments, and writing as active teaching and learning strategies in the calculus classroom. Preliminary results indicate that students who participate in such activities perform better on both procedural and conceptual exam questions. We will present our framework for instruction, a description of activities, sample student responses, and some qualitative and quantitative results. We will also discuss the impact this has had on GTA training. (Received August 28, 2015)

1116-R5-502 **Janet Sharp** and **Jennifer D. Wagner*** (jennifer.wagner1@washburn.edu), Department of Mathematics and Statistics, Washburn University, 1700 SW College Ave., Topeka, KS 66621. *Calculus activities to enhance student understanding.* Preliminary report.

The purpose of this study was to develop and utilize a multi-class period, student-centered set of activities that were aimed at allowing college students to thoughtfully describe the ideas behind the definitions of derivatives and integrals using geometric language, pictures and visualizations. While structuring the activities, we relied on the van Hiele theory on geometric learning and research on concept attainment from mathematics education literature. The results of this study include (1) a narrative description of individual students' thought processes about these topics and their resulting descriptions and definitions and (2) a description of patterns of thought that emerged among students as they worked through the sequenced activities. Our presentation consists of a description of the activities, the educational foundations that ground the activities, and our experiences implementing them for the first time in a calculus class. The analyses of student work drew from the activities and follow-up exam problems, as well as student feedback from a structured survey. (Received September 04, 2015)

1116-R5-625 **Ioannis Souldatos*** (souldaio@udmercy.edu), 4001 W.McNichols Ave, University of Detroit Mercy, Department of Mathematics, Detroit, MI 48221. *Do students learn from their mistakes?*

During the Fall of 2014, students in three different undergraduate classes were assessed multiple times throughout the semester. Some of the assessment problems re-appeared multiple times. We compare student performance in these problems to determine whether students learned from their mistakes. (Received September 09, 2015)

1116-R5-660 **Jenna R. Van Sickle*** (j.r.vansickle@csuohio.edu). *Flipped learning in college algebra increases student learning but decreases student satisfaction.*

In a college algebra course that used flipped/inverted pedagogy, students achieved learning outcomes at a significantly higher rate, as evidenced by results on the final exam. At the same time, student perception on a number of measures decreased significantly, including how interested students were in the course and whether the instructor effectively facilitated learning. This talk will draw on a wide variety of research to suggest ways to improve student perception in learner-centered instruction. (Received September 10, 2015)

1116-R5-981 **Julie Bergner*** (jbergner@ucr.edu). *Assessing a summer preparatory workshop for mathematics transfer students.* Preliminary report.

We assess a two-week summer workshop designed to help mathematics transfer students transition to upper-level coursework. In addition to introducing students to topics such as set theory and proofs, the program also included problem sessions, readings and discussions on the development of mathematics, and panel discussions. To evaluate the program we consider not only pre- and post-test data from the workshop itself, but also from the introduction to proof course that many of the students took in the subsequent term. We also discuss the effects of the program on students' overall success and participation in department programs following the workshop. (Received September 15, 2015)

1116-R5-1029 **Vesna Kilibarda*** (vkilibar@iun.edu), 3400 Broadway, Gary, IN 46408. *Assessment of Mathematical Reasoning Outcomes in a Mathematics Course for Liberal Arts Students.* Preliminary report.

Several years ago our college adopted common General Education Student Learning Outcomes for all undergraduate degrees that we offer at our university. We have recently finished the first cycle of assessing these outcomes and have begun the second cycle. As part of the second assessment cycle, our department planned and conducted an assessment of Mathematical Reasoning Outcomes (MRO) in a Mathematics Course for Liberal Arts Students.

Two questions that we wanted to answer are: i)How does the performance of our students this semester compare to their performance in the same course the previous assessment? ii)How students' success in this course relates to their success in the next quantitative course, usually introductory statistics.

The same selection of questions addressing MRO from common Midterm and Final Exams was analyzed in two random samples of our students to address the first question. A survey of faculty further revealed the strengths and weaknesses of our students in meeting MRO and we proposed an intervention to help improve their success. We analyzed data available in our student records to determine factors that predict the success of our students in their next quantitative course. The details and results of the study will be presented in this paper. (Received September 16, 2015)

1116-R5-1200 **Janine E. Janoski***, janinejanoski@kings.edu, and **Whitney George**. *How Harry Potter and The Walking Dead Changed Student's Performance in Calculus.* Preliminary report.

We have all been there before, you write the *perfect* word problem. The context is clever and the numbers work out perfectly. Then your students read the question and interpret it as: "Mary buys 150 fish from the Pike Street Market while a train leaves New York City traveling west at 80 mph. If Aliens invade Seattle, at what rate does the ladder slide down the wall?" So how do we create a context of a problem that the students can relate to?

We examine how student success in calculus word problems is correlated with student engagement and interest to content. This study involves two calculus courses from a small private college and two calculus courses from a medium sized public university. One section from each college was given the standard calculus word problems, while the other was given word problems themed in the context of current popular movies and TV shows. In this talk, we present samples of themed content, student reactions and feedback, and an analysis of student performance. We conclude with how to extend our findings to other content courses to help in student engagement and success. (Received September 17, 2015)

1116-R5-1730 **Andrea Young***, younga@ripon.edu, and **Kathryn Bruhns**. *Direct Embodiment in Differential Calculus.* Preliminary report.

In this talk, we present preliminary results concerning a semester-long study regarding the effectiveness of lessons in which students take an active role in learning geometric concepts in Calculus I by using their bodies to demonstrate the mathematical material. Guided by research in embodied cognition and direct embodiment, we conjectured that students would improve their conceptual understanding of certain calculus concepts by participating in lessons that required them to physically engage with the mathematical content. We developed six direct embodiment activities using floor chalkboards. Students were surveyed about their perceived learning gains after each lesson, and they also completed pre- and post-tests for each activity. (Received September 21, 2015)

1116-R5-1858 **Cassie Williams*** (`willi5cl@jmu.edu`), James Madison University, and **John (Zig) Siegfried**, James Madison University. *Investigating Student Learning Gains from Guided-Inquiry Activities in a Flipped Calculus I Course.* Preliminary report.

The flipped classroom has garnered attention in post-secondary mathematics in the past few years, but much of the research on this model has been on student perceptions rather than its effect on the attainment of learning goals. Instead of comparing to a "traditional" model, in this study we investigated student learning gains in two flipped sections of Calculus I. In this talk, we will focus on the question of determining immediate and longitudinal learning gains from delivering content via guided-inquiry activities in the classroom, and we will explore how these activities can be used to promote conceptual learning. In particular, we will consider a sequence of three activities designed to develop the conceptual definition of the derivative. We will share qualitative and quantitative data gathered from post-activity surveys and quizzes, as well as aggregate data from exams and student work samples. (Received September 21, 2015)

1116-R5-2042 **Annela R Kelly*** (`a3kelly@bridgew.edu`), 131 Summer Street, Bridgewater, MA 02325. *College Graduates and Marketable Learning Outcomes.* Preliminary report.

In January 2015, AAC&U published a national survey to determine what learning outcomes are rated as most valuable in job market. The research determined that employers give college graduates low scores for preparedness in majority of learning outcomes while students think they are better prepared. In my research, I will assess how well prepared are students in these learning outcomes at BSU (Bridgewater State University). My presentation discusses the following questions: a) How large is the gap between the skills students have and they think they have? b) How do our students compare to national average? c) How to build awareness of these skills? (Received September 21, 2015)

1116-R5-2131 **Milé Krajcevski*** (mile@mail.usf.edu), University of South Florida, Dept. of Mathematics & Statistics, CMC 342, 4202 E. Fowler Av., Tampa, FL 33620-5700. *Students' Inclination to Incorporate Sketches During Problem Solving.* Preliminary report.

We often use technology to help visualize complex mathematical notions. But when dealing with relatively simple objects like lines, circles, cylinders or cubes, using free sketching during class presentations seems to be more natural. Many times students justify their reluctance to sketch images during problem solving activity with their inexperience or inability to draw these images. In this talk we present results of a preliminary study that examines students' ability to sketch typical mathematical objects in a Calculus III course, and their inclination to use images that can help them acquire additional information when solving a mathematical problem. We assessed students' notebooks and evaluated their responses on particular test questions that were designed in such a way that visual insights into the problems had potential for simplifying their analytical solutions. (Received September 21, 2015)

1116-R5-2215 **Warren J. Code*** (warcode@science.ubc.ca), **Joseph Lo**, **Wed Maciejewski**, **Sandra Merchant** and **Matthew Thomas**. *Mathematics Attitudes and Perceptions Survey: Assessing Students' Expert-like Conceptions of Mathematics.*

Part of the purpose of an undergraduate mathematics education is to foster the development of students' expert-like conceptions of mathematics. In this presentation, we introduce the Mathematics Attitudes and Perceptions Survey (MAPS), designed to assess these conceptions in authentic educational settings by scoring student responses based on their alignment with those of mathematics faculty. The development and validation of MAPS will be briefly outlined, followed by the main results that have emerged from use of MAPS in a selection of undergraduate courses. These results corroborate results from other STEM disciplines: MAPS scores correlate with course grades; students tend to move away from expert-like orientations over their first semester or year of taking a mathematics courses; and, compared to traditional lecturing, interactive-engagement type lectures appear to have less of a negative impact - though not necessarily a positive impact - on students' orientations relative to experts. (Received September 22, 2015)

1116-R5-2528 **Cinnamon Hillyard*** (ch7@uw.edu), 18115 Campus Way NE, Bothell, WA 98072, and **Emily Gismervig**, **Alex Musselman** and **Robin Angotti**. *Bridging the Gap: What Non-Cognitive Strategies are Effective in a a College Algebra Course?* Preliminary report.

We have been successfully teaching the Carnegie Foundation's Quantway course as our entry level mathematics course. As students transitioned to their subsequent math and science courses, however, they faced challenges with changing pedagogy and expectations. To bridge this gap, we developed a college algebra course that would not only give them the necessary math skills, but also support them through this transition. We included activities that ask students to rethink their mindsets about mathematics, reframe their test anxiety, and learn how to access mathematics materials outside of the classroom. Additionally, we have thoughtfully integrated active learning pedagogies and technology to enhance student learning. We are investigating: How does our student-centered pedagogy in our college algebra course impact students' beliefs about and future engagement with mathematics? To answer this question, we will present evidence from Carnegie's productive persistence survey, student reflections on our stress reappraisal activity, end-of-course interviews, and comparative pass and retention rates for this course. (Received September 22, 2015)

1116-R5-2567 **James S Rolf*** (jim.rolf@yale.edu), **John Hall**, **Sara Epperson**, **Jennifer Frederick**, **James Kim**, **Edward O'Neill** and **Frank Robinson**. *Hybridized Learning in an Online Bridge Program.* Preliminary report.

As part of a 2014 commitment to President Obama to recruit and graduate more STEM majors, Yale developed an online bridge program "Online Experiences for Yale Scholars" (ONEXYS) to boost the quantitative reasoning skills of selected incoming freshmen. The result was a not-for-credit pre-calculus course consisting of online videos, adaptive practice quizzes, challenging applications of math content, and undergraduates acting as coaches for teams of incoming students. We report on evidence of gains in learning and increased feelings of preparedness from the first two summers of ONEXYS as shown by pre/post test data, survey data, and feedback from focus groups. (Received September 22, 2015)

1116-R5-2811 **Edgar Fuller*** (ef@math.wvu.edu), Department of Mathematics, West Virginia University, Morgantown, WV 26506. *Anxiety Levels of Students in a Developmental Mathematics Program.*

Students in developmental mathematics courses sometimes exhibit higher levels of stress related to mathematics courses. In this presentation we will summarize the results of the administration of a 25-item Abbreviated

Mathematics Anxiety Rating Scale (A-MARS) survey (Alexander & Martray, 1989) derived from the 98-item instrument developed by Richardson and Suinn in 1972 and the Big Five Inventory (BFI) survey (John, Naumann & Soto, 2008) to students in a developmental mathematics course covering arithmetic and algebraic skills and concepts leading up to college algebra in the fall of 2015. We will discuss some interaction between the two measures and give an overview of the relative levels of anxiety and different BFI traits analyzed across some demographic subsets. (Received September 22, 2015)

1116-R5-2937 **Steve Cohen** (scohen@roosevelt.edu), **Barbara Gonzalez** (barbara.p.gonzalez@hofstra.edu) and **Melanie Pivarski*** (mpivarski@roosevelt.edu), Mailstop AUD 402, 430 S. Michigan Ave, Chicago, IL 60605. *Students as partners in curricular design: Creation of student-generated calculus projects and their implementation.*

For the past five years advanced students have developed projects for our redesigned Calculus II classes to use. Our student project designers are often mathematically early in their careers, and so this provides them with an opportunity to create and explore new mathematics while giving us the ability to involve students of all levels in research projects. It also gives them the chance to present their work at conferences and local talks.

Our course redesign affected three groups of students: ones taking the class, ones designing projects for the course, and embedded tutors. This qualitative study examines how the second and third groups of students benefited from their experiences and how we can modify our program to improve it. Evidence was gathered from interviews, surveys, and observation of student research work and its implementation in the classroom. (Received September 23, 2015)

The Teaching and Learning of Undergraduate Ordinary Differential Equations

1116-S1-120 **Jana L Gevertz*** (gevertz@tcnj.edu). *Choosing a Solution Strategy: Distinguishing between Analytic, Qualitative and Numerical Approaches.* Preliminary report.

In many undergraduate Ordinary Differential Equations courses that cover first-order initial value problems, students learn analytic approaches for solving such equations, qualitative approaches to extract some solution behavior, and numerical approaches to approximate the solution. As individual techniques, students typically become quite proficient at each of these tasks. However, students often struggle to understand the connections between these approaches, when one approach is more appropriate to answer a given question, or when an approach cannot actually give the desired answer. In this talk, I will share some pedagogical and assessment strategies for encouraging this sort of connected and integrative thinking. A course-culminating project that pushes students to understand the strengths and weaknesses of each solution strategy will also be discussed. (Received July 30, 2015)

1116-S1-129 **Keith A Nabb*** (nabb@morainevalley.edu). *Reflections from Teaching Inquiry-Oriented Differential Equations.*

This presentation will focus on my reflections from teaching Inquiry-Oriented Differential Equations (IO-DE). With inquiry, the pedagogical foci include modeling problem situations, thinking about the associated mathematics, and understanding the structural qualities of DEs. Typical classroom activities consist of small groups of students deriving differential equations from data and giving mathematical meaning to assumptions. At the end of the classroom period, select groups present their findings to the class. The final 15 minutes of class time is used to openly discuss/criticize/admire the work of the groups (a teacher-driven discussion). The culmination of each activity results in reaching a consensus on a practical approach to the problem and linking students' informal reasoning with formal notions. We capitalize on commonalities found across different group's work and associate the findings with mathematical convention. In this session, I will share my initial challenges in adapting to this pedagogy. Discussion points will include lesson preparation, classroom discourse, student expectations, and assessment practices. Attendees new to inquiry will have a better understanding of its nature and the demands necessary for its successful implementation. (Received August 03, 2015)

1116-S1-339 **Samer S. Habre*** (shabre@lau.edu.lb), P.O. Box 13-5053, Beirut, Lebanon. *The Reformed ODE Curriculum: Students' Solution Strategies, Students' Approval of the Qualitative Approach, and the Importance of Incorporating a Writing Component.*

A reformed ODE curriculum has been in use at the Lebanese American University since the beginning of this century. This presentation highlights some of the research conducted on students enrolled in sections I taught using this reformed curriculum. I investigated students' strategies to solve ODEs in a reformed setting; in particular, I examined if students consider slope fields to solve ODEs and whether they can read information from these fields. It was found that students' first attempts to solve equations are mostly quantitative. This was followed by an exploration of students' approval of a geometric approach to solving equations. It was found that students are initially reluctant to accept this approach but eventually appreciate it. The latter results were confirmed by examining the point of view of one student who took the course twice using each time a different approach. The inclusion of a qualitative approach side-by-side with the quantitative one necessitated that the learner is able to combine the two approaches. Incorporating writing came naturally to achieve this goal. Writing skills were initially unsatisfactory, but my research has shown that these can be improved if emphasized by the instructor and expectations are clearly spelled out in the writing assignments. (Received August 26, 2015)

1116-S1-376 **Brian Winkel*** (brianwinkel@simiode.org), 26 Broadway, Cornwall, NY 12518. *SIMIODE - Building a Learning Community to Teach Modeling First Differential Equations.*

We are building a complete environment for and a learning community of teachers and students who are interested in learning differential equations in a modeling first approach. SIMIODE - Systemic Initiative for Modeling Investigations and Opportunities with Differential Equations is about teaching differential equations using modeling and technology upfront and throughout the learning process. You can learn more at our dynamic website, www.simiode.org, where we offer a community in which colleagues can communicate, collaborate, publish, teach, explore, contribute, etc. We will present examples of material and how colleagues can join and contribute their ideas. (Received August 28, 2015)

1116-S1-521 **L. G. dePillis*** (depillis@hmc.edu), Chair, Department of Mathematics, Harvey Mudd College, 301 Platt Blvd, Claremont, CA 91711. *Classroom Module for Using ODEs to Model the AIDS Epidemic.*

Using the AIDS epidemic in the U.S. as a motivating topic, we have developed a classroom module that brings students through the process of model building using ODEs, numerical ODE system solutions, and model refinement. Finding model-based research literature that is still accessible to the student is useful in creating projects with relevant applications. This project was developed using a paper by J.R. Thompson and K.W. Go that was published in 1989, when much about AIDS was still unknown. Starting with an older model allows students to scrutinize model assumptions and predictions in light of information that has surfaced only after publication of the paper. Understanding the epidemiology of AIDS is still of interest to our students; the systems of ODEs used to model the spread of the disease are straightforward extensions of the basic SIR model, and are easily accessible to a student with some introductory ODEs exposure. We will present an outline of the classroom lectures and guided discussions, sample project assignments, and the research literature upon which the project is based. (Received September 05, 2015)

1116-S1-586 **Thomas W Judson*** (judsontw@sfasu.edu), Department of Mathematics and Statistics, Stephen F. Austin State University, P.O. Box 13040-3040 SFA Station, Nacogdoches, TX 75962, and **Theron Hitchman**. *Integrating Sage into an Ordinary Differential Equations Course using MathBook XML.*

The use of technology for the teaching and learning of ordinary differential equations has gained wide acceptance, yet the problem of seamlessly integrating technology into textbooks and other curricular materials is not an easy one. Technology for teaching an ordinary differential equations course usually falls into two categories—using software system such as Sage, MatLab, or Mathematica, or using a dedicated menu-driven ODE solver. Both have their advantages and limitations. One possible solution is MathBook XML, a lightweight XML application for authors of scientific articles, textbooks and monographs. When a document is written in MathBook XML, it is possible to quickly produce LaTeX, HTML print, PDF, web, EPUB, Sage Notebooks, and iPython Notebooks from a single source. With MathBook XML, it is easy for authors to include live Sage cells in a document with preloaded Sage code that can be processed on a remote server. Students may experiment by changing commands. Refreshing the webpage will restore the original Sage code. Since MathBook XML and Sage are open-source, they are ideal tools for both faculty and students. (Received September 08, 2015)

1116-S1-811 **Erich McAlister*** (mcalister_e@fortlewis.edu), Department of Mathematics, Fort Lewis College, 1000 Rim Dr., Durango, CO 81301. *Using Current/Urgent Research to Enhance Undergraduate Differential Equations.* Preliminary report.

In this talk I will outline the use of class projects that are both modern and urgent in order to get students engaged in the study of differential equations as a vital branch of mathematics. Too often, students feel as though the math they are learning is just "textbook math". I will give parameters for, and examples of, going outside of standard topics in order to help students understand that differential equations are something they GET to use for exigent real world problems, rather than the topic of a class they need to get through. (Received September 13, 2015)

1116-S1-1186 **Eric Sullivan*** (esullivan@carroll.edu), Carroll College, 1601 N. Benton Ave., Helena, MT 59625. *Modeling First - Techniques Just In Time.*

The field of differential equations is rich with opportunities for mathematical modeling, but many students leave differential equations courses thinking of the whole field as nothing but a collection of techniques. In this presentation we will discuss the use of modeling scenarios as motivation for learning several traditional analytic solution techniques. Furthermore, the modeling scenarios serve as motivation to learn more advanced techniques such as sensitivity analysis and parameter fitting. Several of our modeling scenarios will be presented along with sample student work and an open discussion of teaching with a modeling-first approach. (Received September 17, 2015)

1116-S1-1488 **Patrice G Tiffany*** (patrice.tiffany@manhattan.edu) and **Rosemary C Farley**. *Using Maple to Promote Modeling in Differential Equations.*

The July, 2015 report of the Differential Equations Working Group of the Committee on the Undergraduate Program in Mathematics of the MAA states that "The ODE course is easily the course in the introductory undergraduate mathematics curriculum in which the use of technology is most essential." The same report states that with technology, modeling problems that were previously inaccessible become accessible. This presentation will demonstrate how the computer algebra system Maple can be used very effectively in the differential equations class to introduce topics that cannot be covered as easily without the use of such a technological tool. Lab assignments and their solutions will be made available to participants. The assignments will involve modeling problems investigated during the MAA PREP workshop SIMIODE–Systemic Initiative for Modeling Investigations and Opportunities with Differential Equations–this summer. These worksheets can certainly be adapted for a different system like Mathematica. (Received September 20, 2015)

1116-S1-1747 **Karl RB Schmitt*** (karl.schmitt@valpo.edu). *Tips, Tools, and Resources for Teaching an Active-Learning motivated Differential Equations Course.*

Have you thought about incorporating active learning or transitioning to an Inquiry-Based Learning (IBL) format, but are hesitant to reinvent the wheel in your Differential Equations course? Would you like to hear about someone else's successes and failures to help you weigh the pros and cons? If you said yes to the above statements and are interested in either IBL resources or stand-alone activities that you can drop into a course to increase student engagement and learning, then you should find this talk beneficial.

During this talk I will describe my experiences teaching an active learning motivated Differential Equations course (not in a traditional IBL style), and more importantly, the resources I used and outcome of the course. The course was loosely based on an IBL text, and supplemented by an array of other materials. These resources will be discussed and include several (free) textbooks, computational labs, modeling mini-projects, and interactive Sage computations. I have taken a critical look at what worked, what didn't and a bit of why. Also included will be open pedagogical questions and general reflections. When I am finished you will have a toolbox of things to try, with concrete suggestions about how to use them in a course, and how to evaluate their impact. (Received September 21, 2015)

1116-S1-1841 **William M Kinney*** (bkinney@bethel.edu), Bethel University, Mathematics and Computer Science Department, P.O. 95, St. Paul, MN 55112. *Teaching an Online Sophomore-Level Differential Equations Class with Mathematica Supplements.* Preliminary report.

I have taught an online sophomore-level differential equations course six times. My original construction of the course relied on topical videos I made to deliver content and the use of Mathematica supplements for the textbook we used by Blanchard, Devaney, and Hall. In the last year I also videotaped my lectures for a traditional section of the course, posted them on YouTube, and used those as my content delivery for online sections. Student reaction has generally been positive, and I will share advice for those contemplating or embarking on the construction their own online course. (Received September 21, 2015)

1116-S1-1871 **Michelle L Ghrist*** (michelle.ghrist@usafa.edu), HQ USAFA/DFMS, 2354 Fairchild Hall, Suite 6D2, USAF Academy, CO 80840. *How High Can You Jump? Modeling Jumping via Differential Equations.* Preliminary report.

I discuss an ODE's project that asks students to model the motion of a person jumping vertically. Students are asked to develop and analyze a basic model and then iteratively refine that model to consider air resistance and other factors. Some initial models can be solved analytically, but more advanced models require approximation via numerical methods. Students will gain experience working with actual data and use that data to estimate parameters for two different kinds of vertical jumps. Development of this project was supported in part by SIMIODE. (Received September 21, 2015)

1116-S1-1903 **Paul E. Seeburger*** (pseeburger@monroecc.edu), Monroe Community College, 1000 E. Henrietta Rd., Rochester, NY 14623. *Valuable Course Components for an Online Differential Equations Course.* Preliminary report.

How do we effectively teach a course like differential equations online? I will share the approach I took to this task and demonstrate and discuss the tools I used to help my students master the material of this course. These tools included: lecture videos recorded in my face-to-face classes, WeBWorK problem sets, freely available OER textbooks, written assignments, visualization tools, graded online class discussions, and student video presentations of example problems. Each of these course components played an important role in the success of my students, and I will explain their benefits from my perspective and from what students said about using them. (Received September 21, 2015)

1116-S1-2058 **Beverly H. West*** (bhw2@cornell.edu). *Teaching Differential Equations without Computer Graphics Solutions is a Crime.*

In the early 1980s computer graphics revolutionized the teaching of ordinary differential equations (ODEs.) Yet the movement to teach and learn the qualitative methods that interactive graphics affords seems to have lost momentum. There still exist college courses, even at big universities, being taught without the immense power that computer graphics has brought to differential equations. Most differential equations that arise in mathematical models are nonlinear, and linearization only approximates solutions sufficiently near an equilibrium. Graphs of phase plane trajectories and time series solutions allow one to see and analyze the crucial behaviors, whether or not analytic solutions exist. Furthermore, interactivity is key to experimenting with parameters in order to modify behaviors. Now, a quarter of a century later, we have far more technology – but many features of the original software have been lost in the rush to the future. I will address both educational and software concerns. This is not only an academic issue – multiple nonacademic agencies (FDA, NIH, USCGS, etc.) immediately took up our software tools in the late 1980s. We should not be depriving today's students of the skills to analyze behaviors of solutions to ODEs . (Received September 21, 2015)

1116-S1-2093 **Therese Shelton*** (shelton@southwestern.edu). *Active DE with Inquiry and More.*

Active pedagogy, including with inquiry, can be effective in DE for both faculty and students. We share an ongoing journey involving technology (Mathematica and the "legacy" versions of Interactive Differential Equations), an institutional Inquiry Initiative, and involvement with various math communities. "Teaching Inquiry-oriented Materials: Establishing Supports" (TIMES) included an online working group that piloted new materials and reflected on pedagogy. Recent involvement with the SIMIODE community will allow the addition of more modeling in DE. POGIL techniques allow greater structure to an inquiry-oriented environment. The result is a flexible format to build student skills in math and communication, and – at least for a single semester – performance. (Received September 21, 2015)

1116-S1-2193 **Christopher S. Goodrich*** (cgood@prep.creighton.edu), Creighton Preparatory School, 7400 Western Avenue, Omaha, NE 68114. *Chaos Theory and Nonlinear Systems in the Differential Equations Classroom.*

I will discuss some of the teaching techniques that I have used when introducing students to nonlinear systems and chaos theory in an introductory differential equations course. In part, I will explain how it is possible to introduce students to limit cycle theory (e.g., Poincaré-Bendixson theory and Dulac's criterion) by means of computer software while at the same time making significant connections back to the students' single and multivariable calculus coursework, including, but not limited to, Green's theorem, parameterized curves, and polar coordinates. I will also discuss some strategies for introducing students to the mathematical discipline of chaos and nonlinear dynamics by means of a variety of teaching tools, including computer software, traditional classroom instruction, and popular literature. (Received September 22, 2015)

1116-S1-2197 **John B Thoo*** (jthoo@yccd.edu), Yuba College, 2088 N BEALE RD, MARYSVILLE, CA 95901. *Teaching Differential Equations the SIMIODE Way.*

When teaching differential equations, we typically introduce a type of equation, explain the methods to solve it, and then assign exercises to practice solving it. A few of these exercises might be modeling scenarios, but almost all are not. SIMIODE proposes to flip this with a "modeling first" approach to teaching differential equations. Either through a hands-on activity to gather data or through a narrative, students first develop a model that introduces a type of differential equation. From there, students might use technology or learn analytical techniques to solve the model equation or equations of that type. As described at www.simiode.org, this is "modeling forward differential equations . . . for modern times based on the strong tradition of the field in its origin—modeling change." This talk presents concrete examples to illustrate this approach to teaching differential equations. (Received September 22, 2015)

1116-S1-2394 **Chris Rasmussen** and **Karen Allen Keene*** (karen_keene@ncsu.edu). *Software Tools That Do More with Less.*

Over the past decade we have been engaged in creating and investigating innovative learning environments in differential equations that make use of a wide range of technologies, from applets to mainstream software such as Maple and Mathematica. A key distinguishing feature of the applets we use is that they do much less for users than many of the prepackaged, commercial software tools. In this report we illustrate a less-is-more applet that students use at the beginning of a first course in DEs. The applet requires the user to input a DE and then simply allows the user to move a point and its associated tangent vector around in a corresponding slope field. The applet does not sketch in a solution or provide any type of analytic or numerical solution. This minimalist approach requires students to creatively imagine the behavior of the solution functions for the given differential equation. As a result, students conceptually distinguish between an exact solution and an approximate solution and eventually reinvent Euler's method. In this presentation, we present examples from this work. (Received September 22, 2015)

1116-S1-2498 **Robert Sachs*** (rsachs@gmu.edu). *Similarities in a first differential equations course.*

Similarity transformations help unify a large number of techniques commonly used in a traditional first course in differential equations. Many students and professors find these techniques to be a grabbag of tricks, but with a reformulation using similarity they become coherent, connected and sensible. These classical techniques include: solving the general first-order linear equation; finding the second solution of a constant coefficient equation with a double root in the characteristic equation; reduction of order more generally; the two methods of solving inhomogeneous linear equations (undetermined coefficients and variation of parameters); construction of the matrix exponential for first-order systems with constant coefficients; fundamental solution matrices; Laplace transforms. The use of operator notation hearkens back to factoring polynomials as a useful reformulation and also looks to parallel notions in linear algebra and ahead towards many more advanced topics. (Received September 22, 2015)

1116-S1-2573 **Catherine E Cavagnaro*** (ccavagna@sewanee.edu), 735 University Avenue, Sewanee, TN 37383. *Aircraft Longitudinal Oscillations.*

In many ways, an airplane acts as a spring-mass-damper system with mass, spring constant, damping coefficient and forcing function determined by the manufacturer, the pilot and, sometimes, mother nature. In particular, we apply the theory of second-order linear differential equations to flight in an airplane covered in ice. (Received September 22, 2015)

1116-S1-2574 **Ben Vanderlei*** (ben.vanderlei@ufv.ca), University of the Fraser Valley, 33844 King Road, Abbotsford, BC V2S7M8, Canada. *A Technical Writing Project for Differential Equations Students.*

The rich applications and theory in a differential equations course make it an ideal setting for students to gain experience in technical writing. I will present details of a technical writing project that I have implemented as part of a traditional second year course in ordinary differential equations. In addition to writing about topics outside of the traditional curriculum, the assignment also requires that students act as reviewers of the papers of their classmates. (Received September 22, 2015)

1116-S1-2713 **Itai Seggev*** (is+research@cs.hmc.edu), 2000 Trade Center, Champaign, IL 61820. *Using symbolic ODE solvers' full potential to bring out your students' full potential.*

In the past decade, symbolic ordinary differential equation solvers have moved beyond their traditional focus on solving classical equations in terms of special functions. Solvers for piecewise or "engineering function" driving terms, hybrid or event-driven equations, differential-algebraic equations, and even delay-differential equations are now available. These new solvers greatly expand the range of models for which symbolic solutions are possible, and which students can therefore explore from a varienty of perspectives. In this talk I will survey these topics and how you can explore them using *Mathematica*. (Received September 22, 2015)

1116-S1-2721 **Ron Buckmire***, Mathematics Department, Occidental College, 1600 Campus Road, Los Angeles, CA 90041, and **Treena Basu**, Mathematics Department, Occidental College, 1600 Campus Road, Los Angeles, CA 90041. *An Investigation Of The Effects of Different Pedagogical Practices in an Introductory Differential Equations Course On Teaching and Learning.* Preliminary report.

In this talk we shall provide preliminary findings from our investigation into the differences between two parallel sections of an introductory differential equations course taught at a small, private, highly selective liberal arts college. The instructors used the rare opportunity of having two roughly equal sections of an introductory differential equations course taught in the semester to conduct an impromptu experiment in the effects of different pedagogical practice on various measurable outcomes related to teaching and learning. The two sections had almost all course materials coordinated to be identical (textbook, homework, midterm exams and final exam). The primary difference between the two classes was that in one section student polling (also known as classroom voting) occurred and in the other it did not. The questions of how, whether and what measurable differences are observed will be summarized and discussed. (Received September 22, 2015)

1116-S1-2728 **Zhengyi Zhou** and **Angela Gallegos*** (`angela.gallegos@lmu.edu`). *Road Rage and You! Exploring ODEs and Modeling through Traffic Models.* Preliminary report.

Mathematical Models for traffic flow are often introduced as applications of shock and rarefaction waves arising from partial differential equations (PDEs). However, ordinary differential equations (ODEs) can be used for traffic flow from a macroscopic perspective. Using such models, one can have students experiment with inflow and outflow functions, perform dimensional analyses, qualitatively analyze the model system, and perform numerical simulation with parameters relevant to their own experience. We also suggest that these macroscopic traffic models can be used for students to begin to investigate delay-differential equations (DDEs). Traffic flow models provide straightforward, adaptable examples for numerical experimentation and analysis that can enhance the curriculum within an ODE or modeling course. (Received September 22, 2015)

1116-S1-2766 **Rachel L. Bayless*** (`rbayless@agnesscott.edu`), Agnes Scott College, 141 E. College Ave, Decatur, GA 30030, and **Rachelle C. DeCoste**. *Modeling word propagation: a connection between ODE and linguistics.* Preliminary report.

The rate that a particular word propagates through the English vernacular can be modeled via differential equations. Google Ngram Viewer compiles data (dating back to the 1500's) on the number of times specific words are printed in texts each year. In this talk, we explain how the data from Google Ngram Viewer can be used to create a variety of modeling projects. We also introduce an in-class exercise that walks students through modeling the propagation of the word "jumbo" via exponential growth. (Received September 22, 2015)

1116-S1-2791 **Amy H Erickson*** (`aerickso@ggc.edu`), 1000 University Center Lane, School of Science and Technology, Lawrenceville, GA 30043, and **Keith A Erickson** (`kericks0@ggc.edu`), 1000 University Center Lane, School of Science and Technology, Lawrenceville, GA 30043. *Student discovery of selected topics in differential equations using modeling scenarios.*

We will present modeling scenarios used in an ordinary differential equations course to motivate student learning of boundary-value problems and linear systems. In this modeling-first approach, students learn concepts by working through activities rather than listening to a traditional lecture and then solving homework problems. The SIMIODE community (www.simiode.org), Systemic Initiative for Modeling Investigations and Opportunities with Differential Equations, advocates teaching and learning differential equations using this approach and maintains a large collection of modeling scenarios for use throughout an undergraduate differential equations curriculum. We will discuss our experiences implementing these projects including student work, measures of learning, what we thought went right and wrong, and how we can expand on this in future classes. (Received September 22, 2015)

1116-S1-2840 **Douglas B Meade*** (`meade@math.sc.edu`) and **William E Boyce**. *A New Perspective on Variation of Parameters.*

The traditional motivation for the method of variation of parameters for finding a particular solution for a non-homogeneous second-order linear ODE leaves a lot to be desired. In particular, when looking for a solution in the form $y_p = u_1(x)y_1(x) + u_2(x)y_2(x)$, where $\{y_1, y_2\}$ is a fundamental set of solutions, why should $u_1'y_1 + u_2'y_2$ be zero?

In this talk the authors will present a new perspective on variation of parameters in which this constraint arises naturally. This approach also extends to the method of variation of parameters to higher-order ODEs, and is consistent with the derivation of an integrating factor for first-order problems.

This derivation combines a number of fundamental concepts found in most introductory ODE courses: equivalence between an n^{th}-order linear ODE and a first-order linear system of n ODEs, the linear independence of fundamental sets of solutions, and the non-vanishing of the Wronskian of fundamental sets of solutions.

The original idea for this approach came from correspondence with Professor Weishi Liu at the University of Kansas. (Received September 22, 2015)

1116-S1-2876 **Paul D. Olson*** (pdo2@psu.edu). *Introducing Laplace Transforms early in an applied Differential Equations course.*

A course in ordinary differential equations is usually recommended after a student successfully completes Calculus II (a course which includes partial fractions for integration , series representations , and improper integrals) . In working with second order , linear ode's with integer coefficients , the students learn about the characteristic equation and how its roots help generate the homogeneous solution to the equation . For nonhomogeneous equations , we study the method of undetermined coefficients or the method of variation of parameters to help generate the general solution . Our applied differential equations course is designed for engineering technology majors or plastics technology majors . An important goal is to have the students gain experience with solving equations using Laplace Transforms . By introducing Laplace Transforms early , the students have a longer time to master those techniques . The subject shows the use of improper integrals and partial fractions . The students feel that knowing the Laplace Transform method strengthens their understanding of the classical methods of solutions . Applied mathematics can be a bridge to pure mathematics . Careful considerations of course content can be inventive and useful . (Received September 22, 2015)

Topics and Techniques for Teaching Real Analysis

1116-S5-119 **Russell A. Gordon*** (gordon@whitman.edu), Whitman College, 345 Boyer Avenue, Walla Walla, WA 99362. *A bounded derivative that is not Riemann integrable.*

We present an example, different than Volterra's, of a bounded derivative that is not Riemann integrable. The existence of such functions was one of the motivations for Lebesgue to devise a different integration process. The goal of the presentation is to keep the ideas at a level appropriate for an undergraduate student. (Received July 30, 2015)

1116-S5-966 **Suzanne M. Seager*** (suzanne.seager@msvu.ca), Mathematics Department, Mount Saint Vincent University, 166 Bedford Highway, Halifax, NS B3M 2J6, Canada. *An Alternative Path Towards Delta-Epsilon Proofs.*

For most of my students, Real Analysis I is the first and only analysis course they will ever take (only a few will continue to Real Analysis II and possibly graduate school). Delta-epsilon proofs are initially difficult for everyone, but weaker students are especially overwhelmed. To help I reordered Real Analysis to slowly build up all of the logical and algebraic skills essential to delta-epsilon proofs well before we encounter them. Our motivation is defining the reals, so we start with the axioms for an ordered field. However we don't reach completeness until almost halfway through. We first develop skills at working with inequalities, absolute value, and logic, then move on to sequences and their limits, working on one skill at a time so that the epsilons are manageable. By the time we have defined the reals and reached limits of real-valued functions, the full delta-epsilon definition is easy to handle. I will discuss the details of the path I take through analysis, and techniques I use to help students cope. (Received September 15, 2015)

1116-S5-1045 **Peter A. Loeb*** (ploeb@illinois.edu). *Integration and local maximal functions.*

Differentiation and absolute continuity are difficult topics for students in a course on integration. The talk outlines a simplified approach that has cut almost in half the time previously spent by the speaker in covering these topics. The simplified approach uses a local maximal function. The advantage gained with this device is that many limit results can be established just by proving them for sets where the relevant input vanishes. The discussion also employs the Radó-Aldaz optimal covering theorem for the real-line. (Received September 16, 2015)

1116-S5-1340 **Robert Kantrowitz*** (rkantrow@hamilton.edu), Hamilton College, 198 College Hill Rd., Clinton, NY 13323, and **Michael M. Neumann** (neumann@math.msstate.edu), Department of Mathematics and Statistics, Mississippi State, MS 39762. *Further variations on the theme of completeness.* Preliminary report.

The condition that all sequences of bounded variation in an ordered field are convergent is equivalent to the Dedekind completeness of the field. This criterion allows for short proofs for other expressions of completeness and facilitates the inclusion of a few more reformulations featuring the series tests of Dirichlet, Dedekind, and Abel. In particular, for any ordered field, it turns out that the validity of any of these three tests in conjunction with the geometric series test characterizes Dedekind completeness. (Received September 18, 2015)

1116-S5-1464 **Erik Talvila*** (erik.talvila@ufv.ca). *Continuous functions in the extended real plane.* Preliminary report.

The extended real line is $\overline{\mathbb{R}} = [-\infty, \infty]$. A function $f : \overline{\mathbb{R}} \to \mathbb{R}$ is continuous if and only if it is continuous on $\mathbb{R}$ and has real limits at ∞ and $-\infty$. The topology of $\overline{\mathbb{R}}^2$ is more complicated. If the double integral $\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} g(s,t)\, ds dt$ exists then the function $f(x,y) = \int_{-\infty}^{x} \int_{-\infty}^{y} g(s,t)\, ds dt$ is a common example of such a function. (Received September 20, 2015)

1116-S5-1487 **Antonia E. Cardwell***, Department of Mathematics, Millersville University, P. O. Box 1002, Millersville, PA 17551. *Differentiating a cross-listed introductory Real Analysis course.*

Many schools, including Millersville University, offer a one-semester introductory real analysis course that is offered cross-listed at both the 400 (senior-level) and 500 (first-year graduate) levels. The challenge can be in differentiating the content and assessment methods for the undergraduate and graduate students in the course, in a way that naturally fits the course while at the same time not introducing an overwhelming burden on the instructor or the student. I will share a couple of approaches that I have used in teaching the cross-listed course, and would be interested in hearing any strategies used by colleagues at similar schools. (Received September 20, 2015)

1116-S5-1527 **Judit Kardos*** (kardosj@tcnj.edu), The College Of New Jersey, Mathematics and Statistics Department, Ewing, NJ 08628. *Pósa.s Discovery method in Real Analysis.*

The aim of this talk is to introduce the method of teaching mathematics developed by an eminent mathematician and educator Lajos Pósa. The main principle of Pósa's method is that students discover mathematical concepts on their own through working on tasks that build on each other, all the while having the experience of thinking like mathematicians. The method was originally developed for gifted students in mathematics camps. I added a mandatory fourth hour, called a problem seminar, to all my Real Analysis classes and used the extra time to experiment with the Pósa method. I will share work sheets and problem sets related to sequential convergence. Participants will be asked to play the role of the student and then to reflect on the learning experience as a teacher. (Received September 20, 2015)

1116-S5-1728 **William W. Johnston*** (bwjohnst@butler.edu). *The Lebesgue Integral for Undergraduates.*

A so-called "Daniell-Riesz approach" effectively introduces the Lebesgue integral, including the general integral with respect to any Borel measure. This presentation compares its surprisingly minimal prerequisite list with the prerequisites needed for Riemann's integral and studies the stunning conclusion that the Lebesgue integral is easier. (Received September 21, 2015)

1116-S5-2519 **Paul Martin Musial*** (pmusial@csu.edu), Chicago State University, Department of Mathematics and Comp. Sci., 9501 South King Drive, Chicago, IL 60628. *Assessment of Student Learning in the Age of the Internet.*

The internet makes an almost limitless quantity of interesting problems, publications and learning tools available to the real analysis instructor. However, it also provides students with the ability to circumvent hard work in solving problems and in the writing of proofs in analysis. We will discuss ways to teach students use internet sources wisely, and to help insure that students genuinely meet learning outcomes. We will also discuss methods of assessment that encourage creative, independent thinking and discourage rote copying from internet sources. Audience members will be given the opportunity to share their experiences and suggestions. (Received September 22, 2015)

Trends in Undergraduate Mathematical Biology Education

1116-T1-345 **John Wesley Cain*** (jcain2@math.harvard.edu), Harvard University, Department of Mathematics, One Oxford Street, Cambridge, MA 02138. *Exchanging Ideas and Experiences Regarding Students' Initial Exposure to Biomathematics.*

Designing an introductory undergraduate course in mathematical biology presents a dizzying array of difficult choices for the instructor. What are the learning objectives, both mathematical and biological? How might course content facilitate those learning objectives? Should both deterministic and stochastic models be discussed? How data-driven should the topics be? Is there a suitable textbook? How might the course factor into the students' future development as scholars?

I want this presentation to gravitate towards an open discussion among audience members regarding strategies, trends, and best practices. As a conversation starter, I will describe how several colleagues and I have designed a rather unusual introductory biomathematics course for students who have completed one year of calculus. In particular, I will relate some of the successes (e.g., persistence of students in quantitative biology, dramatically increased confidence in reading research articles, emergence of long-term undergraduate research projects) and shortcomings (e.g., difficulties of incorporating computation/simulations). In keeping with the session theme, I hope to record and circulate a list of trends and ideas that emerge from our discussion. (Received August 26, 2015)

1116-T1-544 **Pablo Duran*** (pduran@utexas.edu), Austin, TX 78703. *The Use of Mathematics in EEB and Developmental Biology: A Content Analysis.* Preliminary report.

The results of a study on the mathematics in use in the areas of ecology, evolution and behavior and developmental biology will be presented. This study consisted of a content analysis of peer-reviewed publications in these areas. A sample of highly cited articles published during the last 15 years was considered. The analysis focused on identifying the main mathematical and statistical tools used, as well as the most common problems for which these tools were used. Implications of the results of the study on the development of the undergraduate biological sciences curriculum as it relates to mathematics will be discussed. (Received September 06, 2015)

1116-T1-1248 **Timothy D Comar*** (tcomar@ben.edu), Department of Mathematics, Benedictine University, 5700 College RD, Lisle, IL 60532. *Pulse Vaccination Models: Dynamics and Sensitivity Analysis.*

This particular talk with focus on results we have obtained with undergraduate students researchers on the dynamics of epidemic models. The models are pulse vaccination models using impulsive differential equations. A pulse vaccination strategy periodically provides a fraction of the population with vaccination against a particular disease. One of the models incorporates a time delay for the period of time required for an exposed individual to become infective. Conditions for disease free period solutions and endemic solutions are provided. We also perform sensitivity analysis of model parameters and show how these models can be used to study the spread of diseases such as malaria and polio. We also discuss some avenues for future work by considering the introduction of stochastic behavior into these models and agent based versions of some of these models. (Received September 18, 2015)

1116-T1-1267 **Troy Day*** (tday@mast.queensu.ca), Jeffery Hall, Queen's University, Kingston, Ontario K7L3N6, Canada, and **James Stewart**. *Using Case Studies to Integrate Life Science content in Introductory Calculus Courses.*

Virtually all branches of the life sciences continue to become increasingly quantitative. As a result there is a growing demand for mathematics and statistics courses tailored to life science students. For example, many institutions are interested in developing introductory calculus courses specific to biology but it can be difficult to go beyond simply providing a standard course in which physical examples are swapped for biological ones. I will discuss how real-world case studies can be used to provide a richer integration of mathematics with biology. This will be illustrated with an example case study focusing on vaccination and pathogen virulence evolution. I will discuss how this case study can be used to motivate the development of several different mathematical ideas in calculus and how it thereby ties together multiple concepts that are taught throughout such a course. (Received September 18, 2015)

1116-T1-1351 **Hannah Lea Callender*** (callende@up.edu), University of Portland, 5000 N Willamette Blvd, MSC 60, Portland, OR 97203, and **Carrie Eaton** (ceaton@unity.edu). *Biocalculus: Changing Minds One Derivative at a Time.*

As the necessity for quantitative literacy among life science majors becomes increasingly more apparent, many institutions have created various types of biocalculus courses in effort to better meet the quantitative needs of these students. The motivation behind this decision often stems from the observation that these students are not exposed to the need for mathematics in their field of study and also do not see the relevance of mathematics in the traditional calculus classroom. With the wealth of literature connecting motivation to achievement and retention, the creation of a biocalculus course seems a natural choice for improving student attitudes and perception of mathematics while at the same time providing a rigorous atmosphere for increasing mathematical content knowledge. However, little research has been conducted on the advantages and successes of such biocalculus courses. Here we will share results from two different first semester biocalculus courses developed at different institutions, with promising trends in both student performance and attitudinal changes towards mathematics over the course of the semester. We will also provide assessment suggestions for faculty who are interested in assessing the effectiveness of their courses. (Received September 21, 2015)

1116-T1-2027 **Gabriella A Pinter*** (gapinter@uwm.edu) and **Istvan G Lauko**. *Computational labs based on research papers from science journals in a mathematical modeling course.*

In this talk we present a series of computational labs that are used as a component of a mathematical modeling course sequence for science and mathematics majors. On one hand, these labs teach elementary programming skills so students could simulate and explore models extensively, on the other hand they illustrate practical methods of model building, parameter estimation and model selection. The majority of the labs is based on research papers from science journals, and provides a powerful way to present mathematical methods in a biological context. The use of current research literature motivates students to read and explore more, while the computational and mathematical techniques learned give them confidence to ask new questions and to investigate them. As the course progresses the labs become increasingly open-ended, and the students are asked to analyze and simulate models independently as well as to develop them further. Many of these papers could serve as a good starting point for individual research projects. (Received September 21, 2015)

1116-T1-2173 **Boyko Gyurov*** (bgyurov@ggc.edu), Georgia Gwinnett College, 1000 University center lane, D1469, Lawrenceville, GA 30043. *Implementing mathematical techniques in a undergraduate biology research during calculus with tropical biology study abroad bundle.* Preliminary report.

Teaching mathematical concepts in the abstract is a non-starter in the nowadays undergraduate classes. Constantly demonstrating the mathematical ideas with suitable applied problems helps the exposition, but requires the use of diverse applied choices to address the diversity of the science and (in some cases) non science majors present in the classes. The motivation of the students also varies widely, which is especially true for open enrollment institutions. We overcame many of the above mentioned problems by setting up a study abroad month long program with three courses taught simultaneously and enhancing each other – Calculus, Tropical biology and Undergraduate research in Biology. This paper compiles the scientific, pedagogical and sociocultural findings in the inaugural execution of the program. (Received September 22, 2015)

1116-T1-2177 **Meredith L. Greer*** (mgreer@bates.edu), Hathorn Hall, Bates College, Lewiston, ME 04240. *Estimating Parameters and Responding to Questions During an Outbreak: Modeling Ebola in Fall 2014.*

In fall 2014, students in a Mathematical Biology course mathematically modeled the ongoing outbreak of Ebola. Techniques used included SIR-style models, R_0 computation using the Next Generation Method, and numerical simulation of model results. A particular difficulty, and therefore the source of many enlightening conversations, was the vagary of hoped-for model parameters while the outbreak was still occurring. Methods of modeling and finding parameter values form the first half of this talk.

Math Biology students also interacted with a Presidential Campaign Rhetoric course. Students in that course run a mock campaign, with two parties and a media presence. Their campaign featured an Ebola crisis (created for the course; not identical to the actual outbreak). To best confront the crisis, the political parties and media met with Math Biology students. Campaign Rhetoric students had to learn the underlying science and math of Ebola; Math Biology students had to explain their work in a way that interested non-experts could use in press releases. Assessment of this cross-course interaction showed unanimous excitement at the chance to use math modeling, actively, with students in a very different discipline. This connection of courses forms the second half of this talk. (Received September 22, 2015)

1116-T1-2331 **Jeff Pullen*** (pullen_j@mercer.edu), **Katie Northcutt**, **Chamaree de Silva** and **Jarred Jenkins**. *Integrating Mathematics, Biology, Physics and Psychology to Target At-Risk Students.* Preliminary report.

Program in Integrative Science and Mathematics (PRISM) is a pilot project at Mercer University, designed to guide a selected cohort of our at-risk, non-calculus ready, incoming student population. Traditionally, this group of students has had a lower freshmen retention rate compared to that of our calculus-ready students. In this program, students study Statistics, Precalculus, Biology, Physics, and Psychology in an integrated manner with four faculty members over the first two semesters. Students not only learn how these subjects are not stand-alone disciplines, but also conduct an authentic research project using the squirrel population on campus. (Received September 22, 2015)

1116-T1-2344 **Dan Hrozencik*** (dhro@att.net), Department of Mathematics HWH 332, Chicago State University, Chicago, IL 60423. *A Course in Mathematical Biology Using Algebra and Discrete Mathematics.*

In an effort to stimulate undergraduate research in his department, the author developed a summer course in mathematical biology (Math 4900: Introduction to Mathematical Biology) with minimal prerequisites. This talk will discuss the motivation and goals for the course as well as the prerequisites, recruitment of students, the content, assignments, pacing, final projects, plans for continuing research after the course, and lessons learned. (Received September 22, 2015)

1116-T1-2454 **Robert A Drewell*** (rdrewell@clarku.edu), Biology Department, Clark University, 950 Main Street, Worcester, MA 01610, and **Jacqueline M Dresch** (jdresch@clarku.edu), Dept. of Mathematics and Computer Science, Clark University, 950 Main Street, Worcester, MA 01610. *Integrating research and teaching in quantitative biology: mathematical modeling of gene regulation.*

The 4 College Biomath Consortium (4CBC) consists of faculty and students from Amherst, Hampshire, Mount Holyoke and Smith Colleges. Through the 4CBC, a course titled “Frontiers in Biomath” is offered each year to give students the opportunity to explore biological questions using tools from the life sciences together with modeling and analytical tools from the mathematical, computational and statistical sciences. We developed a module for this course that focuses on modeling gene regulation in Drosophila.

In the Drosophila fruit fly, the identity of cells in the developing embryo falls under the control of a complex network of genes. The expression of each of these genes is in turn controlled by interactions between protein transcription factors (TFs) and cis-regulatory modules (CRMs) in the neighboring intergenic DNA regions. A major goal of current research is to understand how the sequence architecture of TF binding sites mediates the functional activity of these CRMs using integrated computational and molecular genetic experimental approaches. In this interdisciplinary module we explore some of the research tools that are available to study protein-DNA interactions and investigate mathematical models of their functional activity. (Received September 22, 2015)

1116-T1-2585 **Sarah A Hews*** (shews@hampshire.edu) and **Christina Cianfrani**. *Introducing Mathematical Modeling and Improving Quantitative Skills in Collaborative Courses.*

The First Year Integrated Sciences Program is a new initiative at Hampshire College that aims to challenge students to learn about complex systems and systems thinking, improve quantitative skills, make connections among fields of science, to design innovative collaborative projects, and create a vibrant science community. During the first semester of the new program, three natural science faculty combined to teach three quantitative science courses centered around a new Living Building on campus. The three courses were Water, Carbon, and Nutrient Flows in a Living Building, Modeling Systems in a Living Building, and Microbes in a Living Building. Student met with their respective classes twice a week learning field specific skills and met all together once a week to complete interdisciplinary labs. In this talk the faculty who taught the collaborative courses will give a brief overview of the program, describe in detail the structure of the collaborative courses including how quantitative skills and mathematical modeling were included, and share data collected on the effectiveness of the collaborative courses. (Received September 22, 2015)

1116-T1-2638 **Shabeena Ahmed*** (shabeena_ahmd@yahoo.com), Santa Clara, CA. *Lineage – Viewed Through a C-set.*

There have been many recent developments in the treelike structures. One important field of recent study has been in the area of evolutionary biology. A pedigree is a directed acyclic graph that represents ancestral relationships between individuals in a population. The relation between species has been studied extensively in phylogenetics and has opened new areas of research.

An area of study that still needs to be explored is the study of interplay between pedigrees and phylogenetics with C-sets and D-sets, which occurs in the study of primitive Jordan Groups. So the question is the following.

Problem: Can we trace lineage in terms of a C-set? If yes, can there be some sort of classification?

Construction of a C-set with restrictions is presented and shown that the first part of the question is yes. The connection between pedigrees and phylogenetics with C-sets and D-sets is studied. Finally the different fields that can collaborate on this study are illustrated. In conclusion, this study is an attempt to portray the importance of this area of research in opening new interdisciplinary studies.

Key words: C-set, Pedigree, Phylogenetics (Received September 22, 2015)

1116-T1-2715 **Raina S Robeva*** (rainarobeva@rmc.edu), Randolph-Macon College, Copley Science Center 231, Ashland, VA 23005-5505. *Embracing the Algebraic Approach to Mathematical Biology.*

Over the past 15 years, many advances in biology have utilized algebraic and discrete mathematical approaches. Relatively little progress has been made, however, in introducing those approaches to the mainstream undergraduate mathematical biology curriculum, even though for many of them the level of mathematical sophistication and the nature of the material are entirely appropriate. Thus, while the more traditional mathematical biology topics including difference equations, ODEs, and continuous dynamical systems have already successfully worked their way into classes and standard curriculum, discrete and algebraic techniques have remained relatively invisible. The talk will highlight some ideas and new educational resources for successfully bridging the gap between what is now common practice in research and the use of algebraic methods for biology at the undergraduate level. We further argue that adopting the algebraic approach offers distinct pedagogical advantages, since fundamental concepts including network interactions, long-term behavior, steady states, attractors, and multi-stability can be explained and analyzed without the prerequisite of calculus. (Received September 22, 2015)

1116-T1-2749 **Frank H Lynch*** (lynch@ewu.edu), Department of Mathematics, 216 Kingston Hall, Cheney, WA 99004. *Mathematical modeling of competitive binding on a microarray.*

Competitive binding on a microarray can be used as a model of identification of single nucleotide protein (SNP) mutation in DNA. We model this binding with a nonlinear system of ordinary differential equations and show how a dimensionless formulation gives a small parameter. In order to identify parameters, results of the model are compared to real (gasp!) data. This application of differential equations is accessible for undergraduates who study planar systems of differential equations. (Received September 22, 2015)

1116-T1-2753 **Olcay Akman*** (oakman@ilstu.edu), Department of Mathematics, Box 4520, Illinois State University, Normal, IL 61790. *Modernizing Statistics Education via Biology Applications.*

In most traditional statistics courses, instructors use data from different fields in an effort to give the courses an interdisciplinary flavor. They generally fail because these attempts lack the cross-disciplinary concepts connected in a meaningful way beyond just using a data set from another field. In this talk I will discuss modernizing statistics education by i) using evolutionary concepts adapted as computational methods and ii) using biological data to demonstrate abstract statistical methods. (Received September 22, 2015)

1116-T1-2970 **Andrew M. Oster*** (aoster@ewu.edu), Dept of Mathematics, Eastern Washington University, Cheney, WA 99004. *An example of population modeling: the California condor reintroduction project.*

The California condor was on the brink of extinction in the 1980s with only 27 birds in existence in 1987. In this talk, we discuss classical approaches to population modeling, then take an alternate stochastic approach in order to determine optimal reintroduction strategies to release birds raised in captivity to the wild. Due to the nature of the problem, this problem highlights fundamental concepts for modeling in biology at the undergraduate level - demonstrates some weaknesses of deterministic models, the role of stochasticity, and incorporates Markov chains. (Received September 23, 2015)

Using Philosophy to Teach Mathematics Analysis

1116-T5-103 **Daniel C. Sloughter*** (dan.sloughter@furman.edu), Department of Mathematics, Furman University, Greenville, SC 29613. *Making Philosophical Choices in Statistics.*

Most of us tend to believe we are agnostic as to our philosophical convictions when we are in the classroom. For much of what we teach, there is some truth to this belief: although choices have been made, they are so

far in the background that we tend not to think much about them. However, the story is not as simple when we teach statistics. There we are confronted with at least three competing philosophical approaches from which to choose: the frequentist realist view of R. A. Fisher, the frequentist behaviorist perspective of Jerzy Neyman and Egon Pearson, or the subjective view of a Bayes/Laplace development. No philosophy of statistics has a claim to be the standard approach; indeed, some textbooks will present all three of these. Moreover, unlike, for example, an analysis course where the choice between a standard and a nonstandard development influences only the presentation, the philosophical choices we make in statistics influence our conclusions as well. In this talk, I will discuss these three schools of thought, with particular emphasis on the differences between the two frequentist approaches. (Received July 23, 2015)

1116-T5-177 **James R Henderson*** (`jrh66@psu.edu`). *Strange Bedfellows: Thomae's Game Formalism and Developmental Algebra.*

In a developmental math class, learning about manipulating mathematical entities can sometimes grind to a halt when questions about the entities themselves arise. This usually doesn't happen with, say, whole numbers because students can understand them in terms of a simplistic Platonism. Trying to bring these students around to a different way of thinking may be a case of fixing something that isn't broken. But consider, as a single example, when imaginary numbers are introduced. What is a beginner to make of a number that is neither positive, nor negative, nor zero, and when squared produces a negative? Since, to the uninitiated, imaginary numbers are mysterious in a way that whole numbers are not, I ask my students to adopt a formalist approach like that of Johannes Thomae in which math is purely a game with specific rules of play and the background assumption that no mathematical symbol has any meaning outside the game. In particular, i has no meaning, so the job is not to understand it. Rather, the job is to eliminate higher powers of i and square roots of negatives, and it can all be done with techniques familiar to the students. In this way, the puzzling nature of imaginaries never comes into play and new problems are reduced to old ones. (Received August 11, 2015)

1116-T5-608 **Sally Cockburn*** (`scockbur@hamilton.edu`), 198 College Hill Road, Clinton, NY 13323. *Senior Seminar in Set Theory as a Springboard for Mathematical Philosophy.*

A course in naive and axiomatic set theory provides a natural springboard for introducing students to many questions in mathematical philosophy: What is the ontological status of numbers, and does it depend on whether the numbers are finite or transfinite? What criteria should be used to determine the validity of a new mathematical concept, truth or expediency? How do humans, with fallible brains, have access to infallible mathematical truth? Is there any semantic content to mathematics, or it is purely syntax? Does mathematics reside inside human heads, or does it have some sort of external existence? At Hamilton College, I offer a senior seminar in which students spend the first two months learning the technical aspects of set theory using a Moore method approach, and the last month reading papers that address the issues and questions this material inspires. This has proved particularly successful as a "capstone experience" for the concentration. (Received September 08, 2015)

1116-T5-2300 **Luke Wolcott*** (`luke.wolcott@lawrence.edu`). *Gardens of Infinity: Cantor meets the real deep Web.*

The real deep Web – curated, visceral, profound – is an antidote to oversaturated webpages of words and mindless viral videos. The content complements logical arguments with stories and meaningful prompts to contemplate. The format moves away from walls of text towards high-concept design that encourages deep thought.

The Gardens of Infinity project is a collaboration between a mathematician, an interaction designer and a programmer. We present five provocative statements from Cantor's set theory (for example, of course, $\|\mathbb{Z}\| < \|\mathbb{R}\|$), and the translation between rigorous mathematics and metaphor is carefully articulated. Each statement branches down four paths: the user can read a rigorous proof of the statement, a shorter more accessible summary argument of the statement, the story of the people and events surrounding the statement, or a philosophical discussion of what it might mean. These last sections – sometimes presenting conventional philosophical interpretations, sometimes unapologetically metaphorical – are in a sense the real meat of the project, leading the user to contemplate infinity in new ways. My talk will explain and demo this web project, which may or may not be up at gardensofinfinity.com by the time of the conference. (Received September 22, 2015)

1116-T5-2355 **Thomas Drucker*** (druckert@uww.edu), Department of Mathematics, University of Wisconsin, 800 West Main Street, Whitewater, WI 53190. *Role of Real Numbers in an Introduction to Analysis.* Preliminary report.

Most of the courses a student will have taken up to an introduction to analysis will not address in any depth the question of what sort of objects the numbers are which appear in calculations. By the time students have finished an introduction to analysis, one would like them to be mildly familiar with what numbers are. Of course, that can be accomplished by presenting them with an axiomatization of, say, a real closed field. It makes more sense to look at what kinds of properties one needs in order to be able to prove familiar results. By this stage in a student's career, there should be no danger of the student's believing that axioms were handed down from a mathematical Mount Sinai. Instead, it is both more appropriate and exciting for the student to see how much has to be built into an axiom system in order for a user to be able to prove what is needed. (Received September 22, 2015)

1116-T5-2376 **Brian R Zaharatos*** (brian.zaharatos@colorado.edu), Engineering Center, ECOT 331, University of Colorado, Boulder, CO 80309-0526. *Statistics as a Liberal Art.*

Statistics is often classified as a branch of mathematics or as one of the "mathematical sciences". For example, the Department of Statistics at the Florida State University claims that "Statistics is the *mathematical science* involved in the application of *quantitative principles* to the collection, analysis, and presentation of numerical data." [italics added]. Such classifications give the impression that statistics is essentially about numerical manipulation, calculation, and procedure. But at the same time, such classifications conceal a number of important philosophical issues in statistical theory and practice. In this paper, I argue that (1) a number of philosophical issues arise in statistical theory and practice; (2) in part because of these philosophical issues, statistics is better classified as a branch of philosophy, and thus, a liberal art; and (3) classifying statistics as a liberal art would be beneficial for attracting students that are otherwise not initially attracted to the mathematical sciences. (Received September 22, 2015)

1116-T5-2556 **Martin Flashman*** (flashman@humboldt.edu). *Is Philosophy of Mathematics Important for Teachers?* Preliminary report.

There has been much interest in recent years on what mathematical preparation is important for future teachers at all levels. Recommendations from the MAA CUPM on Undergraduate Curriculum and the Common Core in Mathematics are silent on the issue of what role the philosophy of mathematics can play. The author will suggest examples where a discussion of some issues from the philosophy of mathematics in courses taken by future teachers can enrich their backgrounds and training. (Received September 22, 2015)

General Session on Algebra

1116-VA-297 **Kevin Gerstle*** (kevin-gerstle@uiowa.edu), Department of Mathematics, University of Iowa, Iowa City, IA 52242. *Green Rings of Pointed, Coserial Hopf Algebras.* Preliminary report.

Let k be an algebraically closed field with characteristic not equal to 2. By using the multiplication and comultiplication operations of a k-Hopf algebra H, one can induce a comodule structure on the direct sum and tensor product of two H-comodules. In this way, a ring structure called the Green ring $r(H)$ can be induced on the space of isomorphism classes of finite-dimensional comodules of H. In this talk, I will discuss the Green ring structure for a class of pointed, coserial Hopf algebras and show how by decomposing the tensor product of comodules into the direct sum of indecomposables, the corresponding Green rings for these Hopf algebras can be expressed as quotients of integer polynomial rings. (Received August 23, 2015)

1116-VA-842 **Francis Pastijn** and **Justin Albert*** (jalbert@carthage.edu), 2001 Alford Park Drive, Kenosha, WI 53140. *Rank 2 geometries as right regular bands.*

We will show that the category of rank 2 geometries with parallelism is isomorphic to the category of right regular bands with 2 $\mathcal{R}$-classes in which every element belongs to a semilattice transversal. We further show that every right regular band with 2 $\mathcal{R}$-classes is embeddable into the previously mentioned category. (Received September 15, 2015)

1116-VA-938 **Jared Warner*** (jared.warner@guttman.cuny.edu). *A Visualization of Quillen Stratification.* Preliminary report.

Let p be a prime number. A result due to Daniel Quillen states that the cohomology of a finite group Γ with coefficients in the finite field of p elements can be built up from pieces coming from abelian subgroups of Γ with exponent p. In this talk, we briefly review this "stratification" and present a few concrete computations which elucidate Quillen's result. The computations are accompanied by visualizations constructed with the aid of the computer algebra system Magma. We'll also describe how one might use Quillen's stratification to study and compute modular cohomology algebras of finite groups. In particular, we'll present current work using Quillen's result and Magma to understand the cohomology algebra of the finite group $GL_3(\mathbb{F}_p)$. (Received September 15, 2015)

1116-VA-949 **Timothy D. Ferdinands*** (ferdinands_t@mercer.edu), Department of Mathematics, Mercer University, 1400 Coleman Ave., Macon, GA 31207. *Groupoids with root systems in real vector spaces.*

The study of root systems attached to groupoids that resemble Coxeter groups has seen many recent developments. Brink and Howlett introduce one such notion such groupoids in their study of normalizers of parabolic subgroupoids of Coxeter groups in 1999. We discuss these groupoids and their associated root systems, focusing in particular on instances of these where the root system may be realized in a real vector space.

The strongest results we obtain hold when the Coxeter group is finite. In this case we give an correspondence between a realization of the universal covering of the Brink-Howlett groupoid in a real vector space and a simplicial hyperplane arrangement in that vector space. (Received September 15, 2015)

1116-VA-1037 **Andrew J. Hetzel*** (ahetzel@tntech.edu), Department of Mathematics, Tennessee Tech University, TTU Box 5054, Cookeville, TN 38505, and **Ashley M. Lawson** (ala274@g.uky.edu). *On Factorable Rings.*

In this talk, the presenter introduces and discusses the notions of "factorable ring" and "fully factorable ring" for a commutative ring, concepts based upon a certain factorization property of the ideals of the ring. Using a novel sufficient condition for an ideal to be a product of nonfactorable ideals, the speaker classifies the Artinian rings that are fully factorable. (Received September 16, 2015)

1116-VA-1192 **James Joe McCarry*** (joepliar@sbcglobal.net), 214 Northpoint Dr, Laredo, TX 78041. *I*J=-K.*

Hamilton's Broom Bridge rules of multiplication of quaternions will be used to derive the operation table. The table will be tiled to show patters. A slight variation of the table will be introduced to provide a "left hand" rule. (Received September 17, 2015)

1116-VA-1276 **Colby Long*** (celong2@ncsu.edu). *Initial Ideals of Phylogenetic Secant Ideals.*

The ideal of phylogenetic invariants of a phylogenetic mixture model of trees with the same topology is a secant variety. It has been shown that the Hilbert Series of the ideal of the binary Jukes-Cantor model of an n-leaf tree is independent of the tree topology. We show that for trees with six or fewer leaves the same result holds for secants of these ideals and conjecture that this is true for all n.

We also study a class of binomial initial ideals of $I_{2,n}$, the ideal of the Grassmannian $\mathbf{Gr}(2, \mathbb{C}^n)$, which are associated to phylogenetic trees. For a weight vector ω in the Tropical Grassmanian $in_\omega(I_{2,n}) = J_\mathcal{T}$ is the ideal associated to the tree $\mathcal{T}$. The ideal generated by the $2r \times 2r$ Pfaffians of a symmetric matrix is precisely $I_{2,n}^{\{r\}}$, the r-th secant variety of $I_{2,n}$. We prove necessary and sufficient conditions on the topology of $\mathcal{T}$ in order for $in_\omega(I_{2,n}^{\{2\}}) = J_\mathcal{T}^{\{2\}}$. We also give a new class of prime initial ideals of the Pfaffian ideals. (Received September 18, 2015)

1116-VA-1387 **Muhammad Inam*** (minam@huskers.unl.edu). *The word problem for positively presented semigroups and inverse semigroups.*

We consider a class of positive presentations for which the word problem for semigroups and inverse semigroups is decidable. (Received September 22, 2015)

1116-VA-1418 **Brian Drake*** (drakebr@gvsu.edu) and **Evan Peters**. *An upper bound for absolute length of Coxeter group elements.*

The absolute length (or reflection length) in a Coxeter group is the length function where all reflections in the group are taken as generators. We find an upper bound on the absolute length of an element in a Coxeter group as a function of the number of generators of the group and the standard length of the element. For universal Coxeter groups, we show that there are elements which achieve this bound. (Received September 19, 2015)

1116-VA-1539 **Abigail C Bishop***, Iona College, Mathematics Department, 715 North Ave, New Rochelle, NY 10801. *Involution Posets of Non-Crystallographic Coxeter Groups.*

We will examine involution posets of Coxeter Groups of type $I_2(m), H_2, H_3$, and H_4. (Received September 20, 2015)

1116-VA-1697 **Dong Kyu Kim*** (dongkyu0397@gmail.com), Daegu, 702-701, South Korea, and **Jung Wook Lim** (jwlim@knu.ac.kr), Daegu, 702-701, South Korea. *Ascending chain condition in composite Hurwitz rings.* Preliminary report.

Let $D_0 \subseteq D_1 \subseteq \cdots \subseteq D_n \subseteq \cdots$ be an ascending chain of commutative rings with identity. Then we define $\mathrm{h}(\mathcal{D}) = \{d_0 + d_1X + \cdots + d_nX^n \mid d_i \in D_i \text{ for all } i \in \mathbb{N}_0\}$ and $\mathrm{H}(\mathcal{D}) = \{d_0 + d_1X + \cdots + d_nX^n + \cdots \mid d_i \in D_i \text{ for all } i \in \mathbb{N}_0\}$. In this talk, we give equivalent conditions for $\mathrm{h}(\mathcal{D})$ and $\mathrm{H}(\mathcal{D})$ to be Noetherian, to satisfy ACCP, or to be atomic. (Received September 21, 2015)

1116-VA-1829 **Erica Shannon*** (erica.shannon@colorado.edu), University of Colorado Boulder, Department of Mathematics, Campus Box 395, Boulder, CO 80309-0395. *Invariant Forms on Minuscule Representations.* Preliminary report.

A minuscule representation of a simple Lie algebra over the complex numbers is an irreducible representation for which the Weyl group acts transitively on the weights. Minuscule representations are often equipped with invariant multilinear forms that are invariant under the action of the Lie algebra. These include symplectic or orthogonal bilinear forms, as well as an invariant cubic form on a 27-dimensional representation in type E_6, and a symmetric invariant quartic form on the 56-dimensional representation in type E_7. I will discuss how the combinatorial structure of the weights of a minuscule representation can be used to gain insight into these forms. (Received September 21, 2015)

1116-VA-1891 **David A Nash*** (nashd@lemoyne.edu), Le Moyne College, Department of Mathematics, Syracuse, NY 13214, and **Jonathan Needleman** (needlejs@lemoyne.edu), Le Moyne College, Department of Mathematics, Syracuse, NY 13214. *When are finite projective planes magic?*

This research studies a generalization of magic squares to finite projective planes. In traditional magic squares the entries come from the natural numbers. This does not work for finite projective planes, so we instead use Abelian groups. For each finite projective plane we demonstrate a small group over which the plane can labeled magically. In the prime order case we classify all groups over which the projective plane can be made magic. (Received September 21, 2015)

1116-VA-1899 **Bethany Turner***, bnturne2@ncsu.edu. *C-ideals, Cartan subalgebras, and the covering-avoidance property in Leibniz algebras.* Preliminary report.

Leibniz algebras are certain generalizations of Lie algebras. Many researchers are working on generalizing known results for Lie algebras to analogous results in Leibniz algebras. It is known that in a solvable Lie algebra, every Cartan subalgebra has the covering-avoidance property (CAP). The c-ideals of a Lie algebra have been related to both Cartan subalgebras and CAP-subalgebras. In this talk we introduce a definition of c-ideals for Leibniz algebras, extend some known results from the Lie algebra case, and describe the relationship between c-ideals, Cartan subalgebras, and CAP-subalgebras in a solvable Leibniz algebra. (Received September 21, 2015)

1116-VA-1933 **Furuzan Ozbek*** (fzo0005@auburn.edu), **Edgar Enochs** (e.enochs@uky.edu) and **Overtoun Jenda** (jendaov@auburn.edu). *Submonoids of the Formal Power Series.* Preliminary report.

Formal power series come up in several areas such as formal language theory , algebraic and enumerative combinatorics semigroup theory, number theory etc. With the intention of finding applications for undergraduate research workshop at MASAMU Advanced Study Institute, we have been working on the the subset $xR[[x]]$ consisting of formal power series with zero constant term. This subset forms a monoid with the composition operation of series. We classify the sets T of strictly positive integers for which the set of formal power series

$$R[[x^T]] = \{\sum_{t \in T} a_t x^t \mid where\ a_t \in R\}$$

forms a monoid with composition as the operation. We prove that in order for $R[[x^T]]$ to be a monoid, T itself has to be a submonoid of $(\mathbb{N}, \cdot)$. Unfortunately, this condition is not enough to guarantee the desired result. But if a monoid is *strongly closed*, then we get the desired result. We also consider an analogous problem for power series in several variables. (Received September 21, 2015)

1116-VA-2032 **Robert J Won*** (rwon@math.ucsd.edu). *The category of graded modules of a generalized Weyl algebra.* Preliminary report.

The first Weyl algebra $A = k\langle x, y\rangle/(xy - yx - 1)$ is $\mathbb{Z}$-graded with $\deg x = 1$ and $\deg y = -1$. Generalized Weyl algebras are a class of noncommutative $\mathbb{Z}$-graded rings introduced by Vladimir Bavula which generalize the Weyl algebra. In this talk, we investigate the category of graded modules over certain generalized Weyl algebras. We construct commutative rings with equivalent graded module categories and discuss quotient stacks related to these rings. (Received September 21, 2015)

1116-VA-2239 **Minjae Kwon*** (know1122@naver.com), Deagu, South Korea, and **Jung Wook Lim** (jwlim@knu.ac.kr), Daegu, South Korea. *On Nonnil-S-Noetherian rings.* Preliminary report.

A commutative ring R with identity is called Nonnil-S-Noetherian, where $S \subseteq R$ is a given multiplicative set, if for each nonnil ideal I of R, $sI \subseteq J \subseteq I$ for some $s\epsilon S$ and some finitely generated ideal J.

In this talk, we introduce the notion of Nonnil-S-Noetherian rings, and we study some properties. (Received September 22, 2015)

1116-VA-2371 **Jonathan E Lopez*** (lopez11@canisius.edu), 2001 Main Street, Buffalo, NY 14208. *The Lie Algebra Associated to the Filtration of $SL_n(R)$ by Congruence Subgroups.*

Let R be a commutative ring that is free of finite rank k as an abelian group, p a prime, and $SL_n(R)$ the special linear group. We show that the Lie algebra associated to the filtration of $SL_n(R)$ by p-congruence subgroups is isomorphic to the tensor product $\mathfrak{sl}_n(R \otimes_{\mathbb{Z}} \mathbb{Z}/p) \otimes_{\mathbb{F}_p} t\mathbb{F}_p[t]$, the Lie algebra of polynomials with zero constant term and coefficients $n \times n$ traceless matrices with entries polynomials in k variables over $\mathbb{F}_p$. (Received September 22, 2015)

1116-VA-2577 **Jenna Nicole Zomback** (jnz2@geneseo.edu), **Cameron Wright*** (wrightc@carleton.edu) and **Daniel Gonzalez**. *Monotone Catenary Degree In Numerical Monoids.*

Recent investigations on the catenary degrees of numerical monoids have demonstrated that this invariant is a powerful tool in understanding the factorization theory of this class of monoids. Although useful, the catenary degree is largely not sensitive to the lengths of factorizations of an element. In this talk, we study the monotone catenary degree of numerical monoids, which is a variant of catenary degree that requires chains run through factorization lengths monotonically. In general, the monotone catenary is greater than or equal to the catenary degree. We begin by providing an important class of monoids (arithmetical numerical monoids) for which monotone catenary degree is equal to the catenary degree. Conversely, we provide several classes of embedding dimension 3 numerical monoids where monotone catenary degree is strictly greater. We conclude by showing that this difference can grow arbitrarily large. (Received September 22, 2015)

1116-VA-2768 **Samuel Ivy*** (samuel.ivy@usma.edu), United States Military Academy, West Point, NY 10996-. *Classifying the Fine Structures of Involutions Acting on Root Systems.*

Symmetric spaces, as the name suggests, offers the study of symmetries. It can be realized as spaces acted upon by a group of symmetries or motions (a Lie Group). This exposition focuses on the algebraic and combinatorial structures of symmetric spaces including the action of involutions on the underline root systems. The characterization of the orbits of parabolic subgroups acting on these symmetric spaces involves the action of both the symmetric space involution θ on the maximal k-split tori and their root system and its opposite $-\theta$. While the action of θ is often known, the action of $-\theta$ is not well understood. This work focuses on building results and algorithms that enable one to derive the root system structure related to the action of $-\theta$ from the root system structure related to θ. This work involves algebraic group theory, combinatorics, and symbolic computation. (Received September 22, 2015)

1116-VA-2818 **Van C. Nguyen*** (v.nguyen@neu.edu), Northeastern University, and **Linhong Wang** and **Xingting Wang**. *Complete classification of connected prime-cube dimensional Hopf algebras.* Preliminary report.

For finite dimensional Hopf algebras, their classifications over $\mathbb{C}$ (e.g. in characteristic 0) has been investigated for decades with many fruitful results, but their structures in positive characteristic have remained elusive. We provide a complete classification of connected Hopf algebras of dimension p^3 over an algebraically closed field k of prime characteristic $p > 0$. Many new Hopf algebra examples arise from our classification results. (Received September 22, 2015)

1116-VA-2882 **Alfonso E Heras-Llanos*** (aheras@unm.edu). *Arithmetic Differential Subgroups of Gl_n.*
A remarkable and special Galois Theory appears from the study of arithmetic analogue of ordinary differential equations; where functions are replaced by integers, the derivative operator replaced by the "Fermat quotient operator" and differential equations are replaced by arithmetic differential equations. The main result of this presentation will be the study of a very special class of arithmetic subgroup of Gl_n. These subgroups are arithmetic analogues of the differential algebraic groups of E.R. Kolchin and P. Casidy. As a by-product, we found more analogies between the ordinary differential operator and the Fermat Quotient Operator, such as the chain rule and the product rule. We will also introduce a set of functions, that we call Leibniz Systems. These functions "generate" some examples of the differential subgroups of Gl_n. (Received September 22, 2015)

1116-VA-2909 **Andrew Penland*** (adpenland@email.wcu.edu), NC. *Finitely Constrained Groups Having Almost Maximal Hausdorff Dimension.*
Finitely constrained groups are profinite groups of tree automorphisms defined by finite combinatorial patterns coming from finite group actions. We present some new families of topologically finitely generated, finitely constrained groups defined by patterns of size d and having Hausdorff dimension $1-2/2^{d-1}$ (which is the largest possible value for such a group). (Received September 23, 2015)

1116-VA-2935 **Austin H Jones*** (ahjones3@ncsu.edu). *The lattice of ideals of a nilpotent Leibniz algebra.*
Let L be a nilpotent Leibniz algebra over a field of characteristic zero. The lattice of ideals of L (ordered by ideal sum and intersection), $\mathcal{I}(L)$, preserves and encodes some but not all of the structure of L. We examine what $\mathcal{I}(L)$ determines about L as well as what can be said about a nilpotent Leibniz algebra and a non-nilpotent Leibniz algebra whose ideal lattices are isomorphic. Some properties of the structures of both the non-nilpotent and the nilpotent Leibniz algebra are determined. Our work follows the path laid out in the Lie algebra case, with mostly minor adjustments. (Received September 23, 2015)

General Session on Analysis

1116-VB-541 **Soumyadip Acharyya***, 1103 14th Street, Apt 26A, Tuscaloosa, AL 35401, and **Zhijian Wu**. *Hilbert-Schmidtness of difference of two weighted composition operators - A survey.*
Let φ be an analytic self-map of the open unit disc $\mathbb{D}$ and u be a measurable (**not necessarily analytic**) complex-valued function on $\mathbb{D}$. The linear map uC_φ on $H(\mathbb{D})$ defined by

$$(uC_\varphi)(f)(z) = u(z)(f\circ\varphi)(z), \forall f \in H(\mathbb{D}), \forall z \in \mathbb{D},$$

is called the weighted composition operator with weight u and symbol φ. For $\alpha > -1$, the weighted Bergman Space A^2_α consists of all analytic functions in $L^2(\mathbb{D}, dA_\alpha)$.

We study the difference of two weighted composition operators $uC_\varphi - vC_\psi$. We are particularly interested on characterizing the Hilbert-Schmidtness of that operator acting on A^2_α. In general, when u and v are both arbitrary analytic functions, the problem seems to be challenging. The special case of $u = 1$ and $v = 1$ (the unweighted case) has been solved by Choe, Hosokawa and Koo in 2010. We will briefly discuss an alternative proof of their result. Then we will discuss various different cases where u and v are of some specific forms. (Received September 06, 2015)

1116-VB-797 **Laura Dawn Croyle*** (lauradcroyle@gmail.com), 4161 Victoria Way, Apt 18105, Lexington, KY 40515. *L^p solutions to the mixed boundary value problem in C^2 domains.*
We look at the mixed boundary value problem for the Laplacian in a bounded $C^2(\mathbf{R}^n)$ domain, given by

$$\begin{cases} -\triangle u &= 0 & \text{in } \Omega \\ u &= 0 & \text{on } D \\ \frac{\partial u}{\partial \nu} &= g & \text{on } N \end{cases} \tag{MP}$$

Here, we have a Lipschitz dissection of the boundary given by disjoint sets, N and D, with Neumann and Dirichlet data respectively. Expanding on work done by Ott and Brown, we find a larger range of values of p, $1 < p < \frac{n}{n-1}$, for which the L^p mixed problem has a unique solution with the non-tangential maximal function of the gradient in $L^p(\partial\Omega)$. (Received September 13, 2015)

1116-VB-809 **Anna Tarasenko*** (anataras@uaeh.edu.mx), Institute of Basic Sciences and Engineering, Mathematical Research Center, Carretera Pachuca-Tulancingo, Km.4.5, 42184 Pachuca, Hidalgo, Mexico, and **Oleksandr Karelin** (karelin@uaeh.edu.mx), Institute of Basic Sciences and Engineering, Engineering Research Center, Carretera Pachuca-Tulancingo, Km.4.5, 42184 Pachuca, Hidalgo, Mexico. *On Inequalities between Norms in Weighted Hölder and Lebesgue Spaces for Operators with Endpoint Singularities.*

The norms in the Hölder spaces with weight and in the Lebesgue spaces with weight are different in their character and the presence of a direct connection between the norms of these spaces should not be expected. However, in this work, a special class of operators was found, for which we obtained an inequality that connects the norms in weighted Lebesgue spaces and the norms in weighted Hölder spaces for this class of operators. A description of such operators and a relation among parameters of these spaces are given. Integral operators with local endpoint singularities belong to the considered class. These results can be used in the study of operators in weighted Hölder spaces, on the basis of known results for operators in weighted Lebesgue spaces. (Received September 14, 2015)

1116-VB-977 **Waleed Al-Rawashdeh*** (walrawashdeh@mtech.edu), Montana Tech, 1300 West Park Street, Butte, MT 59701. *Composition Operators on Generalized Weighted Nevanlinna Class.*

Let φ be an analytic self-map of open unit disk $\mathbb{D}$. The operator given by $(C_\varphi f)(z) = f(\varphi(z))$, for $z \in \mathbb{D}$ and f analytic on $\mathbb{D}$ is called a composition operator. Let ω be a weight function such that $\omega \in L^1(\mathbb{D}, dA)$, where dA denotes the normalized area measure on $\mathbb{D}$. The generalized weighted Nevanlinna class $\mathcal{N}_\omega$ is the space of all analytic functions belong to $L_{\log^+}(\mathbb{D}, \omega dA)$. In this talk we investigate the boundedness, compactness and the essential norm of these composition operators on the space $\mathcal{N}_\omega$. (Received September 15, 2015)

1116-VB-987 **Spencer N. Tofts*** (spencertofts@gmail.com) and **Robert Strain**. *On the Existence of Solutions to the Muskat Problem with Surface Tension.*

We consider the Muskat Problem with surface tension in two dimensions over the real line, with H^s initial data and allowing the two fluids to have different densities and viscosities. We take the angle θ between the interface and the horizontal, and derive an evolution equation for it. In the periodic case, Ambrose used energy methods to prove local existence for θ. We extend his methods to the real line, obtaining an energy estimate and proving that a solution θ exists locally and can be continued while $||\theta||_s$ remains bounded and the arc chord condition holds. Furthermore, when the viscosity is constant and the initial data is sufficiently small, we show the energy is non-increasing, and that the solution θ exists globally in time. (Received September 15, 2015)

1116-VB-1005 **George R. Exner** (exner@bucknell.edu), Lewisburg, PA, **Joo Young Jin*** (pss9611@knu.ac.kr), Daegu, South Korea, and **Il Bong Jung** (ibjung@knu.ac.kr), Daegu, South Korea. *On Hamburger-type weighted shifts.* Preliminary report.

Let $\alpha = \{\alpha_n\}_{n=0}^{\infty}$ be a sequence of positive real numbers and let W_α be an associated weighted shift with weight sequence α. Define $\gamma_n := \alpha_0^2 \cdots \alpha_{n-1}^2$ $(n \geq 1)$ with $\gamma_0 = 1$. It is known that the positivity of both of the infinite matrices $(\gamma_{i+j})_{0 \leq i,j < \infty}$ and $(\gamma_{i+j+1})_{0 \leq i,j < \infty}$ is an equivalent condition for subnormality of W_α. The positivity of $(\gamma_{i+j})_{0 \leq i,j < \infty}$ is closely related to the Hamburger moment sequence. For $n \in \mathbb{N} \cup \{\infty\}$, the positivity of $(\gamma_{i+j})_{0 \leq i,j < n}$ induces a new property $H(n)$ of W_α. We discuss some flatness properties, completion problem and Aluthge transforms of W_α with property $H(n)$. In addition, we give a formula of property $H(n)$ in some examples W_α. (Received September 15, 2015)

1116-VB-1089 **Colleen Ackermann*** (ackrmnn2@illinois.edu), **Peter Haïssinsky** and **Aimo Hinkkanen**. *Quasiconformal Mappings and Equilateral Triangles.*

Quasiconformal mappings, first discovered nearly a century ago, have found many applications in various fields including PDE's, complex dynamics, and Teichmüller theory. The diversity of applications of quasiconformal mappings may be due to their many different characterizations. I will discuss a new sufficient condition for quasiconformality which depends only on the relative distances between the images of the vertices of equilateral triangles. (Received September 16, 2015)

1116-VB-1091 **Austin Scirratt*** (ascirr1@lsu.edu), **Ladorian Latin** and **Frank Neubrander**. *Evolution Semigroups for Well-Posed, Non-Autonomous Evolution Families.* Preliminary report.

We characterize the existence of strongly continuous evolution families $U(t,s)$ in Banach spaces associated with linear initial value problems $u'(t) = A(t)u(t)$, $u(s) = x$, in terms of evolution semigroups $T(t)f(s) = f(t+s)U(t+s,s)$ and their generators $Af(s) = f'(s) + f(s)A(s)$. This is joint work with Ladorian Latin and

Frank Neubrander and is based on previous work by Balint Farkas and Franziska Kuehnemund on bi-continouous semigroups. (Received September 16, 2015)

1116-VB-1483 **Daniele Garrisi*** (daniele.garrisi@gmail.com), Inha University, Inha-ro 100, College of Mathematics Education 5W443, 402751, Incheon. *Orbital stability of standing-wave solutions to the non-linear Schroedinger equation in dimension one.* Preliminary report.

The orbital stability of standing-wave solutions to the non-linear Schrödinger equation

$$i\partial_t\varphi(t,x) + \Delta\varphi(t,x) + |\varphi(t,x)|^{p-2}\varphi(t,x) = 0$$

relies on the Concentration-Compactness Theorem of P. L. Lions and the fact that there is only one positive, symmetric minimum to the energy functional

$$E(u) = \frac{1}{2}\int_{\mathbb{R}^n} |\nabla u(x)|^2 dx - \frac{1}{p}\int_{\mathbb{R}^n} |u(x)|^p dx$$

on the constraint

$$S = \{u \in H^1(\mathbb{R})^n \mid \|u\|_{L^2} = 1\}.$$

When more general non-linearities are considered, it is not clear whether this uniqueness features still holds. We illustrate how it is possible obtain orbital stability results in cases where no a-priori assumption can be made on the uniqueness of minima of the variational problem we considered. (Received September 20, 2015)

1116-VB-1609 **Ioana Ghenciu*** (ioana.ghenciu@uwrf.edu). *Property (wL) and the Reciprocal Dunford-Pettis Property in projective tensor products.*

A Banach space X has the reciprocal Dunford-Pettis property ($RDPP$) if every completely continuous operator T from X to any Banach space Y is weakly compact. A Banach space X has the $RDPP$ (resp. property (wL)) if every L-subset of X^* is relatively weakly compact (resp. weakly precompact). We prove that the projective tensor product $X \otimes_\pi Y$ has property (wL) when X has the $RDPP$, Y has property (wL), and $L(X,Y^*) = K(X,Y^*)$. (Received September 22, 2015)

1116-VB-1613 **Leonardo Pinheiro***, lpinheiro@ric.edu, and **Gokul Kadel** and **Kit Chan**. *Simple connectivity and the chaotic behavior of operators on a space of harmonic functions.*

We show that for a finitely connected region on the complex plane, the chaotic behavior of certain continuous linear operators on a space of complex valued harmonic functions is equivalent to the simple connectivity of the region. (Received September 20, 2015)

1116-VB-1708 **Gokul R Kadel*** (gkadel@cameron.edu), Cameron University, Lawton, Oklahoma. *Chaotic Differentiation Operators and Simple Connectivity.*

We characterize the simple connectivity of a planar region in terms of the dynamics of differentiation operators on the space of complex-valued harmonic functions on the region. (Received September 21, 2015)

1116-VB-1793 **Michael C. Fulkerson*** (mfulkerson@uco.edu), 100 N University Dr, Box 129, Edmond, OK 73034. *A radial uniqueness theorem in higher dimensions.* Preliminary report.

We extend to higher dimensions a theorem of Lusin and Privalov concerning radial limit zero sets of holomorphic functions on the unit disc. We show that, in contrast to the case in dimension one, the converse fails for holomorphic functions on the unit ball in higher dimensions. Finally, we show that in higher dimensions any characterization of the radial limit zero sets of holomorphic functions on the ball must take into account the complex structure on the sphere. (Received September 21, 2015)

1116-VB-2045 **C. P. Money*** (chad.money@louisville.edu), 328 Natural Sciences Building, University of Louisville, Louisville, KY 40292. *Chaos in a Wider Context.* Preliminary report.

Chaos in a Wider Context

Chad Money, University of Louisville

Though originally formulated for cascades, Devaney chaos can be defined in the context of an arbitrary semiflow (where T is any monoid, X any metric space). We will examine some of the topological consequences of that definition, including some very powerful theorems when T is abelian and some introductory results when T is not. (Received September 21, 2015)

1116-VB-2343 **Yevgeniy Kostrov*** (ykostrov@xula.edu), 1329 saint andrew st apt 2, New Orleans, LA 70130, and **Zachary Kudlak**. *On a First Order Rational System of Difference Equations with Non-Constant Coefficients.*

We investigate the boundedness character of nonnegative solutions of the following nonautonomous rational system

$$\begin{cases} x_{n+1} = \frac{\alpha_n}{\beta_n x_n + y_n} \\ \\ y_{n+1} = \frac{a_n + b_n x_n + c_n y_n}{A_n + B_n x_n + C_n y_n} \end{cases} \quad \text{for } n = 0, 1, \ldots$$

with coefficients that are nonnegative sequences and initial conditions which are nonnegative real numbers, such that the denominators are always positive. We present several theorems which establish the limiting behaviors of special cases of the system when the coefficients are periodic, or bounded above and below by positive constants. (Received September 22, 2015)

1116-VB-2622 **Yevgeniy Kostrov** and **Zachary Kudlak*** (zkudlak@monmouth.edu), Department of Mathematics, Monmouth University, 400 Cedar Ave, West Long Branch, NJ 07764. *On a Second-Order Rational Recurrence Relation with Quadratic Terms.* Preliminary report.

We give the character of solutions of the following second-order rational difference equation with quadratic denominator

$$x_{n+1} = \frac{\alpha + \gamma x_{n-1}}{B x_n + D x_n x_{n-1} + x_{n-1}} \quad \text{for } n = 0, 1, \ldots$$

where the coefficients are positive real numbers, and the initial conditions x_{-1} and x_0 are nonnegative real numbers such that the denominator is nonzero. In particular, we show that there is a unique positive equilibrium, which is stable in some range of the parameters, and for which every solution converges to a unique period-two solution in another. (Received September 22, 2015)

1116-VB-2661 **Michael Benfield*** (mike.benfield@gmail.com). *Geometry of hyperbolic conservation laws.*

The shock and rarefaction curves of a system of hyperbolic conservation laws have an interesting geometric structure. Several questions present themselves: Can we produce conservation laws given prescribed rarefaction curves? The shock curves for a system determine the rarefaction curves – is the converse also true? We investigate these and other questions about the geometry of hyperbolic conservation laws. (Received September 22, 2015)

1116-VB-2717 **Nathan Pennington***, nathanpennington@creighton.edu. *Low regularity local and global solutions of the generalized Magneto-Hydrodynamics equations.*

In this paper, we prove the existence of a unique global solution to the incompressible MHD-α system with fractional diffusion. Letting γ_1 and γ_2 be the regularity of the diffusion terms, we obtain global existence when γ_1 and γ_2 satisfy $\gamma_1, \gamma_2 > 1$, $\gamma_1 \geq n/3$, and $\gamma_1 + \gamma_2 \geq n$ in $\mathbb{R}^n$ for $n \geq 3$. (Received September 22, 2015)

1116-VB-2760 **Swarup N Ghosh*** (swarup.ghosh@swosu.edu) and **Alexander J Izzo**. *A hull with no nontrivial Gleason parts.* Preliminary report.

Suppose X is a compact subset of the n-dimensional complex Euclidean space $\mathbb{C}^n$ with polynomial convex hull $\hat{X}$. It was once conjectured that if $\hat{X}$ is strictly larger than X, then the set $\hat{X} \setminus X$ must contain some analytic structure. However, Stolzenberg gave a counterexample to the conjecture by constructing a compact subset X of $\mathbb{C}^2$ with hull (that is, $\hat{X} \setminus X$ is nonempty) such that $\hat{X} \setminus X$ contains no analytic disc. In this talk we will give a stronger counterexample to the conjecture. We will construct a compact subset X of $\mathbb{C}^3$ with hull such that $\hat{X} \setminus X$ contains no nontrivial Gleason part and does not support any nonzero bounded point derivation. (Received September 22, 2015)

1116-VB-2806 **Joseph P Previte*** (jpp4@psu.edu), School of Science, 4205 College Drive, Erie, PA 16563. *The Beautiful Dynamics of $f(z) = i^z$.*

In this talk, we will explore the dynamics obtained by iterating the complex function $f(z) = i^z$, where the principal branch is used. We explore the basin of attraction of the stable fixed point $i^{(i^{(i^{\cdots})})}$. We will also show that are periodic orbits of all periods as well as orbits that tend to infinity. (Received September 22, 2015)

1116-VB-2807 **Gonzalo Bley*** (gb3kd@virginia.edu) and **Lawrence Thomas**. *Estimates on Functional Integrals of Quantum Mechanics and Non-Relativistic Quantum Field Theory.*

We provide a unified method for obtaining upper bounds for certain functional integrals appearing in quantum mechanics and non-relativistic quantum field theory, functionals of the form $E\left[\exp(A_T)\right]$, the (effective) action

A_T being a function of particle trajectories up to time T. The estimates in turn yield rigorous lower bounds for ground-state energies, via the Feynman-Kac formula. The upper bounds are obtained by writing the action for these functional integrals in terms of stochastic integrals. The method is illustrated in familiar quantum mechanical settings: first, for the hydrogen atom, where the result is sharp in the large T limit, and second, for the harmonic oscillator, even with time-dependent coupling, where we recover Cameron and Martin's computation of the functional integral for quadratic interactions. Finally, we illustrate the method as it applies to the optical multi-polaron model and to regularized massive and massless Nelson models, giving a priori lower bounds on their ground state energies. (Received September 22, 2015)

1116-VB-2821 **Bernd Sing*** (bernd.sing@cavehill.uwi.edu), Department of Mathematics, The University of the West Indies, Cave Hill, P.O. Box 64, Bridgetown, BB11000, Barbados.
Kempner series, their associated power series and logarithmic means. Preliminary report.

A *Kempner series*, also known as *depleted harmonic series*, is formed by omitting all terms in the harmonic series whose denominator expressed in base 10 contain a certain digit (or string of digits). E.g., the series

$$K_1 = \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5} + \frac{1}{6} + \frac{1}{7} + \frac{1}{8} + \frac{1}{9} + \frac{1}{20} + \frac{1}{22} + \frac{1}{23} + \dots,$$

is the Kempner series that omits the digit '1'; this series is convergent with $K_1 \approx 16.17696$. We consider the properties of the associated power series

$$\frac{1}{2}z + \frac{1}{3}z^2 + \frac{1}{4}z^3 + \frac{1}{5}z^4 + \frac{1}{6}z^5 + \frac{1}{7}z^6 + \frac{1}{8}z^7 + \frac{1}{9}z^8 + \frac{1}{20}z^{19} + \frac{1}{22}z^{21} + \frac{1}{23}z^{22} + \dots.$$

This power series has radius of convergence $R = 1$, and while it is bounded on the unit circle, the unit circle is its natural boundary by Fabry's lacunarity condition. Such power series arise in the study of the logarithmic method, an Abel-type summability method. Here, we contrast and compare the power series we obtain for different Kemper series. (Received September 22, 2015)

1116-VB-2873 **Tucker Hartland**, **Petronela Radu** and **Ravi Shankar*** (rshankar@mail.csuchico.edu). *Some results on nonlocal nonlinear diffusion equations.*

We consider a class of nonlocal nonlinear diffusion equations (NNDEs). We present several new qualitative results for nonlocal Dirichlet problems on bounded domains. It is shown that solutions with positive initial data remain positive through time, even for nonlinear problems; in addition, we prove that solutions to these equations obey a strong maximum principle. A striking result shows that nonlocal solutions must have some irregularity at the boundary; otherwise, we have ill-posedness of the initial value problem. (Received September 22, 2015)

1116-VB-2947 **James Cockreham***, jcockreham@uidaho.edu, and **Fuchang Gao**, fuchang@uidaho.edu.
The Metric Entropy of the Space of Separately Convex Functions. Preliminary report.

The ε-metric entropy of a precompact set A in a metric space is the logarithm of the minimum covering number of A by balls of radius ε. In this paper we investigate the metric entropy of the class $\mathcal{F}^d$ of *separately convex functions* on $[0,1]^d$, that is, the class of multivariate functions on $[0,1]^d$ which are convex in each variable while the others are held fixed. In particular, under some mild assumptions we obtain a sharp estimate on the upper bound of the metric entropy of $\mathcal{F}^d$. We extend our result further to the class $\mathcal{F}^d_g$ of functions which are separately convex upon precomposition with an appropriate, given function g. (Received September 23, 2015)

General Session on Applied Mathematics

1116-VC-246 **Kyle L. Golenbiewski***, kyle@math.utk.edu, and **Tim P. Schulze**. *A Kinetic Monte Carlo model for grain boundary migration driven by curvature.* Preliminary report.

The mechanism and dynamics of grain boundary migration has gained considerable attention in the past decade. In this time, continuum models such as phase-field and level set models have become increasingly attractive in terms of their application to grain growth. Furthermore, significant progress has been made from an atomistic approach via molecular-dynamics (MD) models. While MD simulations have been shown to capture many important details of the microscopic dynamics of grain boundary migration, their limitations lend to their inability to accurately capture rates of shrinkage. We propose a Kinetic Monte Carlo (KMC) model that is shown not only to capture many of the same dynamical features, but that also accurately captures the timescale over which the process takes place. Comparisons with MD simulations are discussed, as well as the future goal of this project. (Received August 17, 2015)

1116-VC-347 **J. N. Ndam*** (ndamj@unijos.edu.ng), Dept of Mathematics, University of Jos, PMB 2084, Jos, Nigeria, and **S. Dung**. *A Mathematical Model for the Propagation of an Animal Species on a Plain.*

A mathematical model for the dynamics of an animal species propagating on a plain is constructed. Travelling wave solutions are then sought for two cases, the case with constant diffusion coefficient and that with density-dependent diffusion coefficient. The results show the existence of travelling wave solutions in both cases. The minimum wave speeds as well as the basins of attraction were determined. (Received August 26, 2015)

1116-VC-356 **Jangwoon Lee*** (llee3@umw.edu), University of Mary Washington, and **Hyung-Chun Lee**, Ajou University. *Exponential convergence for stochastic optimal control problems.*

We analyze the hxp version of the finite element method for optimal control problems constrained by elliptic partial differential equations with random inputs. The main result is that the hxp error bound for the control problems subject to stochastic partial differential equations leads to an exponential rate of convergence with respect to p as for the corresponding direct problems. Numerical examples are used to confirm the theoretical results. (Received August 27, 2015)

1116-VC-477 **Pengcheng Xiao*** (px3@evansville.edu), 1800 Lincoln Ave, Department of Mathematics, Evansville, IN 47722, and **Jianzhong Su**. *A Computational Model for PTSD and Cognitive Function.* Preliminary report.

In this paper we study computationally a mathematical model of people with PTSD. It is known that people with PTSD will lead to abnormal levels of hormonal secretion, especially glucocorticoids. As a consequence, the neuronal electric activities also change due to variations in synaptic receptors regualted by hormone levels. We measure the hippocampal plasticity variability computationally through the synaptic spike timing-dependent plasticity characterized in spine's calcium current in the neuronal system, and the results provide the evidence of long term potentiation changes in a Hippocampus model due to PTSD. (Received September 03, 2015)

1116-VC-478 **Nicholas C. Jacob*** (njacob@ecok.edu). *Reynolds' Space Average.*

A velocity, $u(x,t)$, solving incompressible Navier-Stokes cannot be the full velocity at x and t due to dissipation. Reynolds claims $u(x,t)$ is a space average. Taking the limit of Hamiltonian equations of motion with assumptions on standard physical quantities leads to a measure. This measure and disintegration will be used to construct an abstract Reynolds' average which is indeed a space average in the natural sense providing a further justification for space averages. (Received September 03, 2015)

1116-VC-546 **Wei Cui*** (wcui@crimson.ua.edu) and **Zhijian Wu** (zhijian.wu@unlv.edu). *Fractional Brownian Motion and Managing Risk in Long-Term Hedging with Short-term Futures Contracts.*

Under the constraint of terminal risk, we search for an optimal strategy to reduce the running risk in hedging a long-term commitment with short-term futures contracts. We will prove that the existence of the solution to this optimization problem if the market price of the underlying commodities follows a simple differential equation $dS_t = \mu dt + \sigma dB_t^H$, where B_t^H is a fractional Brownian motion with Hurst index $H \in (\frac{1}{2}, 1)$. (Received September 06, 2015)

1116-VC-563 **Roby R Poteau*** (rpoteau2010@my.fit.edu) and **Ugur G Abdulla** (abdulla@fit.edu). *Identification of Parameters in Mathematical Biology.* Preliminary report.

We consider inverse problems for the identification of both constant and functional parameters for systems of nonlinear ODEs arising in mathematical biology. We implement a numerical method suggested in U.G.Abdulla, Journal of Optimization Theory and Applications, 85, 3(1995), 509-526(Part I); 527-543(Part 2). The idea of the method is based on the combination of Bellman's quasilinearization with sensitivity analysis in Banach spaces setting and Tikhonov's regularization. We apply the method to various biological models such as Lotka-Volterra system, bistable switch model in genetic regulatory networks, a three-step pathway modelled by 8 nonlinear ordinary differential equations, etc. Then we test the robustness of the method in the presence of random noise. Numerical results confirm the quadratic convergence. (Received September 19, 2015)

1116-VC-633 **Aleksandr Smirnov*** (asmirn1@tigers.lsu.edu), 4110 Janet Ave, Apt 2, Baton Rouge, LA 70808. *Applications of the partial Wiener-Hopf factorization in Dynamic Fracture Machanics.*

The Wiener–Hopf technique is a powerful tool for constructing analytic solutions for a wide range of problems in physics and engineering. The key step in its application is factorization of a kernel into a product of two functions (matrices) which have different regions of analyticity. However, a closed-form factorization is known

to be constructed only for a small class of the Chebotarev–Khrapkov matrices. In the talk, the technique of the partial Wiener–Hopf factorization is presented, that helps to overcome difficulties of the Wiener–Hopf matrix factorization, while combining advantages of analytic closed-form solutions in dealing with singularities and wide applicability of numerical methods. Their applications to the problems of Dynamic Fracture Mechanics are discussed. (Received September 09, 2015)

1116-VC-654 **Ayush L Joshi*** (ayush.lal.joshi@gmail.com), **Gokul R Kadel** and **Narayan Thapa**, Cameron University, Lawton, Oklahoma. *Comparison of Numerical Solutions of Black-Scholes Option Pricing Model.*

Minimizing financial risk is a prime concern among individuals and business in a rapidly changing and the fastest growing areas in the corporate business world. Thus, mathematical models are essential to implement and price financial instruments. In this interdisciplinary project, we apply a number of numerical techniques to Black-Scholes Option Pricing Model to predict price of option over time. In addition to this, we investigate on (1) Accuracy of methods in estimating price of options over time; (2) Reliability and consistency of methods in estimating price of options over time; and (3) Stability and overall cost effectiveness of methods in estimating price of options over time. (Received September 10, 2015)

1116-VC-655 **Brandon S Payne*** (brandon.payne@cameron.edu) and **James R Dover**, Cameron University, Lawton, OK. *Maximizing Guaranteed Value in a Fair Division of a Cake under Piecewise-Linear Valuations.*

A 3-flavored cake is to be cut into three pieces to be divided among three people having different preferences. A division is fair if each person receives a portion they consider to be worth at least $\frac{1}{3}$ of the cake's total value. A fair division always exists, but due to the different preferences, it may be possible to give each person a higher value than $\frac{1}{3}$. We determine, based on a given set of piecewise-linear preferences, the highest level of value that can be guaranteed to the three people. (Received September 10, 2015)

1116-VC-802 **Narayan Thapa*** (nthapa@cameron.edu), Cameron University, Lawton, OK. *Optimal Parameters in Option Pricing Model.*

In this work, we study parameters associated with option pricing model. Existence, uniqueness, and continuous dependence of solution of the model are established. The necessary conditions for the optimal set of parameters by minimizing the objective functional are established. (Received September 13, 2015)

1116-VC-997 **Ellie Mainou*** (emainou@smith.edu), Box 7221, 1 Chapin Way, Northampton, MA 01063, **Chenyue Lu** (lu23c@mtholyoke.edu), Mount Holyoke College, 50 College Street, South Hadley, MA 01075, and **Olivia Justynski** (justy22o@mtholyoke.edu), South Hadley, MA 01075. *Tuberculosis(TB) Disease Modeling in the US.*

Tuberculosis (TB) is a disease of great global epidemiological importance. According to WHO, one third of the world's population has latent TB. Not only is TB prevalence high, but the future of TB management will also have to face the additional challenge of drug resistance. Strains resistant to the most common first-line drugs for TB treatment are already widespread. We constructed a compartmental mathematical model of TB in the US that encompasses four strains of differing resistance to treatment. This model also takes into account the effect of immigration, which contributes to the prevalence of latent TB in the US. We are currently fitting parameters to recent CDC data on TB morbidity and mortality. Our goal is to use this model to predict the future impact of drug-resistant TB on the US and the most effective means of TB control. (Received September 20, 2015)

1116-VC-1033 **Lluis Antoni Jimenez Rugama*** (ljimene1@hawk.iit.edu), E1, Office 120, 10 W 32 St, Chicago, IL 6061. *Applications of Adaptive Guaranteed Cubatures.*

In recent years we have developed adaptive quasi-Monte Carlo (qMC) cubature algorithms that meet the error tolerance prescribed by the user. These algorithms have been implemented in MATLAB http://gailgithub.github.io/GAIL_Dev/, and they are guaranteed for integrands whose behavior is not too erratic.

This talk presents several applications of these adaptive qMC algorithms, including option pricing, multivariate normal probability, and Sobol indices. These examples illustrate how our algorithms need little a priori information, and we also discuss how they can work with other efficiency enhancing methods such as control variates. (Received September 16, 2015)

1116-VC-1159 **Timothy E Robertson*** (robertsont@andrews.edu), 10623 Red Bud Trail, Berrien Springs, MI 49103, and **Joon H. Kang** (kang@andrews.edu). *Conditions for positive solutions to the general elliptic model.*

We investigate mathematical conditions to guarantee the existence and uniqueness of positive solutions to a general elliptic mathematical model. This result generalizes the existence and uniqueness of positive steady state solutions to a Lotka-Volterra competition model with homogeneous boundary conditions for two species of animals competing in the same environment. Under what conditions do they coexist peacefully? It is natural to say that they can coexist peacefully if their reproduction rates and self-limitation rates are relatively larger than those of competition rates. In other words, they can survive if they interacts strongly among themselves and weakly with others. (Received September 22, 2015)

1116-VC-1290 **Alrazi M Abdeljabbar*** (aabdeljabbar@pi.ac.ae), The Petroleum Institute, P.O Box 2533, AbuDhabi, United Arab Emirates. *Applications of the Pfaffain technique to (3+1)-dimensional soliton equations of KP type.*

Based on Hirota bilinearization method, the Pfaffain technique is employed to construct an explicit exact solutions to 3+1- dimensional nonlinear partial differential equations of KP type with variable coefficients. Pfaffainization procedure will also be applied to extend such equations to a new coupled systems. (Received September 18, 2015)

1116-VC-1466 **Caitlin R. Lienkaemper*** (clienkaemper@hmc.edu). *Obstructions to Convexity in Neural Codes.*

How does the brain encode the spatial structure of the external world? One way is through hippocampal neurons called place cells, which become associated to convex regions of space known as their receptive fields: each place cell fires at a high rate precisely when the animal is in the receptive field. The firing patterns of multiple place cells form what is known as a convex neural code. How can we tell when a neural code is convex? To address this question, Giusti and Itskov identified a local obstruction, defined via the topology of a code's simplicial complex, and proved that convex neural codes have no local obstructions. Curto et al. proved the converse for all neural codes on at most four neurons. Via a counterexample on five neurons, we show that this converse is false in general. Additionally, we describe our work in classifying neural codes on five neurons, supported by our enumeration of connected simplicial complexes on five vertices. Finally, we discuss the relationship between convex sets and good covers. (Received September 20, 2015)

1116-VC-1564 **Ghanshyam Bhatt*** (gbhatt@tnstate.edu), 4409 Kirkbrook ct, Nashville, TN 37221. *Mathematics and Compressed Sensing.* Preliminary report.

The signals, images and other data live in a Hilbert space. This space is equipped with several useful basis needed for applications. Frames generalize the same concepts except they are redundant but there is flexibility in construction. The compressed sensing uses basis, frame and optimizing tools to recover the signal from a fewer measurements of the signal. We study a mathematical formulation of the problem and possible solutions. Some challenging problems are presented. (Received September 20, 2015)

1116-VC-1579 **Owen Michael Richfield*** (orichfie@tulane.edu), #5342, 31 McAlister Dr., New Orleans, LA 70118, and **Paul Cripe** (pcripe@tulane.edu) and **Julie Simons**. *Sperm pairing and measures of efficiency in planar swimming models.*

In order to fertilize the egg, sperm of certain species engage in cooperative swimming behaviors. These cooperative motility patterns result in differences in velocity and efficiency of swimming. In order to understand the empirical effects on the swimming of sperm as a result of various cooperative swimming behaviors, we employ a simple preferred curvature model for a single-flagellum or multi-flagellum system. Flagella are simulated using a two-dimensional mass-spring model, and regularized Stokeslets are employed to simulate the viscous environment these flagella swim through. (Received September 20, 2015)

1116-VC-1598 **Hieu Q Nguyen*** (nguyen084@connect.wcsu.edu), 23 Scuppo Rd, Unit 5-1, Danbury, CT 06811, and **Xiaodi Wang**, 181 White St, Danbury, CT 06810. *Pseudo Color Barcode based on Pseudo Quantum Signal in M-band Wavelet Domain.* Preliminary report.

In the modern digital era, data security has become essential. Whether this data is from a government, a large corporation, or a citizen, the right of privacy should be protected. Recent advancements in Mathematical Cryptography theorems continue to allow the protection of privacy information among all users of the internet. The following research, we applied the Pseudo-Quantum Signal and M-Band Wavelet Transformation to form a Pseudo-3D color barcode that can hold a large size of information. We digitalized the messages to create 3 or more different matrices that represent different colors. We then embedded other digitalized messages into the approximation portion of the wavelet transform of each different matrices.This pseudo color barcode contains 6 or more different pieces of information. Assured by Heisenberg's uncertainty principle and the no-cloning theorem this encryption method will make the data incredibly difficult to decode without codebooks. (Received September 22, 2015)

1116-VC-1600 **Jason Karl Davis*** (jdavis8@ucmerced.edu) and **Suzanne S Sindi** (ssindi@ucmerced.edu). *Better Initial Conditions for Homogeneous Self-Assembly Problems.*

We study homogeneous self-assembly problems from a stochastic framework using the chemical master equation. Applications range from droplet formation to protein polymer assembly. Most treatments of this problem utilize an "all-monomer" initial condition, where all of the system's mass is initially in size 1 particles. However, this is not appropriate for *in vivo* models, or even many *in vitro* models, where the system has existed for some time (allowing the assembly dynamics to evolve the system state for an indeterminate period of time). We propose a class of "least-informed" initial conditions, explicitly give their forms for constant-rate Becker-Döring and Smoluchowski models of assembly, and demonstrate that this choice can realize many orders of magnitude of differences between statistics of interest, such as nucleation time. (Received September 20, 2015)

1116-VC-1657 **Emese Kennedy*** (ekennedy@muhlenberg.edu). *A Modified Energy Based Swing-up Controller for an Inverted Pendulum on a Cart.*

The single inverted pendulum (SIP) system is a classic example of a nonlinear under-actuated system. Despite its simple structure, it is among the most difficult systems to control and is considered as one of the most popular benchmarks of nonlinear control theory. The most common and efficient method for the swing-up of the pendulum uses an energy based approach that was originally proposed in 1996 by Astrom and Furuta for the swing-up of a rotary pendulum. Later, the controller was modified and implemented on a cart pendulum system taking the finite length of the track into account. However, most of the existing swing-up controllers are based on a simplified model for the SIP system, and the effects of friction are frequently disregarded. In this talk, we present a new energy-based controller for the swing-up of an inverted pendulum on a cart. The controller was derived using a more complex dynamical model for the SIP system. We also consider the effects of viscous damping, and incorporate physical restrictions like the maximum deliverable voltage by the amplifier, the capacity of the DC motor that drives the cart, and the finite track length. (Received September 21, 2015)

1116-VC-1734 **Maria Jesus Munoz Lopez*** (munozlom@tcd.ie), **Maureen P Edwards**, **Ulrike Schuman** and **Robert S Anderssen**. *Multiplicative Modelling of Four-Phase Microbial Growth.*

Microbial growth curves, recording the four-phases (lag, growth, stationary, decay) of the dynamics of the surviving microbes, are regularly used to support decision-making in a wide variety of health related activities including food safety and pharmaceutical manufacture. Often, the decision-making reduces to a comparison of some feature of the four-phases. Thus, to obtain accurate estimates of such features, the first step is the determination, from experimental measurements, of a quantitative characterization (model) of the four-phases of the growth-decay dynamics involved, which is then used to determine the values of the features. The multiplicative model proposed by Peleg and colleagues is ideal for such purposes as it only involves four parameters which can be interpreted biologically. For the determination of the four parameters in this multiplicative model from observational data, an iterative two-stage linear least squares algorithm is proposed in this paper. Its robustness, which is essential to support successful comparative assessment, is assessed using synthetic data and validated using experimental data. (Received September 21, 2015)

1116-VC-1772 **Zev Woodstock*** (woodstzc@dukes.jmu.edu), 252 MLK, Jr. Way, Harrisonburg, VA 22801, and **Bryan Félix** (bryanfelixg@gmail.com) and **Anne Shiu** (annejls@math.tamu.edu). *Analyzing Multistationarity in Chemical Reaction Networks using the Determinant Optimization Method.*

Multistationary chemical reaction networks are of interest to scientists and mathematicians alike. While some criteria for multistationarity exist, obtaining explicit reaction rates and steady states that exhibit multistationarity for a given network—in order to check nondegeneracy or determine stability of the steady states, for instance—is nontrivial. Nonetheless, we accomplish this task for a certain family of sequestration networks. Additionally, our results allow us to prove the existence of nondegenerate steady states for some of these sequestration networks, thereby resolving a subcase of a conjecture of Joshi and Shiu. Our work relies on the determinant optimization method, developed by Craciun and Feinberg, for asserting that certain networks are multistationary. More precisely, we implement the construction of reaction rates and multiple steady states which appears in the proofs that underlie their method. Furthermore, we describe in detail the steps of this construction so that other researchers can more easily obtain, as we did, multistationary rates and steady states. http://arxiv.org/abs/1508.07522 (Received September 21, 2015)

1116-VC-1782 **Shelvean Kapita*** (kapita@udel.edu), Department of Mathematical Sciences, 331 Ewing Hall, University of Delaware, Newark, DE 19716, and **Peter Monk** and **Timothy Warburton**. *Residual Based Adaptivity and PWDG Methods for the Helmholtz Equation.*

We present a study of two residual a posteriori error indicators for the plane wave discontinuous Galerkin (PWDG) method for the Helmholtz equation. In particular, we study the h-version of PWDG in which the number of plane wave directions per element is kept fixed. First, we use a slight modification of the appropriate a priori analysis to determine a residual indicator. Numerical tests show that this is reliable but pessimistic in that the ratio between the true error and the indicator increases as the mesh is refined. We therefore introduce a new analysis based on the observation that sufficiently many plane waves can approximate piecewise linear functions as the mesh is refined. Numerical results demonstrate an improvement in the efficiency of the indicators. (Received September 21, 2015)

1116-VC-1805 **Meredith McCormack-Mager***, mmccorm2@wellesley.edu, and **Carlos Muñoz** and **Zev Woodstock**. *Efficiently Testing Thermodynamic Compliance of Chemical Reaction Networks.*

Current algorithms for checking whether a chemical reaction network obeys the second law of thermodynamics are slow. This talk will demonstrate that using matroids to test thermodynamic feasibility is always exponential in the worst case. In joint work with Zev Woodstock and Carlos Munoz, I introduce a new algorithm, based on linear programming, for determining thermodynamic feasibility of chemical reaction networks. This method runs in polynomial time, and promises to improve in complexity as interior point methods are further refined. (Received September 21, 2015)

1116-VC-1812 **Tao Pang** (tpang@ncsu.edu) and **Cagatay Karan*** (ckaran@ncsu.edu), North Carolina State University, 2152 Burlington Labs, 500 Stinson Drive, Raleigh, NC 27695. *A Black Litterman Model for CVaR Optimization.*

The Black Litterman Model (BLM) has contributed to modern portfolio theory a new perfective where the investor views are combined with historical estimates. Bertsimas et.al. 2012 have showed that one can get BLM type results by using inverse optimization. We will show our results for the BLM type optimization problems under CVaR risk measure. (Received September 21, 2015)

1116-VC-1926 **Joon Hyuk Kang*** (kang@andrews.edu), Department of Mathematics, Andrews University, Berrien Springs, MI 49104. *Positive Solutions to a General Non-linear Second Order System with Applications.*

We study mathematical conditions to guarantee the existence of positive solutions to a general non-linear second order system of partial differential equations with homogemeous boundary conditions. This result may apply to illustrate biological conditions under which species of animals residing in the same environment can peacefully coexist forever. (Received September 21, 2015)

1116-VC-1954 **Hilmi Ergören*** (hergoren@yahoo.com). *A New Existence Result for Solutions to Impulsive Fractional Differential Equations.*

This work is devoted to a class of boundary value problems for impulsive fractional differential equations. Some sufficient conditions will be established for the existence of solutions to the problem by using a new fixed point theorem which has not been considered for impulsive fractional differential equations yet. (Received September 21, 2015)

1116-VC-1994 **Anushaya Mohapatra***, 1237 NW 23rd Street Apt 10, Corvallis, OR , and **Mike Field**. *Spike Time Dependent Plasticity in Spiking Neural Network.*

To determine which inputs for a neuron are important and which information a neuron should listen to is an important problem during brain development and during learning. Spike-Timing Dependent Plasticity (STDP) is a physiological adaptation mechanism of synaptic regulation which make a neuron to determine which neighboring neurons are worth by potentiating those inputs and depressing the other. We work on obtaining a good mathematical understanding the mechanism and its ability of frequency detection. (Received September 21, 2015)

1116-VC-2023 **Brandon P Ashley*** (bashley2@cub.uca.edu), Conway, AR 72034. *Asymptotic Tracking and Disturbance Rejection of the Blood Glucose Regulation System.* Preliminary report.

For people with type 1 diabetes, the pancreas does not correctly secrete the amount of insulin to keep the concentration of glucose in the bloodstream within the desired range. To correct this, external insulin pumps have been designed to control the blood glucose system. Mathematically, we can represent these systems as a control model with multiple feedback controllers. For the blood glucose system in particular, it is desirable for controllers to stabilize the system about some reference point while correcting for various disturbances in the glucose levels. Here we wish to design controllers for a blood glucose system about some reference and subject to functional disturbances using asymptotic tracking and disturbance rejection methods. (Received September 21, 2015)

1116-VC-2105 **Gerasim K. Iliev***, Department of Mathematics, Boyd Graduate Studies Research Center, Athens, GA 30602. *Modelling copolymer adsorption near an inhomogeneous surface.*

We will focus on several models related to adsorbing polymers near impenetrable patterned surfaces and discuss the order parameters related to certain geometric properties of such systems. (Received September 21, 2015)

1116-VC-2107 **James Sochacki*** (sochacjs@jmu.edu). *Power Series Method for Hodgkin-Huxley Equations.* Preliminary report.

Ever since 1952 when Hodgkin and Huxley derived the differential equations to describe the propagation of action potentials in the squid giant axon, researchers have used these equations or a modification of these equation to model neurons in many species including humans. Even though the original Hodgkin-Huxley equations have a singularity in the parameters these equations are still used by researchers. Many neuron modelers are now using power series method (PSM) to obtain solutions to the Hodgkin-Huxley equations. This method has problems with dealing with singularities. In this talk methods are presented that address this issue and make the PSM an even more powerful method for solving these equations. (Received September 21, 2015)

1116-VC-2224 **Ryan Christopher Theisen*** (ryan.theisen@asu.edu), 5213 E. Shaw Butte Dr., Scottsdale, AZ 85254. *A Model of Flocking in Three Zones.*

We introduce the Three-Zone Model of flocking as an extension to the model of alignment put forth by Cucker and Smale (2007). The Three-Zone Model describes the “flocking” of particles based on the influence of three forces: attraction, repulsion, and alignment. We say that flocking occurs if the distance between any two particles remains bounded and if the particles move in the same direction. We investigate numerical solutions to the Three-Zone Model and attempt to characterize the resulting formations as either “stable” or “catastrophic” depending on the spatial distribution of particles. (Received September 22, 2015)

1116-VC-2228 **Sergey I Kryuchkov**, **Nathan A Lanfear*** (nlanfear@asu.edu) and **Sergei K Suslov**. *The Pauli-Lubanski Vector, Complex Electrodynamics, and Photon Helicity.*

We critically analyze the concept of photon helicity and its connection with the Pauli-Lubanski vector from the viewpoint of the complex electromagnetic field, E + iH; sometimes attributed to Riemann but studied by Weber, Silberstein, and Minkowski. To this end, a complex covariant form of Maxwell’s equations is used. (Received September 22, 2015)

1116-VC-2244 **Timur Ayhan*** (tayhan002@gmail.com), Department of Primary School-Mathematics of, Faculty of Education, Siirt University, 56100 Siirt, Turkey. *Global Existence and Boundedness of a Certain Nonlinear Vector Integro-Differential Equation of Second Order With Multiple Deviating Arguments.*

In this study, we consider a vector integro-differential equation with the multiple deviating arguments. Based on the Lyapunov-Krasovskii functional approach, the global existence and boundedness of all solutions are discussed. We give an example to illustrate the theoretical analysis made in this work and to show the effectiveness of the method used here. (Received September 22, 2015)

1116-VC-2245 **Max K Black*** (max.black45@yahoo.com) and **Jonas D’Andrea**. *Fractal Image Compression Algorithms and Their Application to Steganography.*

Significant research on various forms of information hiding has been directed towards cryptography. However, an alternative to cryptography is steganography using different image compression techniques. We discuss employing wavelet image compression techniques where the wavelet transform itself acts as the “key” to hiding our information. We investigate a lesser known class of fractal wavelets, first introduced by Dutkay and Jorgensen, as the basis for this image compression. Specifically, we consider wavelets using a dilation by 3 including a two-dimensional Cantor set, and "rotated" Cantor set. We compare these fractal transforms to the Haar wavelet and Daubechies wavelet transforms, with steganography as our goal. (Received September 22, 2015)

1116-VC-2365 **Roger J. Thelwell*** (thelwerj@jmu.edu). *A power series approach to stability and control.* Preliminary report.

Recasting highly nonlinear dynamical systems as quadratic (a technique rediscovered and exploited by Parker and Sochacki) allows series to provide numeric and theoretic insight and intuition. This talk will explore stability and control via series methods. (Received September 22, 2015)

1116-VC-2392 **Robert Lipton** and **Robert P Viator*** (rviato2@lsu.edu), 9989 Burbank Dr, Apt 60, Baton Rouge, LA 70810. *Radii of Convergence for Power Series Expansions of Eigenfrequencies of High-Contrast Photonic Crystals.*

We consider periodic and quasi-periodic transverse electric modes traveling through a high-contrast photonic crystal. The crystal is a 2-dimensional periodic array of unit cells Y consisting of a high-contrast inclusion phase $D \Subset Y$ and a host phase $Y \setminus D$ made of isotropic materials. A power series expansion in the high-contrast limit $\varepsilon_{Y\setminus D}^{-1} = k^{-1} \to 0$ of the eigenfrequencies for this material is calculated, along with an explicit lower bound on the radius of convergence in terms of the quasi-momentum, the Dirichlet spectrum of D, and the spectrum of a related eigenvalue problem associated with a Neumann-Poincaré operator on ∂D. (Received September 22, 2015)

1116-VC-2409 **Fiona Knoll*** (fknoll@g.clemson.edu),)-110 Martin Hall, Box 340975, Clemson, SC 29634. *Explicit Johnson-Lindenstrauss projection of high dimensional data.*

Johnson and Lindenstrauss (1984) proved that any finite set of data in a high dimensional space can be projected into a low dimensional space with the Euclidean metric information of the set being preserved within any desired accuracy. Such dimension reduction plays a critical role in many applications with massive data. There have been extensive effort in the literature on how to find explicit constructions of Johnson-Lindenstrauss projections. In this presentation, we will show how algebraic codes over finite fields can be used for explicit and fast Johnson-Lindenstrauss projections of data in high dimensional Euclidean spaces. This is joint work with Shuhong Gao, Yue Mao, and Lin You. (Received September 22, 2015)

1116-VC-2428 **Melody Alsaker*** (alsaker@math.colostate.edu). *An Introduction to the Mathematics of Electrical Impedance Tomography.*

Electrical impedance tomography (EIT) is an imaging technology with many promising medical applications. In EIT, we apply current to electrodes placed on the body and measure the resulting surface voltage. Using just this boundary information, we reconstruct the internal electrical conductivity distribution within the body, thus forming an image. The EIT problem is very mathematically interesting, and is steeped in the theory of partial differential equations. In this introductory talk, we present an overview of the EIT problem and a glimpse at the mathematics involved in solving this fascinating real-world problem. (Received September 22, 2015)

1116-VC-2439 **Ross Eric Magi*** (ross.magi@wallawalla.edu) and **James P Keener** (keener@math.utah.edu). *Modelling a Biological Membrane as a Two Phase Viscous Fluid with Curvature Elasticity.*

We develop a general model of a multicomponent membrane where we treat the membrane as a two phase viscous fluid flowing on a time dependent surface. Using the tools of differential geometry to describe the surface, Flory–Huggins theory combined with Cahn–Hilliard theory to describe the free energy of a mixture, and Helfrich theory to describe the bending energy of a membrane, we employ a minimum energy dissipation argument to derive equations of motion for the two phase fluid. By examining specific parametrizations of the surface, we explore situations under which the membrane undergoes phase separation, and demonstrate the possibility of curvature induced instability. (Received September 22, 2015)

1116-VC-2492 **Daniel Wood*** (daniel.wood@mavs.uta.edu). *Advancements and Applications of Nonstandard Finite Difference Methods.*

A class of dynamically consistent numerical methods are analyzed for general n-dimensional productive-destructive systems (PDS). Using this analysis, a methodology for constructing positive and elementary stable nonstandard numerical methods is established. The nonstandard approach results in qualitatively superior numerical methods when compared to the standard ones. PDS model a wide range of dynamical systems, including ones with biological, chemical and physical interactions. Building upon this, a nonstandard finite difference method for solving autonomous dynamical systems with positive solutions is constructed. The proposed numerical methods are computationally efficient and easy to implement. Several examples are given which show that the numerical results agree with the theoretical results. (Received September 22, 2015)

1116-VC-2530 **Mihhail Berezovski*** (berezovm@erau.edu), 600 S. Clyde Morris Boulevard, Daytona Beach,, FL 32114. *Advanced study of wave propagation in dynamic materials.* Preliminary report.

The response of many materials of engineering interest to external loading is influenced by their microstructure. The components of such a microstructure may have different material properties, resulting in an enormous complexity in the response of a material. Results of numerical simulations by means of a thermodynamically consistent algorithm are demonstrated on examples of wave propagation. As a preliminary study to more complex situations of interest in small-scale technology, this study envisages the propagation properties of elastic waves in one-spatial dimension when some of the properties may vary suddenly in space or in time. We are interested in so-called dynamic materials (DM). Dynamic materials are artificially constructed structures (like metamaterials) which may vary their characteristic properties in space or in time, or both, by an appropriate arrangement or control. These controlled changes in time can be provided by the application of an external (non-mechanical) field, or through a phase transition. Such materials exhibit very unusual behavior. The special cases of non-instantaneous properties changing is studied. The wave propagation in 2D space geometry of DM is considered. (Received September 22, 2015)

1116-VC-2590 **Christopher Mathewson Stokes*** (mathewsonstokes@gmail.com), 9513 E. Flanders, Mesa, AZ 85207. *Conditions on flocking for the 3 Zone-Model.*

We study a model, which mimics the ideal behavior of a flock. The model is based on three rules: First that individuals align with their neighbors. Second, if two members of a flock are far away they will move closer to each other. Third, if two members are too close they will distance themselves in order to avoid collision. We investigate when this model will result in a "flock", (meaning all members have the same velocity). We have discovered that with strong enough attraction combined with alignment flocking is guaranteed. (Received September 22, 2015)

1116-VC-2591 **Michaela Kubacki*** (mkubacki@middlebury.edu), 05753, and **Vince Ervin**, **William Layton**, **Marina Moraiti**, **Zhiyong Si** and **Catalin Trenchea**. *Partitioned Methods for the Evolutionary Stokes-Darcy-Transport Problem.* Preliminary report.

There has been a surge of work on models for coupling surface-water with groundwater flows, which is at its core the Stokes-Darcy problem, as well as methods for uncouplng the problem into subdomain, subphysics solves. The resulting (Stokes-Darcy) fluid velocity is important because the flow transports contaminants. The numeriical analysis and algorithm development for the evolutionary Stokes-Darcy-transport problem has, however, focused on a quasi-static Stokes-Darcy model and a single domain (fully coupled) formulation of the transport equation. We present a numerical analysis of partitioned methods for the fully evolutionary system, including contaminant transport, that require only one subdomain solve per step. (Received September 22, 2015)

1116-VC-2602 **Brooks K Emerick*** (brooks.emerick@trincoll.edu), Trinity College, 300 Summit Street, Hartford, CT 06106, and **A Singh**. *The effects of host-feeding on stability of discrete-time host-parasitoid population dynamic models.*

Discrete models are the traditional approach for capturing population dynamics of a host-parasitoid system. Recent work has introduced a semi-discrete framework for obtaining model update functions that connect host-parasitoid population levels from year-to-year. This framework uses differential equations to describe the host-parasitoid interaction during the time of year when they come in contact, allowing specific behaviors to be incorporated. We use the semi-discrete approach to study the effects of host-feeding, which is when a parasitoid consumes a potential larva without ovipositing. We find that host-feeding by itself cannot stabilize the system, and both populations exhibit behavior similar to the Nicholson-Bailey model. When combined with stabilizing mechanisms such as density-dependent host mortality, host-feeding contracts the region of parameter space that allows for a stable host-parasitoid equilibrium. Together with a density-dependent attack rate, host-feeding expands the non-zero equilibrium stability region. We show that host-feeding causes inefficiency in the parasitoid population, which yields a higher population of hosts per generation. This suggests that host-feeding may have limited impact in terms of suppressing host levels for biological control. (Received September 22, 2015)

1116-VC-2697 **Costa Lasiy*** (kl0822@westminstercollege.edu). *A Fractal wavelet-based DE solver.* Preliminary report.

We consider fractal wavelet-based methods for solving differential equations in lieu of traditional Fourier and standard wavelet methods. Specifically we compare use of a Sierpinski-gasket fractal wavelet to a 2-dimensional

Haar wavelet in solving a diffusion model under different initial conditions. The methods differ only in the filters used in the wavelet constructions, where the geometry of the Sierpinski-gasket is in embedded in the fractal wavelet transform. Additionally, we explore systems with chaotic dynamics. (Received September 22, 2015)

1116-VC-2707 **Thomas G. Stojsavljevic*** (tgs@uwm.edu), 1428 E. Capitol Drive, Apartment 1, Shorewood, WI 53211. *Parameter identification and sensitivity analysis for a phytoplankton competition model.*

Phytoplankton live in a complex environment with two essential resources forming various gradients. Light supplied from above is never homogeneously distributed in a body of water due to refraction and absorption from biomass present in the ecosystem and other sources. Nutrients in turn are typically supplied from below. Here we present a model of two phytoplankton species competing for two nutrients. The parameter space of the model is then analyzed for parameter identifiability- the ability for a parameter's true value to be recovered through optimization, and for global sensitivity- the influence a parameter has on model response. The results of these analyses are then interpreted within their biological context. (Received September 22, 2015)

1116-VC-2708 **Benjamin D. Jackson*** (benjamin.jackson@wallawalla.edu), Walla Walla University, 204 S College Ave, College Place, WA 99324. *Transport of Particulate Matter in a Biofilm-lined Hot Spring Effluent Channel.* Preliminary report.

Biofilms are commonly found in natural and industrial systems, including hot spring effluent channels under flow conditions. Thus, modeling biofilms in the context of channel flow is important in understanding many natural systems. In this talk I develop a model which addresses the rate at which cells move in or out of the flow in a natural hot spring drainage channel. This is done by building a two-dimensional partial differential equation model of the stream. The model is parameterized using data gathered at Mushroom Spring in Yellowstone National Park. Using this data, I calculate erosion and adhesion rates at steady state in both upper and lower regions of the stream. (Received September 22, 2015)

1116-VC-2740 **Tim Marrinan*** (marrinan@math.colostate.edu), **Michael Kirby**, **Chris Peterson**, **Ignacio Santamaria** and **Louis Scharf**. *Schubert variety constrained averaging on Grassmann manifolds.* Preliminary report.

Let V be an n-dimensional real vector space, and let $W_1 \subset W_2 \subset \cdots \subset W_l \subset V$ be a distinguished flag such that the dimension of $W_j = j$. Additionally suppose that the set $\{V_i\}_{i=1}^p$ is made up of p-dimensional subspaces of V that correspond to points on the associated Grassmann manifold, denoted $\mathrm{Gr}(n,p)$. We seek to find a flag, $U_1 \subset U_2 \subset \cdots \subset U_l$, where each U_j in the flag is as close as possible to the set $\{V_i\}_{i=1}^p$ with respect to a geometrically motivated cost function and with the added constraint that U_j is contained in the Schubert variety $\Omega(W_j, k_j)$ for some choice of k_j and for each j. In other words, the constraint requires that $\dim(U_j \cap W_j) \geq k_j$ for each j. We present a novel solution to the associated optimization problem and discuss applications to signal processing and pattern recognition. (Received September 22, 2015)

1116-VC-2741 **Sebastien Motsch**, **Alexander Reamy*** (areamy@hargray.com), **Ryan Theisen** and **Matt Stokes**. *A Mathematical Description of Flocking and Swarming Behaviors.*

We derive a model describing the formation and evolution of a flock, accounting for three types of behavior: attraction, repulsion, and alignment. "Flocking" is said to occur if the distance between particles is bounded and all particles move in the same direction; we prove that both conditions are satisfied when attraction is sufficiently strong. This is an original result that expands upon the existing Cucker-Smale model. In cases where flocking occurs, we also investigate the structure of the flock. We have identified a criterion that determines whether the flock is stable (meaning particles are evenly spread) or catastrophic (meaning particles form a ring-like shape). (Received September 22, 2015)

1116-VC-2820 **Ilyssa A Summer***, PO Box 873901, Tempe, AZ 85287, and **Angela Peace** (a.peace@ttu.edu), Texas Tech University, Department of Mathematics and Statistics, Lubbock, TX 79409. *Virotherapy and Immunotherapy Combinations towards Cancer.* Preliminary report.

Oncolytic viruses are a form of cancer treatment used to target tumor cells without harming healthy cells. These viruses have been engineered to specifically infect and kill cancer cells. Immunotherapy boosts the body's natural defenses towards cancer. This combination is shown through a deterministic system of nonlinear differential equations, for gaining insight into the viral and immunological cancer interactions. Key simulation results will be shown. (Received September 22, 2015)

1116-VC-2834 **Alma Malibekova** (amalibekova1@cub.uca.edu), 201 Donaghey Ave PO BOX 4305, Conway, AR 72034, and **Diana Marcela Morales*** (dmorales1@cub.uca.edu). *Mathematical Modeling of Epidemic with Exposed Group.* Preliminary report.

Our research focuses on mathematical modeling of an epidemic within a population. It consists of a system of four non-linear ordinary differential equations that represent the groups of potential, exposed, infected and removed populations. Three steady states for the system are found and their stability is analyzed using Routh-Hurwitz criterion. The goal of the research is to find and study the endemic stability state. (Received September 22, 2015)

1116-VC-2871 **Barrett James Anderies*** (banderie@asu.edu), **Erica Rutter** (erutter1@asu.edu), **Eric Kostelich** (kostelich@asu.edu) and **Yang Kuang** (kuang@asu.edu). *Computational Modeling of Murine GL261 Brain Tumors.* Preliminary report.

Glioblastoma Multiforme (GBM) is an aggressive and deadly form of brain cancer with a median survival of approximately one year with treatment. Treatment is informed by MR and CT images acquired at diagnosis, however, treatment seldom results in a significant increase in longevity, partly due to the lack of precise information available to physicians. This lack of information arises from the physical limitations of MR and CT imaging coupled with the diffusive nature of glioblastoma tumors. The imaging information is most incomplete at the edge of the tumor where the density of GBM cells is too low to be resolved. We consider a model of tumor growth based on the reaction-diffusion PDE to better predict tumor growth:

$$\frac{\partial u}{\partial t} = \nabla \cdot (D\nabla u) + \rho u(1 - \frac{u}{K})$$

We consider both stochastic and non-stochastic parameterizations of this model, and use an error minimization (based on the Jaccard distance) algorithm to find optimal parameter values. The model is optimized on data from an animal model of GBM (GL261 tumors in immunocompetent mice). Initial results show that our model adequately predicts tumor growth for short time periods, but struggles to capture some of the long term growth behavior of certain tumor cases. (Received September 22, 2015)

1116-VC-2875 **Nathan McClanahan*** (mcclanah@math.montana.edu). *Deformation of a Biofilm Using an Energy Based Model.* Preliminary report.

Biofilms are attached microbial communities made up of many different components. Biofilms are found throughout nature as well as in industrial and medical settings. Understanding how these biofilms spread is important in helping the prevention and treatment of diseases and to prevent contamination. We created an energy based model of a flow channel using partial differential equations, first in 1D and later in 2D. We solved this system using a finite difference method in C++. Doing this would allow us to look more closely at why some parts of the biofilm are washed away under flow while others stay attached to a surface. (Received September 22, 2015)

1116-VC-2879 **Rommel G Regis*** (rregis@sju.edu), Saint Joseph's University, Department of Mathematics, 5600 City Avenue, Philadelphia, PA 19131. *On the Convergence of Adaptive Random Search Methods for Constrained and Multi-Objective Black-Box Optimization.* Preliminary report.

Although there are many theoretical results on the convergence of random search methods for continuous black-box global optimization, relatively few address the issue of black-box constraints and multiple black-box objective functions. This talk will present some results that guarantee the convergence in probability of a class of adaptive random search algorithms for constrained black-box global optimization. Then, these results are used to prove the convergence in probability of adaptive random search algorithms to Pareto optimal solutions in a multi-objective setting. (Received September 22, 2015)

1116-VC-2885 **Xinyao Yang*** (xywp8@mail.missouri.edu), 701 S. Providence Road, Apt 1-I, Columbia, MO 65203. *Stability for Perturbations of a Steady State at the One Dimensional Case.*

In this presentation, stability results are proved for traveling waves in a class of d-dimensional combustion diffusion systems moving forward in a fixed direction $\vec{e}$. A weight function that decays exponentially is required to stabilize the spectrum. Perturbations of the steady state solution that are small in both the weighted norm and the unweighted norm are shown to stay small in the unweighted norm and to decay exponentially to a shift of the steady state in the weighted norm, provided the linearized operator has no eigenvalues in the right half-plane. A decomposition of the variables that yields a triangular structure for the linearization is used to prove the results. (Received September 22, 2015)

1116-VC-2916 **Stanley R Huddy*** (srh@fdu.edu), 1000 River Road, Teaneck, NJ 07512, and **Jie Sun**. *Master Stability Islands for Oscillation Death in Networks of Delay-Coupled Oscillators.*

Oscillation death (also called amplitude death) is a coupling induced stabilization of a fixed point of a dynamical system. This phenomenon has been shown to occur on networks of identical and/or nonidentical oscillators under various coupling schemes. An interesting result of oscillation death is the emergence of enclosed regions in delay and coupling space, called oscillation death islands, where the dynamics of the coupled system cease to oscillate when parameters values are chosen from within these regions. However, the size of these island regions depends on the network topology, so they must be computed separately for each network. In our work, we develop a master stability island approach to solve this issue. We compute islands that are independent of network topology and this allows us to determine the occurrence of oscillation death for any range of delay and coupling parameters. Examples of the master stability island approach using the Rossler system and Chen's system are also presented. (Received September 23, 2015)

1116-VC-2972 **Shane Lubold*** (shane@lubold.com). *Application of Wasserstein distance to biological systems.*

In many biological systems, we observe the emergence of complex spatial organizations (such as flocks of birds, swarms of bees). Our goal is to understand and classify those patterns according to an adapted metric. In this talk we discuss the Wasserstein distance (WD) and its application to biological systems. The WD measures the distance between probability density functions. In one dimension, the WD is the area between the quantile functions of two density functions. In two dimensions the same approach is not feasible. In this talk we provide numerical results for one-dimensional Gaussian functions and Dirac Delta distributions, for two-dimensional density functions, and for the expected error in computing the WD between normally distributed Dirac delta distributions. As an application, we use our framework to test the validity of different dynamics proposed to model swarming behavior. (Received September 23, 2015)

General Session on Assessment

1116-VD-612 **Catherine Paolucci*** (paoluccic@newpaltz.edu), Department of Secondary Education and, Department of Mathematics, State University of New York at New Paltz, New Paltz, NY 12561. *Exploring the potential for alternative assessments to promote meaningful learning in an undergraduate mathematics course.*

This paper will discuss an alternative assessment strategy employed in two different undergraduate Combinatorics classes. The classes consisted of students from a range of programs, including Pure Mathematics, Elementary and Secondary Education, Engineering and Biology.

In addition to the homework, quizzes and examinations in this course, students were required to complete at least one extension activity. They were offered a choice from several options. These options involved either delving more deeply into a topic which was mentioned in class (or in the text), or identifying and discussing applications of the course content within the field of their major.

Findings from an analysis of the content of the resulting assignments revealed a level of learning that extends beyond what was otherwise assessed on the quizzes and exams. In addition, student feedback related to the extension activity indicated that they valued the opportunity to engage with the course content in a way that was personally meaningful. (Received September 08, 2015)

1116-VD-723 **Alison Ahlgren Reddy*** (ared@illinois.edu), Mathematics Department, 1409 W. Green Street, Urbana, IL 61801. *The University of Illinois Math Placement Program: A Retrospection on 8 years and 75,000+ students.* Preliminary report.

In 2007 the Department of Mathematics at Illinois began a new placement and assessment program. This talk will be a retrospection on 8 years and 75,000+ students, in particular we will compare program data from Fall 2009 to 2014. The data will show continued and consistent success rates in Calculus I since the inception of the program. Students arrive at the University of Illinois with diverse mathematical backgrounds. This results in a diversity of mathematical knowledge, augmented by the fact that what constitutes precalculus at the various institutions varies greatly, as do grading procedures used by different high schools, confounding traditional indicators of students' mathematical knowledge and maturity. Getting students started in the appropriate math class is important not only for their mathematical success, but their success on campus in general. Thus there is a great need to evaluate preparedness precisely and implement placement policies effectively. (Received September 11, 2015)

1116-VD-1447 **Perry Y.C. Lee*** (plee@kutztown.edu), Department of Mathematics, Kutztown University of Pennsylvania, Kutztown, PA 19530, and **Padraig McLoughlin** (mcloughl@kutztown.edu), Department of Mathematics, Kutztown University of Pennsylvania, Kutztown, PA 19530. *An Assessment Study Across Multi-Sections of 'Large' College Algebra Classrooms: An On-going Report.* Preliminary report.

During the past 2014/15 academic year and this past Fall 2015 semester, an assessment study was conducted to obtain student-learned outcome data from multi-sections of 'large' College Algebra classrooms. The lead author incorporated the Flipped (or inverted) and the Inquiry-Based Learning (IBL) approaches (or the F/IBL method) into each of his large classrooms, and instructors from other multi-sections of large College Algebra classrooms taught their classes predominantly using the traditional lecture-style approach. In these 'large' multi-section classrooms, student scores were collected by administering the assessments twice during each of the three semesters: the pre-assessment and the post-assessment using Educational Testing Service's (ETS) standardized Elementary Algebra Skills Assessments (EAS). The presentation will provide how this F/IBL method is implemented and managed into his 'large' classrooms. Also, a summary of assessment data based on student-learned outcomes from those multi-sections of College Algebra classrooms that participated in this study is presented. (Received September 20, 2015)

1116-VD-2401 **Kathryn Rhoads*** (kerhoads@uta.edu), **James A. Mendoza Epperson** and **R. Cavender Campbell**. *Mathematical Problem Solving Item (MPSI) Development Project.* Preliminary report.

Nationwide, high failure rates in foundational undergraduate mathematics courses, such as college algebra and calculus, indicate that the current focus on procedural knowledge and skills is ineffective for many students. Instead, researchers have argued that a primary goal of mathematics instruction should be for students to develop problem solving skills (e.g., Schoenfeld, 1992). However, most university exams lack assessment of students' mathematical problem solving (MPS), and no efficient tools exist that provide an inventory of students' MPS skills.

The purpose of the MPSI Development Project is to create a pool of problems and associated assessment items that can measure students' MPS in five key areas that we have identified through previous research (Campbell, 2014). We propose that valid and reliable MPSI items can provide an efficient and less costly means for researchers to answer key questions for the learning and teaching of MPS in undergraduate mathematics. In this paper, we report on the ongoing development and refinement of MPSI items, including the piloting of items through a pre- and post-assessment design with over 500 students enrolled in college algebra or calculus. This research is partially supported by NSF DUE grant no. 1544545. (Received September 22, 2015)

1116-VD-2485 **Berit Nilsen Givens*** (bngivens@cpp.edu), Department of Mathematics & Statistics, 3801 W Temple Ave, Pomona, CA 91768, and **Arlo Caine** (jacaine@cpp.edu). *Writing good questions: How and why we wrote our own bank of clicker questions.* Preliminary report.

Clicker questions, also called concept tests, are a proven teaching technique for engaging students in class. While there are many very good repositories of clicker style questions available, we decided to write our own question bank. We present the factors that led to our decision to write the bank – the "why" – and the process by which we developed and wrote questions – the "how". Our goal in this ongoing project is to write questions that can be used right off the shelf with high quality and professional graphics. In addition, the questions are tailored to our particular student population at a large regional public university. At this talk, we reflect upon our experiences and give advice for anyone contemplating writing their own set of questions. Finally, we present and discuss examples of our questions. (Received September 22, 2015)

General Session on Geometry

1116-VE-27 **Yeon June Kang***, yeonjunekang@gmail.com. *Triangulations via Iterated Largest Angle Bisection.*

For a given triangle $\triangle ABC$, with $\angle A \geq \angle B \geq \angle C$, the *largest angle bisection* procedure consists in constructing AD, the angle bisector of angle $\angle A$, and replacing $\triangle ABC$ by the two newly formed triangles, $\triangle ABD$ and $\triangle ACD$.

Let $\triangle_{01}$ be a given triangle. Bisect $\triangle_{01}$ into two triangles, $\triangle_{11}$ and $\triangle_{12}$. Next, bisect each $\triangle_{1i}, i = 1, 2$, forming four new triangles $\triangle_{2i}, i = 1, 2, 3, 4$. Continue in this fashion. For every nonnegative integer n, $T_n = \{\triangle_{ni} : 1 \leq i \leq 2^n\}$, so T_n is the set of 2^n triangles created after the n-th iteration.

Define m_n, the *mesh* of T_n, as the length of the longest side among the sides of all triangles in T_n. Also, let γ_n be the smallest angle among the angles of the triangles in T_n. We prove the following results:

- $\gamma_n \geq min(\gamma_0, 30^\circ)$.
- $m_n \to 0$ as $n \to \infty$.
- Unless $\triangle_{01}$ is an isosceles right-angle triangle, the set $\bigcup_{n=0}^{\infty} T_n$ contains infinitely many triangles no two of which are similar.

(Received June 02, 2015)

1116-VE-121 **Hyun Jin Kim*** (hyunjin.sun.kim@gmail.com), Hofstra University, Hempstead, NY 11549-1000, and **Hyun Sun Kim**. *Special Configurations of Triangle Centers.*

For a given triangle, the circumcenter is the unique point in the plane of the triangle at equal distance from all three vertices. Similarly, the orthocenter is the point of intersection of the altitudes of the triangle. Euler proved that for any triangle, the midpoints of the sides, the feet of the altitudes and the midpoints of the segments joining the vertices of the triangle to the orthocenter lie on a circle. The center of this circle is the 9-point center of the triangle. We prove the following: Let A_1, A_2, A_3, A_4 be four points in the plane, no three on a line, all four not on a circle. For all $1 \leq i \leq 4$, let O_i and ω_i be the circumcenters and the 9-point centers of triangle $A_{i+1}A_{i+2}A_{i+3}$, respectively. Then the four-point configurations (O_1, O_2, O_3, O_4) and $(\omega_1, \omega_2, \omega_3, \omega_4)$ are similar. Moreover, the similarity ratio is not constant but depends on the initial points A_i in a way that is made explicit.) There are many triangle centers: these special points can be defined either as the result of some geometric construction (as it is the case with the circumcenter, the orthocenter, and the 9-point center) or may just have a pure algebraic description as explained in the paper. (Received July 31, 2015)

1116-VE-240 **Brian Allen*** (allen@math.utk.edu), 820 Red Saile Road, Knoxville, TN 37909. *Asymptotic Analysis of Non-Compact Inverse Mean Curvature Flow in Hyperbolic Space.*

Inverse Mean Curvature Flow (IMCF) is an important geometric evolution equation which has been used to prove the Riemannian Penrose Inequality in General Relativity as well as other important geometric inequalities. I will discuss my own work on non-compact IMCF in Hyperbolic space which is the first general look at IMCF for non-compact initial data. First we will describe a long time existence result for the flow when the initial hypersurface can be represented as a graph over a hyperplane. Then we will go on to discuss the asymptotic properties of the flow, convergence of the rescaled flow as well as applications to geometric inequalities. (Received August 17, 2015)

1116-VE-296 **Man Wai Cheung*** (m1cheung@ucsd.edu). *Theta basis and quiver representation.* Preliminary report.

Scattering diagrams were first developed by Kontsevich and Soibelman, later by Gross and Siebert, to solve problem in mirror symmetry. The original idea was to construct an order-by-order description of degeneration of Calabi-Yau manifold. Later on, it is found that the diagrams encodes information about cluster translation. While the canonical basis for cluster algebra is still unclear, Gross-Hacking-Keel-Kontservich proposed a basis for cluster algebra constructed from scattering diagram. And they are able to solve one of the major conjecture in cluster algebra by using this construction. In the talk, we are going to describe this construction and show that this basis is the same as another proposed basis, greedy basis, in the cluster algebra world. (Received August 23, 2015)

1116-VE-380 **Derege Mussa*** (dxm146130@utdallas.edu), Department of Mathematical Science, University of Texas at Dallas, Richardson, TX 75080. *Existence of Self Dual Tetrahedon.*

Tetrahedron (plural Tetrahedra) is a three dimensional solid having four, vertices, four triangular faces and six edges which don't lie in a single plane. A six tuple S = (a, b, c, d, e, f) exists if the tetrahedron is facial and that the McCrean determinant is positive.

If S is a sextuple for (potential) tetrahedron T, S = (a, b, c, d, e, f) then T has faces a, b, c; a, e, f; b, d, f and c, d, e and the edges at the vertices has the pattern a, b, f ; a, c, e ; b, c, d and d, e, f. If we have a potential tetrahedron T and where the pattern of faces and vertices is interchanged then T is called the dual of tetrahedron T. Theorem (Derege Mussa) : If the potential tetrahedron T has sextuple S = (a, b, c, d, e, e, f). then the sextuples (f, e, d, c, b, a) gives rise to the potential dual tetrahedron. The question is If two tetrahedra are dual are they necessarily exist and if they are dual are they necessarily exist ? Conjecture: If S is a self dual for partition of tetrahedron then S can't exist. The paper discusses about 1.the dual of Tetrahedron 2. proof the conjecture using partition of tetrahedra (Received August 29, 2015)

1116-VE-468 **Elena Alicia Gonzalez Malloy*** (elena.malloy@yale.edu), 13 Yearling Chase, Mount Laurel, NJ 08054. *The Geometry of the Discriminant over Finite Fields.* Preliminary report.

In his paper, *A Remarkable Geometry of Discriminant Varieties*, Katz concludes the problem of finding the solutions to a polynomial is equivalent to the problem of finding tangent hyperplanes to the discriminant. Although tangency is difficult to visualize in the same manner over a finite field, the formal derivative allows us to preserve the behavior of a derivative without limits, thus also preserving the tangent. Because of this, the relationship that Katz concluded translates to any field—in particular the finite field F_q, where $q = p^k$, for some prime p and integer k. To depict this relationship we have experimented with ways of visualizing the natural structure of F_q. These visualizations each consider all the monic quadratics in the field to answer the question: Is it on the discriminant, does it have two unique solutions or does it have no solution? To interpret these results, we used Katz' conclusions to bridge the gap between number theory and geometry. In further studies, we analyzed the distribution of the discriminant for polynomials of degree $n = 2, 3, 4$ over finite fields. Combined, these results help us better understand the pattern of the discriminant over finite fields and its connection to the geometry of solutions. (Received September 03, 2015)

1116-VE-479 **andrew simoson*** (ajsimoso@king.edu), King University, 1350 King College Road, Bristol, TN 37620. *Minimizing Utopia.* Preliminary report.

Sir Thomas More wrote *Utopia* 500 years ago in 1516. In the opening pages of Book II, he itemizes some clues about the shape of Utopia island: (1) The island has 54 city states, each separated from its nearest neighbor by at least 24 miles, and each city state is rectangular having lengths of at least 20 miles, (2) the island has a circular shaped harbor with a mouth of 11 miles making a perimeter of about 500 miles, rendering the island's shape somewhat like a crescent, (3) each cross section of the island is about 200 miles except at the extremes where it collapses to 0; the capital city is in the center of the island and is 60 miles from the sea on one side and 140 miles on the other. Given these clues, what is a possible minimal area for the island of Utopia? After interpreting these somewhat ambiguous clues by making some assumptions, we offer a map of Utopia island with [1] an elliptical shoreline, [2] a harbor whose shoreline is almost an *osculating circle* at one end of the ellipse, [3] its capital city at the *centroid* of the island, and [4] clues (1), (2), and (3) satisfied. (Received September 03, 2015)

1116-VE-699 **Zengxiang Tong*** (ztong@otterbein.edu), Department of Mathematical Sciences, Otterbein University, Westerville, OH 43081, **Jingzhong Zhang** (ztong@otterbein.edu), Guangzhou University, Guangzhou, Guangdong , Peoples Rep of China, and **Zhaozhi Zhang** (ztong@otterbein.edu), The Journal of Research in Advanced Mathemati, Northwest Poly Technology University, Xi'An, Shanxi , Peoples Rep of China. *Area Methods in Geometry Proving.* Preliminary report.

Though Euclid (300 B.C.) used an area comparison to prove Pythagorean Theorem in his Elements, this approach has never been popular in geometry proving. This presentation uses several intriguing examples to show that the area method is a fundamental method in geometry proving and it provides a new approach in organizing our geometry structure, which can help students to learn more effectively. (Received September 10, 2015)

1116-VE-702 **Jingzhong Zhang*** (ztong@otterbein.edu), Guangzhou University, Guangzhou, Guangdong , Peoples Rep of China, **Zhaochi Zhang** (ztong@otterbein.edu), The Journalof Research in Advanced Mathematic, Northwest Poly Technology University, Xi'An, ShanXi , Peoples Rep of China, and **Zengxiang Tong** (ztong@otterbein.edu), Department of Mathematical Sciences, Otterbein University, Westerville, OH 43081. *Integrated Trig-Geometry.*

Based on Prof. Zhang's decades of research, this presentation outlines an ambitious plan of reorganizing the courses of geometry and trigonometry in high school. With a very basic knowledge, we introduces the sine function sinA using areas, and use the trigonometry and area methods to integrate trigonometry and geometry. The teaching experiments have shown that even middle school students can learn it very effectively, and the students learning the integrated Trig-Geometry perform better than students learning them using traditional textbooks. (Received September 10, 2015)

1116-VE-1538 **Hulya Kadioglu*** (hkadio@yildiz.edu.tr), Yildiz Technical University, Department of, Mathematics Education, Esenler, 34220 Istanbul, Turkey. *Canonical Involution on Double Jet Bundles.* Preliminary report.

We present a secondary vector bundle structure on a 1-jet of a vector bundle. In terms of the manifold structures, we prove that both belongs to the same atlas. We also prove that 1-jet of a jet bundle can be considered as a quotient of a second order jet bundle. Moreover, we show that these two structures are isomorphic on 1-jet bundle of a jet bundle by defining a canonical involution that interchanges between such structures. (Received September 20, 2015)

1116-VE-1771 **Neha Gupta*** (ngupta10@illinois.edu). *Geometric Group Theory and Untangling Ear-Phones.*

Suppose you get your ear-phones entangled around a doughnut with two holes... an entirely probable scenario! Then how "big" does your doughnut need to be to in order for you to successfully untangle your ear-phones? This is going to be a gentle introduction to groups, and how they connect to geometry. We will slowly build up to answering our original question. This is joint work with Ilya Kapovich. (Received September 21, 2015)

1116-VE-1856 **Ross Sweet*** (rsweet@math.northwestern.edu), 2033 Sheridan Road, Evanston, IL 60208, and **Takashi Kimura**. *Adams Operations on the Virtual K-Theory of* $\mathbb{P}(1,n)$.

We analyze the structure of the virtual (orbifold) K-theory ring of the complex orbifold $\mathbb{P}(1,n)$ and its virtual Adams (or power) operations, by using the non-Abelian localization theorem of Edidin-Graham. In particular, we identify the group of virtual line elements and obtain a natural presentation for the virtual K-theory ring in terms of these virtual line elements. This yields a surjective homomorphism from the virtual K-theory ring of $\mathbb{P}(1,n)$ to the ordinary K-theory ring of a crepant resolution of the cotangent bundle of $\mathbb{P}(1,n)$ which respects the Adams operations. Furthermore, there is a natural subring of the virtual K-theory ring of $\mathbb{P}(1,n)$ which is isomorphic to the ordinary K-theory ring of the resolution. This generalizes the results of Edidin-Jarvis-Kimura who proved the latter for $n = 2, 3$. (Received September 21, 2015)

1116-VE-1979 **Samantha Moore*** (moor4213@bears.unco.edu) and **Robert Dickens** (robertd2@umbc.edu). *Packing Three Equal Circles Onto a Flat Klein Bottle.*

The study of maximally dense packings of disjoint equal circles is a problem in Discrete Geometry. The optimal densities and arrangements are known for packings of small numbers of equal circles into hard boundary containers, including squares, equilateral triangles and circles. In this presentation, we will explore packings of small numbers of equal circles onto a boundaryless container called a flat Klein bottle. Using numerous figures we will introduce all the basic concepts (including the notion of a flat Klein bottle, an optimal packing, and self-tangencies), illustrate some maximally dense arrangements, and outline the proofs of their optimality. This research was conducted as part of the 2015 REU program at Grand Valley State University. (Received September 21, 2015)

1116-VE-2341 **Douglas D Knowles*** (ddk4@geneseo.edu), 11 Town Pump Circle, Spencerport, NY 14559. *Numerical Ranges over Finite Fields.*

Let p be a prime number congruent to 3 modulo 4. We will work in the finite field $\mathbf{F}_p[i] = \{a + bi \mid a, b \in \mathbf{F}_p\}$, where $\mathbf{F}_p = \{0, 1, ..., p-1\}$ and $i = \sqrt{p-1} = \sqrt{-1}$. Let A be a matrix with entries from $\mathbf{F}_p[i]$. Let $\bar{x}^T$ denote the conjugate transpose of x. Consider a number $k \in \mathbf{F}_p$. Let S_k be the set of all vectors x with entries in $\mathbf{F}_p[i]$ where the product $\bar{x}^T x = k$. The author has created a definition of a new concept, the k-numerical range $W_k(A)$, which is the set of numbers of the form $\bar{x}^T Ax$, for all x in S_k. We investigate the properties of these k-numerical ranges, and explore the fundamental differences between $W_0(A)$ and $W_k(A)$ for nonzero k. We will then discuss our pioneering work in classifying the shapes $W_1(A)$ can take. This includes the author's proof that $W_1(A)$ can be a union of pairwise disjoint lines.
(Received September 22, 2015)

1116-VE-2406 **Alessio Figalli**, **Joseph Palmer*** (j5palmer@ucsd.edu) and **Álvaro Pelayo**. *Symplectic capacities, group actions, and integrable systems.*

We present some recent work studying the capacities of toric and semitoric integrable systems which is related to the natural group actions on these systems. This is presented in a general framework. (Received September 22, 2015)

1116-VE-2523 **John Donnelly*** (jrdonnelly@usi.edu), 8600 University Blvd, Evansville, IN 47712. *Equivalences in Absolute Plane Geometry.*

Absolute Geometry is plane geometry in which we assume no parallel postulate. Absolute Geometry can be thought of as being a common ground between Euclidean Geometry and Hyperbolic Geometry, and the axioms of Absolute Geometry are satisfied by both Euclidean and Hyperbolic Geometry. There are several ways to develop an axiom system for Absolute Geometry. One of the axioms often used when developing an axiom system for Absolute Geometry is the Side-Angle-Side criterion for congruence of triangles. It is well known that if one removes Side-Angle-Side as an axiom and replaces it with Angle-Side-Angle as a new axiom, then the resulting new axiom system is also Absolute Geometry. We will talk about the consequences of replacing Side-Angle-Side with either Side-Angle-Angle or Side-Side-Side as new axioms. (Received September 22, 2015)

1116-VE-2896 **Andrew V Yarmola*** (`yarmola@bc.edu`), Department of Mathematics, Maloney Hall, Fifth Floor, Boston College, Chestnut Hill, MA 02467, and **Nicholas G Vlamis**, 1859 East Hall, Department of Mathematics, University of Michigan, Ann Arbor, MI 48109. *Basmajian's identity in higher Teichmüller-Thurston theory.*

We prove an extension of Basmajian's identity to Hitchin representations of compact bordered surfaces. For 3-Hitchin representations, we show that this identity has a geometric interpretation for convex real projective structures analogous to Basmajian's original result. As part of our proof, we demonstrate that the limit set of an incompressible subsurface of a closed surface has measure zero in the Lebesgue measure on the Frenet curve associated to an n-Hitchin representation. This generalizes a classical result in hyperbolic geometry. Finally, we recall the Labourie-McShane extension of the McShane-Mirzakhani identity to Hitchin representations and note a close connection to Basmajian's identity in both the hyperbolic and the Hitchin setting. (Received September 22, 2015)

General Session on Graph Theory

1116-VF-7 **Darren Narayan*** (`dansma@rit.edu`), School of Mathematical Sciences, Rochester Institute of Technnology, Rochester, NY 14623-5604. *Graph theory metrics for analyzing functional MRI data and brain connectivity.*

We will present several graph theory metrics related to graph connectivity and show how they can be applied to analysis of functional MRI data. Our analysis will also include the use of temporal/dynamic networks which are more appropriate for studying changes in the brain over a time courses of data. (Received May 02, 2015)

1116-VF-387 **Wing Hong Tony Wong*** (`wong@kutztown.edu`), Mathematics Department, Kutztown University of Pennsylvania, 15200 Kutztown Road, Kutztown, PA 19530. *Diagonal forms and zero-sum (mod 2) bipartite Ramsey numbers.*

Let G be a subgraph of a complete bipartite graph $K_{n,n}$. Let $\mathbf{h}$ be the characteristic vector of G, i.e. $\mathbf{h}$ is a column vector of length n^2 indexed by the edges of $K_{n,n}$, with 1 if the edge is in G and 0 otherwise. Let $N(G)$ be the matrix with $2(n!)^2$ columns, each column representing an image of $\mathbf{h}$ under the action of the graph automorphism group on $K_{n,n}$.

In this paper, a general formula for a diagonal form of $N(G)$ is found for every G, and the question as to whether the row space of $N(G)$ over $\mathbb{Z}_p$ contains the vector of all 1's is settled. This implies a new proof of Caro and Yuster's results on zero-sum (mod 2) bipartite Ramsey numbers. Zero-sum Ramsey problems were studied by Bialostocki and Dierker as well as Alon and Caro.

Apart from applications in zero-sum Ramsey problems, these results on the diagonal forms of $N(G)$ also provide necessary and sufficient conditions for the existence of a signed bipartite graph design. (Received August 30, 2015)

1116-VF-530 **Daniela Ferrero*** (`dferrero@txstate.edu`), Texas State University, San Marcos, TX 78666. *Zero forcing and the power domination problem in graphs.* Preliminary report.

Zero forcing is a process on a graph that starts with a 2-coloring of its vertices, traditionally black and white. Zero forcing continues as long as it is possible to change the color of a vertex by the application of the following rule: every black vertex with exactly one white neighbor changes the color of its white neighbor to black. If at the end of the process all vertices are black, the initial set of black vertices is called a zero forcing set. The zero forcing problem consists of finding zero forcing sets of minimum cardinality.

Power domination is a graph process in which initially a set of vertices observe its closed neighborhood. The process continues as long as the following rule can be applied: an observed vertex with exactly one un-observed neighbor observes the un-observed vertex. If at the end of this process all vertices are observed, the initial set of vertices is a power dominating set. The power domination problem consists of finding power dominating sets of minimum cardinality.

In this talk we will show the relation between these two processes and its contribution to the advancement of research in both problems. Some results are joint work with several co-authors. (Received September 07, 2015)

1116-VF-613 **JU ZHOU*** (`zhou@kutztown.edu`). *On Group Connectivity of Graphs.*

Tutte conjectured that every 4-edge-connected graph admits a nowhere-zero Z_3-flow and Jaeger et al. [Group connectivity of graphs–a nonhomogeneous analogue of nowhere-zero flow properties, J. Combin. Theory Ser. B

56 (1992) 165-182] further conjectured that every 5-edge-connected graph is Z_3-connected. These two conjectures are in general open and few results are known so far. A weaker version of Tutte's conjecture states that every 4-edge-connected graph with each edge contained in a circuit of length at most 3 admits a nowhere-zero Z_3-flow. Devos proposed a stronger version problem by asking if every such graph is Z_3-connected. In this paper, we first answer this later question in negative and get an infinite family of such graphs which are not Z_3-connected. Moreover, motivated by these graphs, we prove that every 6-edge-connected graph whose edge set is an edge disjoint union of circuits of length at most 3 is Z_3-connected. It is a partial result to Jaeger's Z_3-connectivity conjecture. (Received September 08, 2015)

1116-VF-631 **C. Ray Rosentrater*** (rosentr@westmont.edu), Westmont College, Dept. of Mathematics, 955 La Paz Rd., Santa Barbara, CA 93108. *Bicycle Routes and Euler Double-paths.*

What configurations of roads are amenable to creating a bicycle route that traverses each segment exactly once in each direction? As stated, every configuration of roads can be so traversed. However, the question becomes much more interesting when U-turns are not allowed. This talk identifies the conditions under which a connected graph has a non-reversing, Euler double-path. (Received September 09, 2015)

1116-VF-668 **Theodore Molla**, **Michael Santana*** (santana@illinois.edu) and **Elyse Yeager**. *Refinements of results on cycles and chorded cycles.*

Erdős conjectured that every graph on at least $3k$ vertices with minimum degree at least $2k$ contains k vertex-disjoint cycles. Proven by Corrádi and Hajnal in 1963, this result has been the impetus of various research including graph factors, equitable colorings, and tilings. Recently, Kierstead, Kostochka, and Yeager proved a refinement of Corrádi and Hajnal's theorem which characterizes graphs on at least $3k$ vertices and minimum degree $2k-1$ that do not contain k vertex-disjoint cycles.

In this talk, we present an analogue of the Kierstead, Kostochka, and Yeager result for chorded cycles. This in turn refines previous results of Finkel and Chiba et al. (Received September 10, 2015)

1116-VF-843 **Jian Cheng***, 320 Armstrong Hall, P.O. Box 6310, Morgantown, WV 26506. *Integer Flows in Signed Graphs with No Odd-K_4-minors.*

Bouchet conjectured that every signed graph admitting a nowhere-zero integer flow will admit a nowhere-zero 6-flow. He verified the conjecture is true when 6 is replaced by 216. Zýak improved this result to 30. Xu and Zhang showed that it is true for 6-edge-connected graphs. For 4-edge-connected graphs, Raspaud and Zhu proved the existence of nowhere-zero 4-flows. An odd-H is a signed graph H with no positive edges. Our main result is that for any 3-connected signed graph G which admits a nowhere-zero integer flow, if G has no odd-K_4-minors, then G admits a nowhere-zero 8-flow. This is joint work with Y. Lu, R. Luo and C.-Q. Zhang from West Virginia University. (Received September 14, 2015)

1116-VF-853 **Tien Y Chih*** (tien.chih@newberry.edu), Newberry College, 2100 College St, Newberry, SC 29108. *The Inverse Semigroups of Graphs.*

Automorphism groups have long been a part of the study of graphs as a means of understanding the symmetry of graphs. However, this approach to understanding symmetry hides much of the partial or local symmetries that may be present in a graph, but not reflected in the automorphism group. As a result, many graphs with very different local symmetries have identical automorphism groups, and much research has been done to distinguish such graphs which gives rise to notions such as fixing and distinguishing numbers.

In this talk, the author presents a notion of studying partial symmetries of graphs with an inverse semigroup. Inverse semigroups have been used to study partial symmetries in other areas of mathematics. We define 4 possible inverse semigroups for a graph, describe the idempotent lattice of these inverse semigroups, and describe the ideals and ideal lattice of these graphs. (Received September 14, 2015)

1116-VF-876 **Guoli Ding** and **Kimberly D'souza*** (ksevin2@lsu.edu). *Decomposition of a Graph into its Quasi 4-Connected Components.*

In this talk we will discuss how to decompose a 3-connected graph G into its quasi 4-connected components. We will also define operations for reconstructing the graph G from its quasi 4-connected components. Finally, we will look at an application of this decomposition result to the problem of describing the class of graphs which excludes a weakly 4-connected graph H as a minor. (Received September 14, 2015)

1116-VF-1021 **Stephen H Dong*** (sdong@students.kennesaw.edu) and **Erik E Westlund** (ewestlun@kennesaw.edu). *Interval edge-colorings of Cayley graphs.* Preliminary report.

A proper t-edge-coloring of a graph G is called *interval* if all t colors (integers in $\{1,\ldots,t\}$) are used, and the edges incident to each vertex form an interval of integers, e.g, $[a,b]=\{a,a+1,\ldots,b-1,b\}$. The graph G is called *interval colorable* if there exists an interval t-edge-coloring of G for some $t>0$. Interval colorable graphs were introduced by Asratian and Kamalian in 1987 who established that $\chi'(G)=\Delta(G)$ is necessary (though not sufficient) for G to be interval colorable. Previous work has investigated this problem on several classes of graphs: cliques, n-cubes, planar graphs, trees, and certain complete multipartite graphs among others. Even restricting to regular graphs and bipartite graphs, the decision problem is NP-complete. We present some new preliminary results related to interval colorability and bounds on the largest size of the color palette for certain Class 1 Cayley graphs. (Received September 16, 2015)

1116-VF-1022 **Antonio J Golubski**, **John H Vandermeer** and **Erik E Westlund*** (ewestlun@kennesaw.edu). *Hypergraphs in Ecological Network Analysis.*

In the field of ecology, unraveling the tremendous complexity of ecological systems is crucial for understanding their structure and function, despite challenges it poses. Ecologists have gained much insight in recent decades from studying the topologies of ecological networks: patterns of interactions between species. Almost universally, however, this work has involved networks modeled by traditional (di)graphs. That approach is ill-suited for considering many ecologically important phenomena, which are fundamentally properties of more than two species. Hypergraphs are a natural generalization capable of considering interactions between sets of three or more vertices (species), and have recently proven extremely valuable for the study of biomolecular networks. Here, we discuss the potential value of using hypergraphs and corresponding tools from network analysis to study the topology of ecological networks, as well as challenges associated with doing so. We demonstrate the approach using a real-world complex coffee agroecosystem. (Received September 16, 2015)

1116-VF-1046 **Sarah E. Vigliotta*** (svigliotta@wesleyan.edu). *An algorithm for the independence number of incidence graphs.*

In 1993, Brualdi and Massey defined the incidence graph of G, $Inc(G)$, to be the graph whose vertices are the set of incidences - pairs of the form (u,e) where u is a vertex of G and e is an edge of G containing u as an endpoint - and where two incidences (u,e) and (v,f) are adjacent if (i) $u=v$, (ii) $e=f$ or (iii) $uv=e$ or $uv=f$. We will describe an algorithm to find a maximum independent set of $Inc(T)$, where T is a rooted tree. Finally, we give some generalizations of this algorithm to find the independence number of incidence graphs of graphs other than trees. (Received September 16, 2015)

1116-VF-1211 **Noah James Watson***, James Madison University, VA , and **Jonathan M Gerhard**, James Madison University. *Smith and Critical Groups of the Rook's Graph and its Complement.*

Let R_n denote the graph with vertex set consisting of the squares of an $n\times n$ grid, with two squares of the grid adjacent when they lie in the same row or column. This is called the square rook's graph, and on it, we can play a "chip-firing" game. In this game, we start with some initial configuration of chips (an assignment of some integer to each vertex), and consider two configurations equivalent if we can get from one to the other through a series of chip-firing operations. These operations are: 1) Firing a vertex: the vertex loses its degree and any vertices adjacent to it gain a chip, and 2) Pulling a vertex: the vertex gains its degree and all vertices adjacent to it lose a chip. We can put a group structure on the set of equivalence classes of configurations, where the operation is vertex-wise addition. The group that arises is called the Critical group of R_n, and through similar means, we can find another group called the Smith group. In this talk, we discuss the group structure on R_n and its complement. (Received September 21, 2015)

1116-VF-1262 **Peter Maceli*** (pmaceli@wesleyan.edu). *Structure of self-complementary graphs.* Preliminary report.

A graph is called self-complementary if it and its complement are isomorphic. The class of self-complementary graphs is structurally and algorithmically very rich, yet little is known about decomposing or explicitly constructing such graphs. In this talk, we will discuss a structural conjecture of Trotignon, as well as a number of general techniques for constructing self-complementary graphs. (Received September 18, 2015)

1116-VF-1377 **Carlos M Ortiz*** (cortiz@math.uh.edu) and **Vern I Paulsen** (vpaulsen@uwaterloo.ca). *Non-Local Games on Graphs: An Operator Algebraic Approach.* Preliminary report.

In a non-local game, two non-communicating players cooperate to convince a referee about a strategy that does not violate the rules of the game. A quantum strategy for such a game enable players to determine their answers by performing joint measurements on a shared entangled state. In this talk we will concentrate on non-local games motivated by problems in graph theory. We will survey known results, explain why the study of such games is important, and introduce some new findings that come from the theory of operator algebras. (Received September 19, 2015)

1116-VF-1482 **Caitlyn Parmelee*** (s-cparmel1@math.unl.edu) and **Carina Curto**. *Predicting neural sequences from network structure.* Preliminary report.

One of the basic unanswered questions in neuroscience is: how does the architecture of a neural circuit shape its dynamics? We investigate this question in the context of a simple neural network model, where the connections (synapses) between neurons are binary, and the network is thus defined from a directed graph. If the graph is oriented and has no sinks, it has been shown that the network has bounded activity and no stable fixed points. What kinds of dynamics emerge? And how do they depend on the structure of the underlying graph? Computational experiments show that in small networks, the dynamics typically converge to a limit cycle where the neurons fire in a regular sequence. Similar patterns have been observed in cortex and hippocampus. Can we predict the firing sequence from the structure of the graph? In this talk, I will describe a new graph deconstruction algorithm that allows us to successfully predict the sequence in most small networks. More generally, the algorithm is successful in graphs without a balanced induced subgraph. In addition to limit cycles, we have also observed chaotic behavior in networks with as few as 5 neurons. If time permits, I will discuss current work where we try to predict the presence of chaotic attractors from the structure of the graph. (Received September 20, 2015)

1116-VF-1494 **Neal Owen Bushaw*** (neal@asu.edu) and **Nathan Kettle**. *Extremal Numbers for Forestable Graphs.*

The extremal number, $ex(n, G)$, of a graph G is the maximum number of edges among all G-free graphs of order n. Of considerable recent interest is the case when the forbidden graph is made up of several disjoint copies of some smaller graph. Equivalently, one can consider $ex(n, k \cdot G)$ - the maximum number of edges among all n vertex graphs not containing k vertex disjoint copies of G. The Erdős-Stone Theorem tells us that for a 3-chromatic (or higher) graph, the asymptotics for this are identical to the asymptotics for $ex(n, G)$. For bipartite graphs, however, $ex(n, G)$ and $ex(n, k \cdot G)$ can differ significantly, even in the limit.

Perhaps the most natural way to construct an order n graph which is kG-free is to take an extremal G-free graph of order $n - k + 1$, and join it to the complete graph K_{n-1}, adding all possible edges between the two. This graph is certainly $k \cdot G$-free, as any copy of G must contain a vertex from the complete subgraph - but does it maximize the number of edges among all $k \cdot G$-free graphs?

We discuss recent progress on this question; in particular, we show that the given construction is extremal for a large class of bipartite graphs, including those which have a vertex adjacent to all cycles. (Received September 20, 2015)

1116-VF-1503 **Jennifer Irene Wise***, University of Illinois, Department of Mathematics, 1409 W Green St, Urbana, IL 61801, and **Douglas B West**. *Topics in game f-matching.* Preliminary report.

A capacity function f on a graph G assigns a nonnegative integer to each vertex of $V(G)$. An *f-matching* in G is a set, M, of edges of G such that the number of edges in M incident to v is at most $f(v)$ for all vertices $v \in V(G)$. We consider a competitive version of f-matching, in which two players Max and Min alternately choose edges of G to build an f-matching; the game ends when the chosen edges form a maximal f-matching. Max wants the size of the final f-matching to be large; Min wants it to be small. The *game f-matching number* is the outcome under optimal play. We extend some prior results on the special case of game matching, where $f(v) = 1$ for all $v \in V(G)$, due to Cranston, Kinnersley, O, and West. In particular, we study lower and upper bounds on the game f-matching number and how much the outcome can be affected by who plays first. (Received September 20, 2015)

1116-VF-1523 **Yijin Wei*** (ywei@smith.edu), 1 Chapin Way Unit 8306, Northampton, MA 01063, **Ben Baumer** (bbaumer@smith.edu), Clark Science Center, 44 College Lane, Northampton, MA 01063, and **Gary S. Bloom** (not_available@email.com). *The Smallest Non-autorgraph.*

Suppose that G is a simple, vertex-labeled graph and that S is a multiset. Then if there exists a one-to-one mapping between the elements of S and the vertices of G, such that edges in G exist if and only if the absolute difference of the corresponding vertex labels exist in S, then G is an *autograph*, and S is a *signature* for G. While it is known that many common families are graphs are autographs, and that infinitely many graphs are not autographs, a non-autograph has never been exhibited. In this paper, we identify the smallest non-autograph:

a graph with 6 vertices and 11 edges. Furthermore, we demonstrate that the infinite family of graphs on n vertices consisting of the complement of two non-intersecting cycles contains only non-autographs for $n \geq 8$. (Received September 20, 2015)

1116-VF-1639 **Tyler Seacrest*** (tyler.seacrest@umwestern.edu), The University of Montana Western, 710 S Atlantic St, Dillon, MT 59725, and **Jitender Deogun**. *A new proof of Nash-Williams–Tutte and generalizations to S-connectors.*

We give a new proof of the Nash-Williams–Tutte theorem that characterizes when a graph has k edge-disjoint spanning trees. While many proofs have been given to this well-known theorem, ours is particularly nice and leads to results in packing S-connectors, a generalization of spanning trees introduced by Wu and West. (Received September 20, 2015)

1116-VF-1682 **Elliot M Laforge*** (elliot.m.laforge@wmich.edu). *Chromatic Connections in Graphs.*

Let G be an edge-colored connected graph. A path P is a proper path in G if no two adjacent edges of P are colored the same. If P is a proper u-v path of length d(u, v), then P is a proper u-v geodesic. An edge coloring c is a proper-path coloring of a connected graph G if every pair u,v of distinct vertices of G are connected by a proper u-v path in G, while c is a strong proper-path coloring if every two vertices u and v are connected by a proper u-v geodesic in G. The minimum number of colors required for a proper-path coloring and strong proper-path coloring of G is called the proper connection number and strong proper connection number of G, respectively. Several results and open questions are presented in this area of research. (Received September 21, 2015)

1116-VF-1705 **Axel Brandt*** (axel.brandt@ucdenver.edu), **Bernard Lidický** (lidicky@iastate.edu) and **Florian Pfender** (florian.pfender@ucdenver.edu). *Short Induced Cycles in Graphs.*

In 1975, Pippinger and Golumbic conjectured that the maximum induced density of a k-cycle in graphs is $k!/(k^k - k)$ when $k \geq 5$. Recently, Balogh, Hu, Lidicky, and Pfender solve this conjecture for $k = 5$. In this talk, we investigate larger k using flag algebra computations and stability methods. (Received September 21, 2015)

1116-VF-1800 **Jessie Lenarz*** (jklenarz@stkate.edu). *Using Graphs to Examine Benzene-like Structures.*

Benzene is an important structure in chemistry due to its stability and the stability it can provide to a molecule. Benzenoids are structures that have benzene rings in them and can be modeled by a graph composed of hexagons with a perfect matching to indicate the placement of double bonds. The Fries number of a hexagonal system is the maximum number of benzenes in a perfect matching of the system, while a Fries structure is a perfect matching realizing its Fries number. Similarly, the Clar number of a hexagonal system is the maximum number of benzenes in a perfect matching of the system so that no two benzenes are adjacent, while a Clar structure is a perfect matching realizing its Clar number while maintaining the non-adjacency condition. We determined the Fries and Clar numbers for certain hexagonal systems and enumerated the Fries and Clar structures for those systems in an effort to determine the stability of the associated molecules. (Received September 21, 2015)

1116-VF-1968 **Dalal Alrowaili*** (daa2v@mtmail.mtsu.edu), **Dong Ye** and **Xiaoya Zha**. *Finding all small induced cycles in polynomial-time.* Preliminary report.

Let G be a graph. A cycle of G is induced if it has no chords. In computational chemistry, graphs serve as abstract models for molecules. Small induced cycles of graphs are referred to rings of molecules, which have important physical meanings in Chemistry. In this talk, we develop a polynomial time algorithm to find all small induced cycles in a given graph. (Received September 21, 2015)

1116-VF-1977 **Demitri Plessas*** (plessas@nsuok.edu), Dept. of Mathematics and Computer Science, Northeastern State University, 611 N. Grand Ave., Tahlequah, OK 74464, and **Tien Chih** (tien.chih@newberry.edu), Newberry College, 2100 College St., Newberry, SC 29108. *Graphs Are Uniquely Determined by Their Inverse Semigroup.*

Automorphism groups are one of the primary algebraic tools of Graph Theory. However, automorphism groups are too coarse an algebraic tool to distinguish graphs, and many non-isomorphic graphs will have isomorphic automorphism groups. One may view the study of the fixing number and the distinguishing number as a way to refine this coarse nature of the automorphism group via group actions.

Algebraically formalizing Lovàsz's use of local symmetry to solve the edge reconstruction conjecture for graphs with n vertices and m edges where $m \geq 1/2\binom{n}{2}$, we define the full inverse semigroup of a graph to be the inverse semigroup of all partial isomorphisms between subgraphs of the graph. We show the full inverse semigroup determines the graph in the sense that two graphs are isomorphic if and only if their associated inverse semigroups are isomorphic. (Received September 21, 2015)

1116-VF-1987 **Miaomiao Han*** (mahan@mix.wvu.edu) and **Rong Luo** (rongluo2007@gmail.com). *Neighbor sum distinguishing total coloring of graphs.* Preliminary report.

A proper k-total coloring of a graph G is a mapping from $V(G) \cup E(G)$ to $\{1, 2 \cdots, k\}$ such that no adjacent or incident elements in $V(G) \cup E(G)$ receive the same color. Let $m(v)$ denote the sum of colors on the edges incident with v and the color on vertex v. A proper k-total coloring of G is called neighbor sum distinguishing if $m(u) \neq m(v)$ for each edge $uv \in E(G)$. Let $\chi^t_\Sigma(G)$ be the neighbor sum distinguishing total chromatic of a graph G. Pilśniak and Woźniak proposed the conjecture that for any graph G, $\chi^t_\Sigma(G) \leq \Delta(G)+3$. In this paper, we obtain that if G is a graph with treewidth $l \geq 3$, and $\Delta(G) \geq \max\{8, 3l-2\}$, then $\chi^t_\Sigma(G) \leq \Delta(G) + l - 1$. (Received September 21, 2015)

1116-VF-2043 **Daniel J Poole*** (poole@math.osu.edu), 231 W 18th Ave, Columbus, OH 43210. *The giant strong component in random directed graphs.*

We study the random directed graph models $D(n, m)$ and $D(n, p)$. In 1990, Karp for $D(n, p = c/n)$ and independently Łuczak for $D(n, m = cn)$ proved that for $c > 1$, with probability tending to 1, there is an unique strong component of size of order n. Karp showed that the giant component has likely size asymptotic to $n\theta^2$, where $\theta = \theta(c)$ is the unique positive root of $1 - \theta = e^{-c\theta}$. We prove that, for both random digraphs, the joint distribution of the number of vertices and number of arcs in the giant strong component is asymptotically Gaussian with the same mean vector $n\mu(c) := (\theta^2, c\theta^2)$, and two distinct 2×2 covariance matrices, $nB(c)$ and $n[B(c)+c\mu'(c)^T\mu(c)]$. To this end, we introduce and analyze a randomized deletion process which determines the directed (1,1)-core, the maximal subgraph with minimum in-degree and out-degree at least 1. We show that the likely numbers of peripheral vertices and arcs in the (1,1)-core, those outside the largest strong component, are of poly-log order. By approximately the likely realization of this deletion process with a deterministic trajectory, we obtain our distributional result via exponential supermartingales and Fourier-based techniques. Joint with Boris Pittel. (Received September 21, 2015)

1116-VF-2075 **Addie E. Armstrong*** (aearmstrong@uri.edu). *On three coloring planar graphs containing no C_4, C_5, or triangles sharing a vertex.*

In 1976, Richard Steinberg conjectured that any planar graph without 4-cycles or 5-cycles can be three-colored. Like the related Four Color Problem, a great deal of work has been directed toward proving Steinberg's conjecture, but to date none has been entirely successful. An (i_1, i_2, i_3)-coloring is a defective three-coloring in which any vertex colored in the first color may have i_1 neighbors sharing its color, any vertex colored with the second color may have i_2 neighbors of the same color, and so on. In this talk, we discuss a method to attack Steinberg's conjecture using defective three-colorings and a restriction upon triangles sharing vertices. (Received September 21, 2015)

1116-VF-2185 **Misa Nakanishi*** (misa.nakanishi@gmail.com). *The decomposition of a cubic graph for the domination number.*

We investigate the domination number and independent domination number for a graph. It is fundamental to decompose a graph into two parts so that the domination number is counted for each part. First, we give a decomposition of general graphs. Second, we consider it for a cubic graph. Previously, it was conjectured that the difference between the domination number and independent domination number for a cubic graph with connectivity three is at most one and it was disproved. In this talk, we present that the domination number and independent domination number for a cubic graph are the same as the lower bounds. A cubic graph is decomposed into two parts that have minimum dominating sets as independent sets. (Received September 22, 2015)

1116-VF-2187 **Christine T Cheng** and **Will Rosenbaum*** (wrosenbaum@math.ucla.edu). *Stable Matchings with Bounded Preferences.* Preliminary report.

An instance I of the Stable Marriage Problem consists of a finite bipartite graph, $G = (M \cup W, E)$, where each vertex has *preferences* in the form of a linear order over its neighbors. The goal is to find a matching μ which is *stable* in the sense that no pair $(m, w) \in E$ mutually prefer each other to their partners in μ. In their seminal work, Gale and Shapley prove that such a stable matching exists for any instance I.

The set of all stable matchings forms a distributive lattice, which can be realized as the lattice of order ideals of the *rotation poset* $\Pi(I)$. We prove that even if G is restricted to have maximum degree 3, given any finite poset $\mathcal{P}$, one can efficiently construct an instance I such that $\Pi(I) \simeq \mathcal{P}$. Thus, the distributive lattice of stable matchings can be arbitrary for bounded degree graphs. Our construction—which extends a classical result of Irving and Leather—has applications to computational complexity and economics. (Received September 22, 2015)

1116-VF-2219 **Mathias Hudoba de Badyn*** (hudomath@uw.edu), Seattle, WA 98195. *Algebraic Graph Theoretic Methods in Control Theory.*

In this talk, I will present an overview of results from the control theory of networked systems that use methods based in algebraic graph theory. First, I will discuss how the graph Laplacian spectrum relates to the controllability and observability of the controlled diffusion (or consensus) dynamics. Secondly, I will discuss how the graph automorphism group is used to characterize controllable graphs. Lastly, I will present some open problems in the field. (Received September 22, 2015)

1116-VF-2325 **Steven Schluchter*** (sschluch@gmu.edu), Department of Mathematical Sciences, George Mason University, 4400 University Drive, MS: 3F2, Fairfax, VA 22030, and **Tom Wilson** (twilso19@masonlive.gmu.edu), Department of Mathematical Sciences, George Mason University, 4400 University Drive, MS: 3F2, Fairfax, VA 22030. *Prime labelings of generalized Petersen graphs and large cubic bipartite graphs.*

A graph G is called prime if there exists a labeling of the vertices of G with distinct labels $1, 2, \ldots, |V(G)|$ such that the labels on any two adjacent vertices are relatively prime. S. Schluchter, J. Schroeder, T. Wilson, et. al. conjectured that the generalized Petersen graph $P(n,k)$ is prime iff $P(n,k)$ is bipartite (which is true for even n and odd k), and they verified the conjecture for all even $n \leq 50$ and odd $k < \frac{n}{2}$. We introduce a labeling method that we have used to produce prime labelings for $P(n,k)$ for $n \leq 8000$ and $k < \frac{n}{2}$. We also introduce another labeling method that we have used to produce prime labelings for all cubic bipartite graphs having at most 22 vertices, except $K_{3,3}$, which is not prime. (Received September 22, 2015)

1116-VF-2358 **Justin R Hughes*** (jhughes@towson.edu), 7800 York Rd Room 365, Towson, MD 21252. *A Group Action on Neighborhood Complexes of Cayley Graphs.*

Given G a group generated by $S = \{g_1, .., g_n\}$, one can construct the Cayley graph. Given a distance set D, a subset of nonnegative integers, and a Cayley graph, one can construct a D-neighborhood complex. This neighborhood complex is a simplicial complex to which we can associate a chain complex. The group G acts on this chain complex and this leads to an action on the homology of the chain complex. These group actions decompose into several representations of G. This presentation will discuss tools from group theory, representation theory, and homological algebra which are used to further our understanding of the interplay between generated groups, corresponding representations on their associated D-neighborhood complexes, and the homology of the D-neighborhood complexes. This presentation will quickly summarize known results for the case when $|S| = 2$ and will then discuss the current work on the case when $|S| > 2$. (Received September 22, 2015)

1116-VF-2367 **Henry E Escuadro*** (escuadro@juniata.edu), **Ian Garces**, **Agnes Garciano**, **Reginaldo Marcelo** and **Mari-Jo Ruiz**. *On the Star Arboricity of the Zero-Divisor Graph $\Gamma(Z_{p^n})$.*

A *star forest* is a forest each of whose components is a star. The *star arboricity* of a graph G, denoted by $st(G)$, is the minimum number of star forests whose union covers all the edges of G. A nonzero element of a commutative ring R with unity is said to be a *zero-divisor* of R if there exist a nonzero element $y \in R$ such that $xy = 0$. Given a ring R with unity, the *zero-divisor graph of* R, denoted by $\Gamma(R)$, is the graph whose vertex set consists of the zero divisors of R and two vertices $x, y \in V(\Gamma(R))$ are adjacent if and only if $xy = 0$ in R. This paper investigates the star arboricities of the zero divisor graphs $\Gamma(Z_{p^n})$ where $n, p \in N$ and p is a prime. In particular, we give bounds for $st(\Gamma(Z_{p^n}))$ and determine the values of $st(\Gamma(Z_{p^n}))$ when n is even. (Received September 22, 2015)

1116-VF-2418 **Dennis Hall*** (dennis@dennishall.net). *Unavoidable Minors for 2-connected k-hypergraphs.* Preliminary report.

It is well know that, for any integer n greater than one, there is a number r such that every 2-connected simple graph with at least r edges has a minor isomorphic to an n-edge cycle or $K_{2,n}$. This result was extended to matroids by Lovasz, Schrijver, and Seymour who proved that every sufficiently large connected matroid has an n-element circuit or an n-element cocircuit as a minor. An analogous result for k-polymatroids has been partially developed, but lacks an explicit description of the minors in all cases except for when $k = 2$. However, an explicit description is possible for 2-connected k-hypergraphs. In this talk, we use results on polymatroids to provide a list of unavoidable minors for 2-connected k-hypergraphs. (Received September 22, 2015)

1116-VF-2613 **Jozsef Balogh**, **Theodore Molla*** (molla@illinois.edu) and **Maryam Sharifzadeh**. *Factors in graphs, weighted graphs and directed graphs.*

A factor is a subgraph that contains all of the vertices of its host graph. For instance, a perfect matching is a factor consisting entirely of disjoint edges and a Hamiltonian cycle is a factor that is a cycle. Many celebrated theorems in graph theory give sufficient conditions for the existence of a specific factor. For example, Dirac's Theorem states that if G is a graph on n vertices, $n \geq 3$ and the minimum degree of G is at least $n/2$, then G contains a Hamiltonian cycle. In this talk, we will describe several related theorems for graphs, directed graphs and weighted graphs. For example, we will discuss the following recent result: For every $\varepsilon > 0$ there exists $\gamma > 0$ such that if G is a graph on n vertices, the minimum degree of G is at least $(1/2 + \varepsilon)n$ and the independence number of G is at most γn, then G has $n/3$ vertex disjoint copies of K_3 when n is sufficiently large and divisible by 3. (Received September 22, 2015)

1116-VF-2618 **Jiaao Li*** (joli@mix.wvu.edu), Department of Mathematics, West Virginia University, Morgantown, WV 26506-6310, and **You Lu** and **Rong Luo**. *Adjacent vertex distinguishing total coloring of graphs with small maximum degree.*

An adjacent vertex distinguishing (for short, AVD) total k-coloring ϕ of a graph G is a total k-coloring of G such that no pair of adjacent vertices meets the same set of colors, where the set of colors at an vertex v is $\{\phi(v)\} \cup \{\phi(e) : e \text{ is incident to } v\}$. Zhang et al. conjectured in 2005 that every graph with maximum degree Δ has an AVD total $(\Delta + 3)$-coloring. In this paper, by applying the Combinatorial Nullstellensatz, we verify the conjecture for all graphs with $\Delta \leq 4$. This is a joint work with You Lu and Rong Luo. (Received September 22, 2015)

1116-VF-2640 **Murong Xu*** (xumurong@math.wvu.edu), Department of Mathematics, Morgantown, WV 26505-6310, and **Hong-Jian Lai** (hjlai@math.wvu.edu), Department of Mathematics, Morgantown, WV 26505-6310. *r-hued coloring of graphs having no $K_{3,3}$ minor.*

For positive integers k and r, a (k, r)-coloring is a proper k-coloring c of G such that $|c(N(v))| \geq \min\{d(v), r\}$ for any $v \in V(G)$. We will present some of the recently achieved results on r-hued coloring of graphs having no $K_{3,3}$ minor. (Received September 22, 2015)

1116-VF-2724 **Sarvasva Raghuvanshi*** (kepler1729@gmail.com), 2944 Forest Creek Lane, Naperville, IL 60565. *New Results on Ramsey Multiplicity and Graph Commonality.* Preliminary report.

Social network-based companies like Twitter and Facebook rely on their ability to analyze large networks and exploit structures within these networks for profit. We can study these large networks by analyzing what structures we are guaranteed to find inside any large network with a minimum frequency; these small structures are known as *common graphs*. This presentation provides a modern proof of the existing result that a structure formed from disjoint copies of a common graph is also common. The method of proof yields novel partial results and poses new questions about the commonality of disjoint graphs. We also prove the commonality of the pentagon with a chord, resolving an outstanding open question in the field of graph commonality.

The work behind this research has applications to analysis of any large network (like a social network or the Internet) by paving the road towards identifying substructures that are high-value research targets. This paper also has applications to ecology and urban planning by identifying common habitat patterns (like a forest with two lakes, which can be modeled in a large graph by a pentagon with a chord). These specific habitats can be prioritized for development or preservation depending on their environmental impact. (Received September 22, 2015)

1116-VF-2826 **Wayne Goddard** and **Honghai Xu*** (honghax@g.clemson.edu). *Vertex Colorings without Rainbow Subgraphs.*

Consider a coloring of the vertices of a graph. We say that a subgraph is *rainbow* if all its vertices receive different colors. We define the F*-upper chromatic number* of G as the maximum number of colors that can be used to color the vertices of G such that there is no rainbow copy of F. We present some results on this parameter for certain graph classes. The focus is on the case that F is a star or triangle. For example, we show that the K_3-upper chromatic number of any maximal outerplanar graph on n vertices is $\lfloor n/2 \rfloor + 1$. (Received September 22, 2015)

1116-VF-2846 **Nándor Sieben*** (nandor.sieben@nau.edu). *The t-pebbling number of a path of graphs.* Preliminary report.

Given a distribution of pebbles on the vertices of a connected graph, a pebbling move removes two pebbles at a vertex and places one pebble at an adjacent vertex. One pebble is the cost of transportation. A vertex is t-reachable if at least t pebbles can be moved to the vertex using pebbling moves. The t-pebbling number of a graph is the minimum number of pebbles that ensures that any vertex is t-reachable from any initial distribution of the pebbles. A path of graphs is a path in which every vertex is replaced by a graph, and new vertices replacing old adjacent vertices are joined by edges. We determine the t-pebbling number of a path of graphs. (Received September 22, 2015)

1116-VF-2894 **Daniel Johnston*** (daniel1.johnston@umontana.edu). *On k-Ramsey Numbers of Non-bipartite Graphs.*

In a red-blue coloring of a graph G, every edge of G is colored red or blue. For two graphs F and H and an integer k with $2 \leq k \leq R(F,H)$, where $R(F,H)$ is the Ramsey number of F and H, the k-Ramsey number $R_k(F,H)$ of F and H is the smallest order of a balanced complete k-partite graph G such that every red-blue coloring of G results in a red F or a blue H. When F and H are bipartite, $R_k(F,H)$ is know to exist for each such integer k. When F and H are not bipartite that is not the case. We look at some of these results. (Received September 22, 2015)

1116-VF-2899 **Janet Fierson*** (fierson@lasalle.edu), Dept. of Mathematics and Computer Science, La Salle University, 1900 W. Olney Ave., Philadelphia, PA 19141, and **Jackson Swindells**. *Variations on coloring graphs under rainbow connection.*

Given a graph G, positive integer k, and coloring method M, there are various ways to create a k-coloring graph of G. The first two steps in the process are always the same: Identify all proper colorings of G using up to k colors under method M. Then, for each such coloring, create a vertex in the k-coloring graph of G. Different rules are possible for placing edges in the coloring graph, but a common practice is to create an edge between two vertices if and only if their corresponding colorings of G differ in a single vertex or edge.

The concept of the coloring graph had previously been investigated under the methods of vertex coloring and edge coloring. We recently presented preliminary results for the coloring graph under rainbow connection using the common practice for specifying edges described above. In this talk, we provide a more comprehensive set of results for this case and highlight the results that are unique to rainbow connection. We also consider a method with more restrictive requirements for coloring the original graph G, as well as variations on the rules for creating edges in the coloring graph. (Received September 22, 2015)

1116-VF-2960 **Taoye Zhang*** (tuz3@psu.edu), 120 Ridge View Dr, Dunmore, PA 18512. *Pancyclicity of 4-Connected Claw-free Net-free Graphs.*

A graph G is said to be pancyclic if G contains cycles of lengths from 3 to $|V(G)|$. The net $B(i,j)$ is obtained by associating one endpoint of each of the path P_{i+1} and P_{j+1} with distinct vertices of a triangle. Ferrara et al. (2013) showed that every 4-connected $\{K_{1,3}, B(i,j)\}$-free graph with $i+j=6$ is pancyclic. We prove that every 4-connected $\{K_{1,3}, B(i,j)\}$-free graph with $i+j=7$ is either pancyclic or it is the line graph of the Petersen graph. (Received September 23, 2015)

General Session on History of Philosophy of Mathematics

1116-VG-106 **Amy Ackerberg-Hastings*** (aackerbe@verizon.net). *John Playfair and His Misnamed Axiom.*

Despite widespread knowledge of "Stigler's law of eponymy," references to the misattributed "Playfair's Axiom" continue to appear in textbooks and online. This talk will look at the history of various forms of the statement, including where Playfair himself said he found it. I will also consider candidates for who can be credited with associating Playfair's name with the axiom. I draw upon previous comments, such as those by G. B. Halsted and David Henderson and Daina Taimina, as well as my own ongoing biographical work on Playfair. (Received July 25, 2015)

1116-VG-946 **Colm Mulcahy***, colm@spelman.edu. *A model for public documentation and sharing of the long-term achievements of graduates of mathematics programs in both regional and institutional contexts.* Preliminary report.

How does one document the careers of "all" mathematicians from a certain region, such as Ireland, say for the last 200 years? Or the careers of all mathematics graduates of a certain institution, such as Spelman College? Web searches quickly reveal the limitations, inaccuracies and incompleteness of what is already freely available online.

We present a model for shareable "archives" on the web which has been used to successfully document some key facts about more than 2000 people in the two categories indicated. We also discuss the use of social media in helping to disseminate worthy highlights in both cases, such as via @IrishMathsFacts and @Spelman_Math on Twitter.

Advantages include building community, engaging alumni, and showcasing the power of mathematics to drive careers, as well as having better evidence when trying to answer questions such as "What percentage of those with masters in a mathematical science go on to get PhDs?" or "What percentage of those with bachelors in mathematics go to law school?" (Received September 15, 2015)

1116-VG-1621 **Shigeru Masuda*** (hj9s-msd@asahi-net.or.jp), 2-18-5, Fuchu, 183-0002, Japan. *The Fluid Dynamics and the Heat Theory by Poisson.* Preliminary report.

We discuss historical development of classical fluid dynamics and heat theory from the viewpoint of mathematical history, in particular, of Poisson.

These situations owe to the arrival of continuum, on which we summarize the trailblazers of the trigonometric series such as Euler, Lagrange, Laplace, et al.,

Poisson issues the last work in 1835 in rivalry to Fourier and Navier, in which he discusses the essential theories for the expression between fluid motion and heat motion, emphasizing mathematical points such as complete integral in his three digressions.

Prévost's work on heat communication, which precedes Fourier, and whose initial scholar work and after it.

Sturm and Liouville refer Poisson's tools such as particular value and particular function, entire function, to solve the differential problems. Poincaré referring to many preceding works such as Laplace, Fourier, Dirichlet, Cauchy, except for Poisson, makes an offer of the modern guidance for mathematics not only on heat theory but also on pure mathematics.

Comparing these books and papers, we show the connection between the hydrodynamics, wave and heat dynamics, and the process of new mathematics putting forth in applied or physical mathematics. (Received September 20, 2015)

1116-VG-1826 **John F. Bukowski*** (bukowski@juniata.edu), Juniata College Dept. of Mathematics, 1700 Moore Street, Huntingdon, PA 16652. *van der Pol's Tablecloth: Highlights from the Balthasar van der Pol Collection at Museum Boerhaave.*

The Museum Boerhaave in Leiden, Netherlands, houses the archive of Balthasar van der Pol (1889-1959), the Dutch mathematician, physicist, and engineer. We will examine highlights of the collection, including correspondence, lecture notes, manuscripts, musical compositions, and a tablecloth based on Gaussian primes. (Received September 21, 2015)

1116-VG-2011 **Johannes C. Familton*** (jfamilton@bmcc.cuny.edu). *Olinde Rodrigues: banker, activist and mathematician.* Preliminary report.

Benjamin Olinde Rodrigues (1795–1851), was born into a family of Iberian Jews residing in France. His interesting life as an activist and banker was superseded by his life as a mathematician. He made three mathematical discoveries that preceded those who were initially given credit for them. For his PhD. Thesis in 1815 he wrote on what would later be connected with Legendre polynomials and is known today as Rodrigues' formula. In 1840 he wrote a paper using Euler's Four Square formula to represent rotations in space, this was a precursor to Hamilton's quaternions. Also in this paper Rodrigues provided an algorithm to compute the exponential map on the Lie algebra SO(3). In this talk Dr. Familton will discuss this fascinating man's life and his mathematical contributions. (Received September 22, 2015)

1116-VG-2086 **Dusty W. Wilson*** (dwilson@highline.edu). *A Triune Philosophy of Mathematics.*

What is mathematics and is it discovered or invented? The Humanist, Platonist, and Foundationalist each provide answers. But are the options within the philosophy of mathematics so limited? Rather than viewing and describing mathematics in a mutually exclusive manner, each of these approaches includes components of truth from a greater triune philosophy of mathematics. This talk will introduce this inclusive triune paradigm through which to explore fundamental questions about mathematics. (Received September 21, 2015)

1116-VG-2182 **Meredith L. Greer*** (mgreer@bates.edu), Hathorn Hall, Bates College, Lewiston, ME 04240. *A 2016 Calendar of Math in Berlin: Twelve Historical Moments That Influence Us Today.*

Berlin is a city rich in mathematical history. Some of the best known mathematicians in the world - Euler, Leibniz, and others - have worked there. Local museums showcase ancient and modern art and architecture that remind us of the influence of mathematical thought across millennia. Past royal family members, including Queen Sophia Charlotte, invited mathematicians and scientists to visit and share their knowledge. City life today, including universities, public monuments, open lectures, activities for children, and more, promotes knowledge and enjoyment of mathematics to a wide variety of audiences.

This talk features twelve selections from the panoply of Berlin mathematical offerings. Discussion of each includes both historical context and current-day impact. (Received September 22, 2015)

1116-VG-2293 **Steve Leonhardi*** (sleonhardi@winona.edu), Winona State University, Department of Mathematics & Statistics, Winona, MN 55987. *Using Debates To Study the History of Mathematics.*

Many debatable questions arise as recurring themes in studying the History of Mathematics. For example, is mathematics advanced and developed more by the creative work of a few individual geniuses, or by supportive mathematical communities? Are mathematical advances stimulated more by theory or by applications? Having students carry out a formal debate can an effective method of investigating such a question. We will discuss logistics, benefits, hazards, and lessons learned. (Received September 22, 2015)

1116-VG-2856 **Samaneh G. Hamidi*** (s.hamidi@mathematics.byu.edu), Department of Mathematics, Brigham Young University, Provo, UT 84604. *Famous Mathematicians From Iran But Whom You May Not Know.*

Iranians have made several significant contributions to mathematics. However, both Iranians mathematicians and their contributions are not well known in the U.S. In this talk, we will present some of these contributions including the Persian Mathematician and Father of Modern Algebra, Muhammad ibn-Musa Al-Khwarizmi; the Persian Mathematician and Poet, Omar Khayyam; and the Persian Mathematician Nasir al-Din Tusi who formulated the famous law of sines. (Received September 22, 2015)

General Session on Interdisciplinary Topics in Mathematics

1116-VH-162 **James A. Vance*** (jav6e@uvawise.edu), One College Avenue, Wise, VA 24293. *Undergraduate Research in Mathematical Biology with limited Faculty, Students, and Resources.*

The University of Virginia's College at Wise is a small liberal arts college with just over 2000 students. The Department of Mathematics and Computer Science has two tenure track professors of mathematics and graduates an average of 6 math majors per year. With such limited faculty, students, and resources, undergraduate research is a challenge. Over half of the math majors are seeking secondary teacher licensure which requires a semester of student teaching. This creates a conflict with the requirement that all math majors complete a semester long research paper and presentation since most students must complete the research before or while taking upper level courses. For mathematical biology, many of our students do not have enough of a biology background to do significant research. If some cases the challenges have been overcome and students have presented their research in mathematical biology at regional undergraduate research conferences and on occasion at conferences like the International Symposium on Biomathematics and Ecology Education and Research. Topics range from elk home range methods to sensitivity equations for omnivory models. A few projects have resulted in publication in peer reviewed journals. (Received August 10, 2015)

1116-VH-169 **Benjamin Morin*** (brmorin@asu.edu), **Charles Perrings**, **Ann Kinzig** and **Simon Levin**. *The social benefits of private infectious disease-risk mitigation.*

Does society benefit from private measures to mitigate infectious disease risks? Since mitigation reduces peak prevalence and the number of people who fall ill, the answer might appear to be yes. But mitigation prolongs epidemics and the time susceptible people avoid infection. These avoidance activities come at a cost. Whether private mitigation yields net social benefits depends on the social weight given to the costs of illness and illness avoidance, now and into the future. We show that, for a large class of infectious diseases, private risk mitigation is socially beneficial. However, in cases where society discounts the future at either very low or very high rates relative to private individuals, or where it places a low weight on the private cost of illness, the social cost of illness under proportionate mixing (doing nothing) may be lower than the social cost of illness under preferential mixing (avoiding infectious individuals). That is, under some circumstances, society would prefer shorter, more intense epidemics without avoidance costs over longer, less intense epidemics with avoidance costs. A sobering (although not surprising) implication of this is that poorer societies should be expected to promote less private disease-risk mitigation than richer societies. (Received August 11, 2015)

1116-VH-533 **Brittany Bannish*** (bbannish@uco.edu). *Enzyme diffusion through a degrading blood clot.*
Fibrinolysis is the enzymatic degradation of the fibrin fibers that stabilize blood clots. We developed a stochastic multiscale model of fibrinolysis which can be used to study both single fiber and full clot degradation. In this talk, we examine the effective diffusion of tissue-type plasminogen activator (tPA) through the clot. tPA (a key fibrinolytic enzyme which is used clinically as a stroke therapy) initiates fibrinolysis by creating plasmin, the enzyme that degrades fibrin. We find that the number of fibers in the clot, as well as the amount of plasmin present in the clot (which can be modulated by inhibitors), help determine the effective diffusion of tPA through the clot. These results can aid in the development of more effective stroke therapies. (Received September 05, 2015)

1116-VH-722 **Mili I Shah*** (mishah@loyola.edu). *Using Mathematics to Aid in the Registration of Robotic Systems.*
Imagine being hired to pick a robot that manufactures parts in an assembly line. There are many robots on the market that employ different computer vision systems that allow the robots to "see." How do you choose which vision system is the best? One method is to compare the data collected from a given vision system with data that is considered ground truth (the true solution). However, the data collected from each vision system are with respect to their own coordinate frame. Thus, transformations are needed to place the data into a common coordinate frame. This talk will begin with an overview of the mathematical tools needed to setup this problem and will conclude with previous and current research related to solving this registration problem. (Received September 20, 2015)

1116-VH-805 **Anastasia Bridner Wilson***, anastas@clemson.edu. *Protein Adsorption in Porous Membranes.*
Protein therapeutics have been widely used over the last 80 years as a treatment for various illnesses (e.g. diabetes, cancer, hemophilia, anemia, infectious diseases). The protein therapeutics market is expected to grow 15% annually through the next decade, and by 2016, 50% of the top 100 drugs will most likely be biologics, that is drugs derived from biotechnology. A high percentage (more than 60%) of the total cost in protein therapeutics is associated with the purification part of the separation; consequently modeling and optimization of the protein purification process could greatly decrease the cost of protein therapeutics.

In this presentation, we will discuss a method of protein separation using multi-modal porous membranes recently developed in Clemson University's chemical engineering department. We will present numerical simulations of the advection-diffusion-reaction equation which can be used to model these membranes. We will focus specifically on different models for protein adsorption. We will also present a brief analysis of the breakthrough curves obtained from the numerical simulations. (Received September 13, 2015)

1116-VH-958 **William Severa*** (wmsever@sandia.gov), **James Bradley Aimone** and **Ojas Parekh**. *A Sparse Coding Model of the Hippocampal Dentate Gyrus.*
Acting as a conduit from the entorhinal cortex (input from neocortex) to the CA3 (associative attractor network) within the hippocampus, the dentate gyrus is believed to increase the sparseness and separation of the original input signal. This action has been described as critical for the formation of fixed-point memories in the attractor landscape downstream. However, rigorous models of these systems' interactions are rare. We take a bottom-up approach and discuss a neural-inspired idealized model of the dentate gyrus sparse coding process. Combinatorial properties of this coding method point to biological plausibility and have implications for a dynamical CA3 attractor network. Moreover, the current canonical grid cell (navigation) model is group isomorphic to a special case of our domain space. By generalizing this special case, we simultaneously obtain biologically realistic scope and resolve several issues with the traditional grid cell model. (Received September 21, 2015)

1116-VH-1090 **Nicole A. Fider*** (nfider@uci.edu) and **Natalia Komarova**. *A numerical method to explain how colors are categorized.* Preliminary report.
Color categorization in humans is a fascinating topic in psychology and linguistics. Understanding color categorization will shed light on how people think about the world in general. We are interested in the mathematics of formalizing the concept of human color categorization. Individuals can divide the color space in different ways; it is accepted that in a linguistically unified society, there exists a specific set of Basic Color Terms (BCT's below) and corresponding Basic Color Regions which the population agrees to use when categorizing the color space. We propose a mathematical method for identifying the BCT's of a given language based on real-world data. By defining a function which measures how well a color term is understood by the population, we can use a threshold value to separate the BCT's from the non-basic color terms. To demonstrate our method, we focus on cultures who are represented in the World Color Survey data archives. (Received September 16, 2015)

1116-VH-1753 **Arnold Yim*** (ayim@purdue.edu), 150 N University St, West Lafayette, IN 47907. *Cake cutting, cartography, and flows along barriers.*

Given a cake, if you makes n cuts, how many pieces will you have? The answer depends rather much on exactly how you make the cuts. Using a counting technique called "deletion-restriction," one can give a recursive answer. This in turn can be used to determine how to make the maximum number of pieces with n cuts, and what that number is.

Seemingly unrelated, if we are given a graph, one might consider the ways to color the vertices of the graph while making sure that adjacent vertices have different colors. Interestingly, we can also count the number of ways using "deletion-restriction."

In yet a different setup, the ideas behind "deletion-restriction" show up when one looks at flows (that is, vector fields) which are tangent to each one of a collection of planes in space. Intriguingly, the study of these flows can actually help us answer our counting problems.

The talk will explain the connections between cutting, coloring, and flowing, by way of pictures and examples. (Received September 21, 2015)

1116-VH-1828 **Kyle Evans*** (kyle.evans@uconn.edu), **Christopher R Bennet**, **Megan E Brunner** and **Fabiana Cardetti**. *Towards developing intercultural competence with interdisciplinary topics in mathematics.*

As today's world becomes increasingly more globalized, there is a greater need to develop intercultural competence (ICC) in children through education. In this study we focused on addressing this need through mathematics by drawing on a model of ICC for education developed by Michael Byram. We created lesson plans to be used in mathematics classrooms that incorporate core ideas of different disciplines to help students get a better understanding of the mathematics while also attending to the development of their intercultural competence. In addition, we created two assessment tools - a survey to assess attitudes towards and knowledge of cultures and learning across content areas, and a rubric to assess interactions and reflections. In this presentation we will share the lesson plans and the assessment tools, as well as describe the theories that guided our work. We will also discuss how these ideas can be expanded or modified to incorporate other interdisciplinary topics in mathematics. (Received September 21, 2015)

1116-VH-1844 **Alison M. Marr*** (marra@southwestern.edu) and **Fumiko Futamura**. *Math and Study Abroad: Two Examples from a London Semester Program.*

Southwestern University offers students a semester long study abroad experience in London every Fall semester. Each year, two Southwestern faculty members from different disciplines help lead the program. In this talk, we will share our two experiences teaching mathematics in the program in 2011 and 2014 respectively. We will discuss how we integrated the London environment into our various course assignments for interdisciplinary classes including statistics, cryptography, math and art, and the history of math during the Victorian era. We will also provide ways in which our classes could be modified for other countries and study abroad experiences. (Received September 21, 2015)

1116-VH-1941 **Christopher J Hanson**, **Matthew R Hayden** and **Rachel G Kaale*** (rachel.kaale@my.simpson.edu). *Removing ocular artifact from electroencephalogram data utilizing eye-tracking technology.* Preliminary report.

Electroencephalogram (EEG) data is often riddled with unwanted artifact including, but not limited to eye blinks and eye movements, interference from AC electrical devices, changes in skin potentials, and muscle activity. These artifacts can make it very difficult to accurately interpret EEG data. Therefore, this research has been dedicated to creating a novel approach for ocular artifact removal in EEG data that utilizes eye-tracking technology, is simpler than other widely-used methods, and requires only a small number of EEG channels. These goals were accomplished with the Simpson College Eye-Track Algorithm (SCETA) which was developed in MATLAB. This algorithm utilized matrix mathematics and statistical analysis to accurately remove artifacts created by eye blinks. During the fall of 2015, an IRB approved study was conducted to test the technique and it was found that while SCETA was not as effective as some other artifact correction techniques such as Independent Component Analysis, its speed, versatility, and applicability to data sets with small numbers of channels make it a strong option as an ocular artifact correction technique. (Received September 21, 2015)

1116-VH-2327 **Carter G. Murray*** (camurray@nmu.edu), 530 South. 32nd Street, Escanaba, MI 49829. *Mobius Transformations: The Orbits of Various Mobius Mappings.* Preliminary report.

A Mobius map is a transformation from the sphere to itself that distorts distance but preserves angles. We will begin by showing that any Mobius transformation is a composition of very basic geometric mappings. Next we will show how beautiful patterns can emerge from repeatedly applying Mobius transformations. This highly visual presentation features many pictures and computer animations and will touch on connections between complex analysis, group theory, linear algebra, dynamical systems and perhaps even art. (Received September 22, 2015)

1116-VH-2410 **Shantia Yarahmadian*** (syarahmadian@math.msstate.edu), **Leonard Richard Young** and **Meisam Sharify**. *A Mathematical Model for Alzheimer Disease and its Treatment Based on the anti-aggregation inhibitors drugs.* Preliminary report.

Alzheimer's disease (AD) is characterized by impaired memory and cognition. A principal criteria for the underlying cause of the disease is the amyloid hypothesis, which argues that amyloid $A\beta$ peptide dysregulation initiates a cascade of neuropathological formation of amyloid plaques, neurofibrillary tangles, synaptic loss, and neurodegeneration that ultimately result in the abrupt decline in cognition and ability to function in daily life that define AD dementia. In this work, we propose a mathematical model as a set of coupled kinetic equations that captures the formation of the $A\beta$ fibrils as well as the impact of small molecule anti-aggregation inhibitors acting as a drug in degradadtion clearance. (Received September 22, 2015)

1116-VH-2412 **Lee Fisher*** (fisherla1@appstate.edu), NC, and **Edith Aromando**, **Loren Anderson** and **Ulysses A Andrews**. *Wave Propagation through a Fractal Medium.*

We consider the wave equation on the unit interval with fractal measure, and use two numerical models to study wave speed and propagation distance.The first approach uses a Fourier series of eigenfunctions of the fractal Laplacian, while the second uses a Markov chain to model the transmission and reflection of classical waves on an approximation of the fractal. These models have complementary advantages and limitations, and we conjecture that they approximate the same fractal wave. (Received September 22, 2015)

1116-VH-2441 **Joseph D. Paulson*** (jpaulson12@wi.rr.com) and **Josh Thompson**. *Mobius Photoshop: Transformations through Pictures.* Preliminary report.

Mobius transformations are mappings of the sphere to itself which distort distance but preserve angles. Through a variety of visual diagrams and animations we will see examples of the beauty of these transformations. We will construct orbits of points under iterations of the mappings and project these patterns stereographically to the plane. We will also show how these transformations are related to group theory, linear algebra and complex analysis. As a fun application, we will show how to deform digital images using Mobius transformations. (Received September 22, 2015)

1116-VH-2467 **Howsikan Kugathasan***, 411 Annex Ave, Apt B4, Nashville, TN 37209, and **Qingxia Li** (qli@fisk.edu), 411 Annex Ave, Apt B4, Nashville, TN 37209. *Grandma Sells Granola?*

The objective of this presentation is to connect the real life problem with the underlying mathematics concept of finding local extrema through a case study, which is appropriate for Calculus I at the lower collegiate level or high school level. Applying case studies in teaching will increase student's interest in learning mathematics and then truly understand the meaning of the mathematics concepts. This case is about how a grandson to help his grandma making maximal revenue by selling granola at a farmer's market. It is an interrupted case with a three part scenario. The first part discusses the case that grandma will only sell granola in bags which causes the problem to calculate the profit with the first derivative test. The second scenario did pass the derivative test because grandma expanded her selling scale by selling the granola at any weight. The third part will be involved with economics model of hiring a new grandma for this business. Through this process, students were also able to understand the mathematical and economical concepts clearly. (Received September 22, 2015)

1116-VH-2504 **Nguyenho Ho*** (nho@wpi.edu) and **Sarah Olson**. *Swimming Speeds of Filaments in Viscous Fluids with Resistance.*

Spermatozoa and bacteria can utilize lateral and spiral bending waves to propagate in a fluid. Often, they encounter different fluid environments filled with mucus, cells, hormones, and other large proteins. These extra materials act as friction, possibly preventing or enhancing forward progression of swimmers. To understand these effects, we employ Taylor's techniques to calculate the asymptotic swimming speeds of a cylinder of infinite extent in a viscous fluid with resistance known as a Brinkman fluid. We find that, up to the second order expansion, the swimming speeds are enhanced as resistance increases. The Stokes limit can also be also recovered from this result as resistance goes to zero. In addition, we show numerical results for a Lagrangian algorithm of a rod waving in a porous medium and compare numerical results to asymptotic swimming speeds. (Received September 22, 2015)

1116-VH-2589 **Barnabas Bede*** (bbede@digipen.edu), Department of Mathematics, DigiPen Institute of Technolgy, Redmond, WA 98052. *Fuzzy systems as mathematical models for detective reasoning.* Preliminary report.

A fuzzy set as defined by Zadeh is intuitively a set with a continuum of membership grades. It can be described mathematically as a function $A : X \to [0, 1]$, with the interpretation of $A(x)$ as the degree of membership of an element x in the fuzzy set A. Linguistic variables, as e.g., small, medium, high, can be modeled using fuzzy sets. Expert knowledge, or sometimes even commonsense knowledge, can be modeled using fuzzy rules of the type "If x is A then y is B", where A, B are fuzzy sets. A fuzzy rule base allows construction of a fuzzy inference system that can provide a conclusion based on given data. This process allows us to model detective reasoning using fuzzy systems, as proposed by Novak. We continue the research direction proposed by Novak, and we consider various solutions to the problem of modeling the reasoning of Lt. Columbo as an example. (Received September 22, 2015)

1116-VH-2735 **Javad Namazi*** (namazi@fdu.edu). *Strategies for teaching cryptography.* Preliminary report.

Cryptography is a favorite course for mathematics as well as computer science majors. It gives students a rare chance to see the immediate applications of mathematics. In this talk we discuss few strategies to make it more interesting. (Received September 22, 2015)

1116-VH-2925 **Anilkumar Devarapu*** (anilkumar.devarapu@asurams.edu), Department of Mathematics and Computer Scienc, 504 College Dr, Albany, GA 31705, and **Zephyrinus C Okonkwo** and **Marrisa Merrell**. *Unsteady boundary-layer flow of nanofluid over a flat plate.*

The unsteady boundary-layer flow of nano-fluid over a flat plate in a free stream is investigated. The model used for the nanofluid incorporates the effects of Brownian motion and thermophoresis. A new self-similar solution is obtained and the resulting system of nonlinear ordinary differential equations is solved numerically using an implicit finite difference scheme in combination with the quasilinearization technique. The solution depends on the Prandtl Number Pr, Lewis number Le, Brownian motion number Nb and thermophoresis number Nt. Numerical results are presented for the skin friction coefficient, the local Nusselt number and the local Sherwood number as well as for the velocity, temperature and the nanoparticle volume fraction profiles. (Received September 23, 2015)

General Session on Linear Algebra

1116-VI-55 **D. Choi** (dchoi@siue.edu), Dept. of Math and Statistics, Southern Illinois University Edwardsville, Edwardsville, IL 62026-1653, and **Anne Greenbaum***. *An Algorithm for Finding a 2-Similarity Transformation from a Numerical Contraction to a Contraction.*

It was shown in [T. Ando, *Structure of Operators with Numerical Radius One*, Acta. Sci. Mat. (Szeged) 34, pp. 11-15] that any matrix A with numerical radius at most 1 is similar to a contraction (a matrix T with spectral norm at most 1) via a similarity transformation with condition number at most 2; that is, $A = STS^{-1}$, where $\|T\| \leq 1$ and $\kappa(S) \equiv \|S\| \cdot \|S^{-1}\| \leq 2$. However, no explicit algorithm was given for producing such a similarity transformation. In this presentation, we give a method for constructing such similarity transformations. As a side benefit, the algorithm indicates if the numerical radius of A is greater than 1 (or greater than some given number r_0) and so can be used to determine (sometimes very quickly) if the numerical radius is greater than a given value. (Received August 05, 2015)

1116-VI-139 **Katherine Cordwell** (ktcordwell@gmail.com) and **George Wang*** (georgeyw@usc.edu). *Multilinear polynomials of small degree evaluated on matrices over a unital algebra.*

Our work branches from a famous result by Kenjiro Shoda that over any field K of characteristic 0, any traceless matrix can be expressed as a commutator. This is equivalent to showing that all traceless matrices are contained in the image of the degree 2 multilinear polynomial $f(x_1, x_2) = x_1x_2 - x_2x_1$.

We consider instead a unital associative algebra R over a field K of characteristic zero. Let f be a multilinear polynomial of degree 3 or 4 over K. Applying methods of combinatorial algebra, we prove that all traceless matrices can be written as the sum of two values of f evaluated over $M_n(R)$, $n > 2$. We conjecture that this result holds for higher values of m, provided that $n \geq m - 1$. Our results extend recent works due to Zachary Mesyan, Dinesh Khurana and Tsit-Yuen Lam. (Received August 04, 2015)

1116-VI-140 **Daeshik Choi*** (dchoi@siue.edu), Dept. of Math and Statistics, Southern Illinois University Edwardsville, Edwardsville, IL 62026. *On arithmetic-harmonic-geometric mean inequalities.*

In this talk, we will show a relationship among the arithmetic mean, the geometric mean, and the harmonic mean. More specifically, we will show inequalities among

$$\begin{aligned}&(a\nabla_\mu b - a\#_\mu b)/(a\nabla b - a\# b),\\&(a\nabla_\mu b - a!_\mu b)/(a\nabla b - a!b),\\&(a\#_\mu b - a!_\mu b)/(a\# b - a!b),\\&(\ln a\nabla_\mu b - \ln a\#_\mu b)/(\ln a\nabla b - \ln a\# b),\\&(\ln a\nabla_\mu b - \ln a!_\mu b)/(\ln a\nabla b - \ln a!b),\\&(\ln a\#_\mu b - \ln a!_\mu b)/(\ln a\# b - \ln a!b),\end{aligned}$$

where

$$\begin{aligned}a\nabla_\mu b &= (1-\mu)a + \mu b,\\a\#_\mu b &= a^{1-\mu}b^\mu,\\a!_\mu b &= ((1-\mu)a^{-1} + \mu b^{-1})^{-1}\end{aligned}$$

for $a, b > 0$ and $0 \le \mu \le 1$. Next, we will apply the result to positive operators. (Received August 05, 2015)

1116-VI-395 **Alexander Ma*** (ama@bowdoin.edu) and **Jamie Oliva** (jo248428@muhlenberg.edu). *On the images of Jordan polynomials evaluated over symmetric matrices.*

A long-standing open question posed by Lvov and Kaplansky asks whether the image of a multilinear polynomial over a field F forms a vector space when evaluated over the full matrix algebra $M_n(F)$. A natural variation of this question asks whether the image of a multilinear Jordan polynomial evaluated over a Jordan algebra forms a vector space, where a multilinear Jordan polynomial is a multilinear polynomial with respect to the non-associative Jordan operation. We will show that the image of any degree-three multilinear Jordan polynomial evaluated over the Jordan algebras of real and complex symmetric matrices forms a vector space. (Received August 30, 2015)

1116-VI-751 **Issac A Odegard*** (issac.odegard@gmail.com), 305 Tulane Court, Grand Forks, ND 58203. *The Quadratic Irrationals and Ducci Matrix Sequences.*

The Ducci map is defined by taking a vector $[v_1, \ldots, v_n]^T \in \mathbb{R}^n$ to $[|v_1 - v_2|, \ldots, |v_n - v_1|]^T$. We concern ourselves with the Ducci map's action in $\mathbb{R}^3$, establishing a connection between the sequences of matrices associated with the action of the Ducci map, continued fraction representations of the real numbers, and the Stern-Brocot tree. It is shown that the real numbers have a representation via sequences of Ducci matrices, and in this Ducci number system there are essentially three types of matrix sequences: one type corresponding to the rationals, one to the quadratic irrationals, and then those types that correspond to all other real numbers. This mirrors the situation for continued fraction representations of the reals. It follows that the Ducci map on $\mathbb{R}^3$ is closely connected to the Euclidean algorithm and, through its action, locates best rational approximations to the irrationals. (Received September 11, 2015)

1116-VI-830 **Sudipta Mallik*** (sudipta.mallik@nau.edu), Flagstaff, AZ , and **Keivan Hassani Monfared** (keivan.hassanimonfar@ucalgary.ca). *Spectral characterization of matchings in graphs.*

We will present a spectral characterization of the matching number of graphs: A graph G of order n has matching number k if and only if its maximum skew rank is $2k$ and for any given set of k distinct nonzero purely imaginary numbers there is a real skew-symmetric matrix A with graph G whose spectrum consists of the given k numbers, their conjugate pairs and $n - 2k$ zeros. (Received September 13, 2015)

1116-VI-1310 **Somantika Datta** and **Jesse Ernest Oldroyd*** (jesseo@uidaho.edu), Moscow, ID 83844. *Constructing approximations to equiangular tight frames.* Preliminary report.

Consider a collection of N unit vectors $\{f_i\}_{i=1}^N$ in $\mathbb{C}^d$ or $\mathbb{R}^d$. This set is called an equiangular tight frame (ETF) if the cross-correlation between any distinct vectors has modulus given by the Welch bound. ETFs have properties that make them useful in signal processing, and their construction has become an important problem in applied harmonic analysis. Unfortunately ETFs do not exist for all choices of N and d, and it is well known that no ETF of N vectors exists for $N > \frac{d(d+1)}{2}$ in the real case and for $N > d^2$ in the complex case. The focus of this talk is to construct unit-normed frames that approximate ETFs in some sense. If $N \le \frac{d(d+1)}{2}$ in the real case or $N \le d^2$ in the complex case, a construction is proposed that starts with a known equiangular frame and then adjusts the eigenvalues of the corresponding Gram matrix by means of random perturbations to improve tightness of the resulting frame. A second construction is proposed for arbitrary N that starts with a known ETF of $m < N$ vectors in $\mathbb{R}^d$ or $\mathbb{C}^d$ and then increases the size of the frame to N by building new frame vectors from the starting m vectors. (Received September 21, 2015)

1116-VI-1547 **Geoffrey Buhl**, **Elijah Cronk**, **Rosa Moreno**, **Kirsten Morris**, **Dianne Pedroza** and **Jack Ryan*** (`jaryan@noctrl.edu`), North Central College, 30 N. Brainard #1129, Naperville, IL 60540. *Matrix Completions for the Commutativity Equation.*

A matrix completion problem attempts to determine if a partial matrix composed of specified and unspecified entries can be completed to satisfy some given property. This project focuses on determining which patterns of specified and unspecified entries for a partial matrix can be completed to solve the commutativity matrix equation $AX - XA = 0$. The conditions under which two matrices commute are well known, but an open question is "can a partial matrix be completed to commute with a given matrix?" We approach this problem with two techniques: converting the matrix equation into a linear equation and examining bases for the solution space of the commutativity equation. We seek to determine whether a particular pattern can be written as a linear combination of the basis elements. If so, the pattern is admissible; otherwise, the pattern is inadmissible. This work classifies patterns as admissible or inadmissible based on the ability or inability of their corresponding partial matrices to be completed to satisfy the commutativity equation for almost any matrix A. Our results present a partial characterization of admissible and inadmissible patterns for the commutativity equation. (Received September 20, 2015)

1116-VI-1816 **Geoffrey Buhl**, **Elijah Cronk**, **Rosa Moreno**, **Kirsten Morris*** (`kirsten.morris@bobcats.gcsu.edu`), **Dianne Pedroza** and **Jack Ryan**. *A Matrix Completion Problem for the skew-Symmetric Equation $AX - A^TX = 0$.* Preliminary report.

A matrix completion problem examines a partial matrix composed of specified and unspecified entries and determines if this partial matrix can be completed to satisfy some given property. We determine if partial matrices can be completed to satisfy the skew-Symmetric equation $AX - A^TX = 0$. If a partial matrix X with a certain pattern of specified and unspecified entries can be completed for almost any matrix A to satisfy the skew-Symmetric equation, we call the pattern *admissible*. Using the Kronecker product, we rewrite the matrix equation as a linear equation, and examine the structure of the nullspace of this linear equation to characterize patterns as admissible or not. Through this approach we obtain a complete characterization of admissible and inadmissible patterns for the skew-Symmetric Equation. (Received September 21, 2015)

1116-VI-2133 **Bal K Khadka*** (`bkhadka@fau.edu`), 630 NW 13th St, Apt 27, Boca Raton, FL 33486, and **Spyros Magliveras**. *Drawbacks of LLL Lattice Basis Reduction Algorithm.*

In this paper we show how to circumvent some drawbacks and peculiarities of the LLL algorithm. To solve the *approximate shortest vector* in hard lattice problems, we have introduced some techniques such as: *lattice diffusion* and *sublattice fusion*, *hill climbing*, *simulated annealing* etc., each requiring a large number of parallel calls of the LLL algorithm, while attempting to solve the lattice basis reduction problem. The *lattice diffusion* and *sublattice fusion* algorithm is a technique based on the LLL algorithm. It relies on performing a large number of LLL reductions on permuted bases of a family of, not necessarily disjoint, sublattices and then fusing the reduced bases of the sublattices. In particular, we obtain best possible results for a number of competition instances in the problem.

Keywords: LLL, Lattice Basis Reduction, permutation matrix, Integer unimodular matrix. (Received September 22, 2015)

1116-VI-2270 **Louis Deaett*** (`louis.deaett@quinnipiac.edu`). *Matroids and the minimum rank of matrix patterns.* Preliminary report.

The *zero-nonzero pattern* of a matrix specifies precisely which of its entries are nonzero. The problem of determining the smallest rank of a matrix subject to this combinatorial description has received a good deal of attention. We give a generalization of this problem to the setting of matroids, and show that analogs to known lower bounds persist in this setting. Moreover, we exploit the matroid-theoretic context to give simpler, unified proofs of some known results, improve upon others, and establish a new result as well. Ultimately, however, the potential of this approach seems largely untapped; we outline directions in which the connections with matroid theory could be strengthened so as to shed more light on the original matrix-theoretic problem. (Received September 22, 2015)

1116-VI-2357 **Piers Lawrence**, **Froilan M. Dopico**, **Paul Van Dooren** and **Javier Perez Alvaro***, School of Mathematics, The University of Manchester, Alan Turing Building, 2.233, Manchester, M13 9PL, United Kingdom. *Fiedler-like linearizations of matrix polynomials.*

The simplest but still most important among nonlinear eigenvalue problems are the polynomial eigenvalue problems (PEPs). Any PEP is associated with a matrix polynomial $P(\lambda) = \sum P_i\lambda^i$, where $P_i \in \mathbb{C}^{m\times n}$. The standard way to numerically solve a PEP is to linearize the matrix polynomial $P(\lambda)$ into a matrix pencil $L(\lambda) = \lambda Y + X$. A matrix pencil is said to be a strong linearization of $P(\lambda)$ if they share the same finite and infinite eigenstructure, which may be computed using any of the well-known algorithms for solving generalized eigenvalue problems. In this work we introduce a new set of linearizations that allows one to design matrix polynomial eigensolvers that are easy to implement, are valid regardless of whether the matrix polynomial is regular or singular, allow one to compute all the eigenstructure of the matrix polynomial, exploit any structure that the matrix polynomial might posses, and include error and condition estimates. These desirable properties allow one to overcome all the drawbacks presented in previous methods, making this linearizations more attractive than the ones known so far. (Received September 22, 2015)

1116-VI-2544 **Chi-Kwong Li*** (ckli@wm.edu), Department of Mathematics, Jones Hall, Williamsburg, VA 23187. *Some optimization problems in quantum information science.*

We describe solutions of some optimization problems in quantum information science. In particular, for given quantum states ρ_1, ρ_2, and a scalar function f such as the trace norm distance, fidelity, etc, we determine the maximum and minimum of $f(\rho_1, \Phi(\rho_2))$, where Φ ranges through all unital quantum channels. We also identify Φ so that $\Phi(\rho_2)$ yields the optimal value. (Received September 22, 2015)

1116-VI-2825 **Keivan Hassani Monfared*** (k1monfared@gmail.com) and **Bryan Shader**. *Using the Jacobian method to solve structured inverse eigenvalue problems.*

For a family of matrices $\mathcal{F}$ we want to find a matrix $A \in \mathcal{F}$ such that A satisfies some spectral properties $\mathcal{P}$, e.g. when $\mathcal{F}$ is the set of real symmetric matrices whose graph is a given graph G, and $\mathcal{P}$ is the property of having a spectrum Λ.

In this talk, we will illustrate when we have a solution for a graph G, how some *genericity* conditions enable us to use the Jacobian method to add in edges and find a solution for the new graph $\widehat{G}$. (Received September 22, 2015)

1116-VI-2897 **Ehssan Khanmohammadi*** (ehssan@fandm.edu) and **Keivan Hassani Monfared**. *A Structured Inverse Eigenvalue Problem for Infinite Matrices.* Preliminary report.

In their 2013 paper [Linear Algebra Appl. 438 (2013) 4348–4358] Hassani Monfared and Shader proved that for a given set of n distinct real numbers Λ and a given graph G on n vertices, there exists a symmetric matrix whose graph is G and its spectrum is Λ. In this talk we show analogous results hold when the set Λ and the graph G are infinite. (Received September 22, 2015)

General Session on Logic and Foundations

1116-VJ-1042 **Erin Kathryn Carmody*** (ecarmod2@nebrwesleyan.edu). *Force to Change Large Cardinal Strength.*

This talk introduces the theme of killing-them-softly between set-theoretic universes. The main theorems show how to force to reduce the large cardinal strength of a cardinal to a specified desired degree, for a variety of large cardinals including inaccessible, Mahlo, measurable and supercompact. The killing-them-softly theme is about both forcing and the gradations in large cardinal strength. Thus, I also develop meta-ordinal extensions of the hyper-inaccessible and hyper-Mahlo degrees. This work extends the work of Paul Mahlo to create new large cardinals and also follows the larger theme of exploring interactions between large cardinals and forcing central to modern set theory. (Received September 17, 2015)

1116-VJ-1198 **Maarten McKubre-Jordens*** (maarten.jordens@canterbury.ac.nz), School of Mathematics & Statistics, University of Canterbury, Private Bag 4800, Christchurch, Canterbury 8140, New Zealand, and **Zach Weber**. *Paraconsistent Measurement of the Circle: An Invitation to Inconsistent Mathematics.*

A theorem from Archimedes on the area of a circle is proved in a setting where some inconsistency is permissible, by using paraconsistent reasoning. The new proof emphasizes that the famous method of exhaustion gives approximations of areas closer than any consistent quantity. This is equivalent to the classical theorem in a classical context, but not in a context where it is possible that there are inconsistent infinitesimals. The area of the circle is taken 'up to inconsistency'. The fact that the core of Archimedes's proof still works in a weaker logic is evidence that the integral calculus and analysis more generally are still practicable even in the event of inconsistency. (Received September 17, 2015)

1116-VJ-1575 **Chandra Kethi-Reddy*** (chan.dra@knights.ucf.edu). *Law of Non-Contradiction Generates Infinite Contradictions.* Preliminary report.

The role of contradiction in mathematics, although often seen as a settled question, is still a very open field of inquiry. First, earlier proofs that the law of non-contradiction implies the explosion principle will be examined. Second, I will argue that the explosion principle generates an infinite number of contradictions. Roughly, if a contradiction C implies any formulable sentence, then it also implies the metacontradiction C & C, which in turn iterates further metacontradictions of the same form. I claim if a contradiction is possible in any system, then it necessarily exists. This would apply to almost every logical system, excepting those like relevance logics in which no contradictions are formulable. As a result, it is necessary to see logics where contradictions occur as those that simply have some rule to manage contradictory formulas, the classical law of non-contradiction functioning as only one example. Mathematics must be able to account for its use and understanding of contradictions. It is not enough to simply reject the possibility of a relationship between contradiction and truth. Incorporating contradictions into mathematics may allow us to circumvent the more sinister problematics of mathematics, such as what to do in the face of incompleteness. (Received September 20, 2015)

1116-VJ-2207 **Cynthia Northrup*** (cynthia.northrup@bellevuecollege.edu). *Toward the Consistency Strength of Stationary Set Reflection on Small Cardinals.* Preliminary report.

We obtain a model M for which every subset of ω_3 focusing on cofinality ω reflects at a point of cofinality ω_1. That is, $M \models \mathrm{Refl}(\omega_3, \omega, \omega_1)$. This is done by adjusting the methods of Gitik in order to get set reflection. This argument may help show the way to getting the consistency strength. (Received September 22, 2015)

General Session on Mathematics and Technology

1116-VK-771 **Myungchul Kim*** (kimm@sunysuffolk.edu), Suffolk County Community College, Dep. of Mathematics and Computer Science, 533 College rd, Selden, NY 11784. *Promote communication with students by using a text phone in a multi variable calculus classroom.* Preliminary report.

The use of classroom response systems can help student learning, engagement and perception during the class. They provide each student a chance to think about and respond to a question before hearing other students' answer. Also, it can enlighten the instructor to sources of student difficulties. In this talk, the effective use of text phone when teaching multi-variable calculus will be presented. (Received September 12, 2015)

1116-VK-1339 **Jeff Holt*** (jeff@virginia.edu), Department of Mathematics, University of Virginia, Charlottesville, VA 22901, and **John Jones** (jj@asu.edu), School of Mathematical and Statistical Sci, Arizona State University, Tempe, AZ 85287. *Updating the WeBWorK Problem Library.* Preliminary report.

WeBWorK is an open source system for delivering and grading homework. In this presentation we describe the status of the WeBWorK problem library, which we have been updating with the support of the National Science Foundation (DUE 1226176/DUE 1226081). Topics will include the new problem organizational taxonomy, elimination of duplicate problems, and cohorting of similar problems. (Received September 18, 2015)

1116-VK-1774 **Caitlin Phifer*** (phiferc@merrimack.edu). *A One-To-One iPad Initiative in Precalculus.* Preliminary report.

Starting in the fall of 2015, each incoming freshman at Merrimack College was issued an iPad. The presenter participated in this one-to-one iPad initiative by teaching a section of precalculus which required all students to have the device. In this presentation, we will discuss what it is like when all of your students have an iPad in class (and when your other section of the course does not require iPads), apps that the students found useful, the advantages of using the technology, and the challenges that come with this type of instruction. (Received September 21, 2015)

1116-VK-1876 **Geillan Dahab Aly*** (geillan@email.arizona.edu). *Goals and Conflicts in a Computer-Centered Mathematics Class.*

Too often, students in mathematics classes are directed to focus on final answers of a problem rather than conceptual understanding, or deriving mathematical theorems and formulas. Some students learning goals may not be focused on getting answers but on understanding. This paper presents the case of a remedial-level mathematics student in a community college. The class limited mathematical agency but provided enough student agency where students could focus on their definition of learning. The class' didactic approach regulated solution methods, answers, and opportunities to demonstrate learning. This limited the mathematical agency of students by giving them problems with limited entry points, requiring multiple-choice or short answers with no consideration given to students' written work. However, the course gave students enough flexibility to work at their own pace. As such, while students could study when, where, and as much as they wanted, WHAT they studied and what they had to do to succeed was quite narrowly defined. This paradox of limited mathematical agency and unlimited student agency provides a setting where students who focus on understanding can do so even if the priority is correct answers. This tension is explored using goal theory from educational psychology. (Received September 21, 2015)

1116-VK-2092 **Heather Pierce*** (pierceh@emmanuel.edu). *STEM Apprentices in the Modern Classroom: Using Technology to Bring Ancient Teaching Techniques into the Modern World.*

Traditionally in education it has been more common for a student to learn from experience rather than instruction. A student would receive general guidelines, then start working in the chosen field. However, in a modern classroom, students are given a lot of instruction and then are left to their own devices to put this instruction to practical use. I believe with modern technology we can rekindle the craftsman/apprentice relationship into our classrooms and teach STEM subjects in a more personable way that is easier to relate to.

In this talk, I will cover some of the history of the apprentice relationship and how it translates to modern flipped classrooms. I will discuss some of the statistics of flipped classrooms in the STEM fields. I will also discuss how to make content available to all students with modern technology and the tools available, as well as some of the disadvantages one may encounter. Lastly I will discuss some of my own and some of my colleagues experiences with flipped classrooms. (Received September 21, 2015)

1116-VK-2267 **Jason Parsley** and **Joseph Rusinko*** (rusinko@hws.edu). *Using technology to foster large scale undergraduate research collaborations.*

The *Collaborative Research Project (CRP)* – a mathematics research experience for undergraduates – offers a large-scale collaborative experience in research for undergraduate students. CRP seeks to widen the audience of students who participate in undergraduate research in mathematics. In 2015, the inaugural CRP had 100 undergraduate participants from across the United States; they collaborated on a monthlong research effort applying tropical geometry to phylogenetics. CRP is envisioned as an annual event, one that scales to accommodate large numbers of interested students. This article describes the motivation for CRP, its structure, and the results of its inaugural iteration, and closes by assessing its future. (Received September 22, 2015)

1116-VK-2400 **Edward D. Kim*** (ekim@uwlax.edu), La Crosse, WI 54601. *Multiple geometry views in GeoGebra through the calculus sequence.*

This talk introduces GeoGebra applets which are relevant throughout the calculus sequence. The applets take advantage of a GeoGebra feature which allows the simultaneous view two graphical panes, side-by-side. The applets will be introduced alongside useful questions to ask in class for inquiry. Bringing an internet-connected laptop is highly encouraged. (Received September 22, 2015)

1116-VK-2408 **Anders O.F. Hendrickson*** (anders.hendrickson@snc.edu), St. Norbert College, Routing No. 07-3A, 100 Grant Street, De Pere, WI 54301. *A LaTeX package to generate Moodle quizzes:* moodle.sty.

The Moodle learning management system offers many ways to enhance mathematics courses with digital content, including automatically graded quizzes. Unfortunately, the process of creating such a quiz using the Moodle interface can be tedious, repetitive, subject to error, and delayed by server lagtime. Including graphics in a quiz adds even more complications to this workflow.

We present a new LaTeX package, moodle.sty, which enables the user to edit a Moodle quiz in LaTeX on one's local machine. The package automatically produces both a printable PDF for proofreading and an XML file that can be uploaded directly to Moodle. Graphics are handled seamlessly. (Received September 22, 2015)

1116-VK-2564 **Petre I Ghenciu*** (ghenciup@uwstout.edu) and **Alexandru G Atim**. *Using technology to enhance student learning in general education mathematics courses.* Preliminary report.

A preliminary report on the use of technology to enhance student learning in two general education mathematics courses at two different universities is presented. The use of the MyMathLab and Blackboard Collaborate is discussed. Difficulties and drawbacks, some university specific, are presented. (Received September 22, 2015)

1116-VK-2744 **Paul R McCreary*** (mccrearp@evergreen.edu). *Animations! Riemann Surfaces and Interactive Computer Animations.*

Come see cartoons featuring your favorite genus-one Riemann surface relationships! See the equivalence of surfaces captured in an interactive animation, which you and your students can manipulate on the screen. How can different shapes actually represent the same Riemann surface? What makes them equivalent? And what about those equivalent points? How do they get arranged in such striking patterns? And paths on parallelograms, what do they look like on the torus?! These perplexing questions and more exposed in living, moving color and action! There may even be time to address questions about the software used to created these animations. (Received September 22, 2015)

General Session on Mentoring

1116-VL-230 **Jeffrey W. Clark*** (clarkj@elon.edu). *Mentoring Mathematical Programming in Undergraduate Research.*

Some undergraduate mathematical research requires programming to implement and develop complicated algorithms or to generate data for hypotheses. This presentation will describe different contexts for programming-based research before describing common problems and solutions in supervising such research. (Received August 15, 2015)

1116-VL-1915 **Paul R. Bialek*** (pbialek@tiu.edu), Department of Mathematics, Trinity International University, Deerfield, IL 60015. *How to Get into Graduate School in Mathematics: What Graduate Schools Are Looking for.*

How do you get into graduate school in Mathematics? The author has surveyed a number of graduate schools and will share the results with you. (Received September 21, 2015)

1116-VL-2203 **Julia P Clark*** (jclark@ucmerced.edu) and **Eric Roberts** (eroberts5@ucmerced.edu). *Mixed peer and graduate student mentoring of undergraduate students in mathematics.*

We propose a model of mixed peer and graduate student mentoring of undergraduate students interested in mathematics. In our model, graduate students and undergraduate students collaboratively organize meetings that involve a mix of open discussions of mathematics and what it means to be a mathematician, active problem solving, and an introduction to undergraduate level research. This models serves both the undergraduate and graduate communities. For the undergraduate population, it models successful collaboration and develops their confidence and ability to engage in mathematical research. Meanwhile, it gives the graduate students hands on experience in being leaders and mentors, skills that are useful in any career trajectory. (Received September 22, 2015)

1116-VL-2881 **Zachary J. Abernathy*** (abernathyz@winthrop.edu). *Tips for Running an REU Program at a Primarily Undergraduate Institution.*

Winthrop University is a public comprehensive university serving approximately 5000 undergraduate and 1000 graduate students. Over the past several years, the math department at Winthrop has made significant efforts to enhance the culture of undergraduate research on the part of its students and faculty, culminating in a 3-year NSF-funded REU grant for 2014-2016. Our main goal will be to share our experience managing the various logistics of this program (timeline, selecting appropriate projects, recruiting students, weekly schedule, expected outcomes, etc.) as well as to offer tips for grant proposals and other lessons learned along the way. (Received September 22, 2015)

General Session on Modeling and Applications

1116-VM-25 **Ogugua N Onyejekwe*** (oguguao@yahoo.com), 171 Cypress Brook Circle, APT#1315, Melbourne, FL 32901. *The application of Homotopy Analysis Method for the solution of time-fractional diffusion equation with a moving boundary.* Preliminary report.

It is difficult to obtain exact solutions to most moving boundary problems. In this paper we employ the use of Homotopy Analysis Method (HAM) to solve a time-fractional diffusion equation with a moving boundary condition. The convergence of the series solution obtained by HAM is shown by the proof of a theorem. The advantages to using HAM is shown through the solution of an example. (Received June 01, 2015)

1116-VM-105 **Amber N. Lee*** (amber.lee@salem.edu), Salem College Dept. of Mathematics, 601 S Church St, Winston Salem, NC 27101, and **Anna Steinfeld** and **Zachary Abernathy**. *Compartmental Competition Model with Cancer Stem Cells in a Colon Crypt.* Preliminary report.

In response to recent support for the cancer stem cell (CSC) hypothesis, many mathematical models of tumor growth have incorporated this new paradigm. Cancer of the colon is a widespread disease with high mortality that has been identified as a strong candidate for the CSC hypothesis. We introduce a compartmental system of six ordinary differential equations to model the CSC hypothesis in the context of colorectal cancer. The model addresses the interactions of healthy and cancerous stem, transit (semi-differentiated), and fully differentiated cell populations at the cellular level within a colon crypt, with colorectal cancer originating from such a crypt. Global stability analysis of steady states in the model is achieved by two-dimensional phase plane analysis, resembling that of classical Lotka-Volterra competition dynamics. We find that cancer persistence is favored in our CSC model under biologically viable parameters, consistent with the cancer hypothesis. (Received July 24, 2015)

1116-VM-118 **Zachary Abernathy** and **Savannah V. Bates***, Savannah Bates, 2800 University Blvd N, PO Box 281037, Jacksonville, FL 32211, and **Rebecca Santorella**. *A Mathematical Model of Cancer Stem Cell Driven Tumor Growth with Radiation and Chemotherapy Treatment.* Preliminary report.

We build a tumor model that incorporates the cancer stem cell hypothesis with chemotherapy and periodic radiation treatment using aspects of current models. We calculate conditions for the existence and local stability of equilibria in the case of no treatment as well as constant radiation with and without chemotherapy. Additionally, for periodic radiation treatment, sufficient conditions for the existence of cancer persistence and cure state periodic solutions are established. Conditions for global stability of the periodic cure state are also derived using a Lyapunov function. Numerical simulations demonstrate that treatments targeting cancer stem cells are more effective in eradicating cancer. (Received July 30, 2015)

1116-VM-255 **Catherine E Patterson*** (catherine-patterson@uiowa.edu), **Bruce Ayati** and **Sarah Holstein**. *The Dynamics of Multiple Myeloma Dysregulated Bone Remodeling.*

Multiple myeloma is a plasma cell cancer that affects the bones, immune system, and kidneys. Here we focus on the impact on the bone, specifically routine bone remodeling. The bone remodeling process is governed by chemical signaling between several cell populations. In multiple myeloma patients, this process is out of balance. Bone destruction outpaces bone replacement, leaving patients with bone lesions. This talk will describe the cell-signaling network that regulates bone remodeling and explain how it is impacted by multiple myeloma. We will then present a moving-boundary PDE model of this biological system, using Savageau's power law approximations for the cell interactions. We will also discuss the model's computational results and their significance. (Received August 18, 2015)

1116-VM-275 **Po-Keng Cheng***, Math Tower B-148, Stony Brook, NY 11794, and **Frank J. Fabozzi** and **Young Shin Kim**. *Speculative Bubbles and Crashes: Fundamentalists and Positive-Feedback Trading.*

In this paper, we develop and examine a simple heterogeneous agent model, where the distribution of returns generated from the model takes into account two stylized facts about financial markets: fat tails and volatility clustering. Our results indicate that the risk tolerance of fundamentalists and the funding rate of positive-feedback traders are key factors determining the path of price fluctuations. Fundamentalists are more able to dominate the market when they are more willing than positive-feedback traders to take risks. In addition, more crises occur as positive-feedback traders' funding costs rise. Our model suggests that fundamentalists cause heavy-tailedness, and positive-feedback traders cause the formation of speculative bubbles. Our model also indicates that the traders' attitudes towards risk vary across time and the generally low level of risk bearing by fundamentalists could explain the frequent occurrence of bubbles. (Received August 20, 2015)

1116-VM-352 **Dr. Boniface Otieno Kwach*** (bkwach@kibabiiuniversity.ac.ke), P. O. Box 1699-50200, Bungoma, and **Prof. Omolo N. Ongati**, **Prof. Michael Oduor Okoya** and **Dr. Amos E. O. Otedo**. *Mathematical Modeling of Insulin Therapy in Patients with Diabetes Mellitus.* Preliminary report.

This study presents a Mathematical Model Insulin Therapy in Patients with Diabetes Mellitus which includes external rate at which blood glucose, insulin and epinephrine are being increased in the form, $\dot{Y} = AY + \vec{r}(t)$ and whose solution was analyzed to provide the systems natural frequency, ω_0, which is the basic descriptor of saturation level of the drug. It was established that the resonance period for the final model, that is, $T_0 = 3.76912$

hrs, is in the acceptable therapeutic range and agrees well with the data for the existing insulin therapy. By employing the model, it is shown that, the peak, which is the time period for insulin to be most effective in lowering blood sugar, is shorter than $T_0 = 5.3199$ hrs, for the existing model. This model would help the medical practitioners to predict drug therapy in patients with Diabetes Mellitus, in such a way that the concentration of the drug remains in the therapeutic range.
Mathematics Subject Classification: Primary 93A30; Secondary 91B74, 93C05
Keywords: Mathematical model, Linear system, Resonance period (Received August 27, 2015)

1116-VM-542 **Jacquelyn L Rische*** (`rische@hws.edu`) and **Natalia L Komarova**. *Mathematical Modeling of Language Regularization by Adults and Children.*

E.L. Newport and colleagues have demonstrated that children and adults have some ability to process inconsistent linguistic input and improve it by making it more consistent. We create a learning algorithm of the reinforcement-learning type, which exhibits patterns reported by Hudson Kam and Newport (2009) and suggests a way to explain them. We find that neither a linear model nor a symmetric, nonlinear model adequately capture the learning behavior in the experiments. In order to capture the differences between children's and adults' learning patterns, we need to introduce a certain asymmetry in the learning algorithm. We assume that the reaction of the learners differs depending on whether or not the source's input coincides with the learner's internal hypothesis. We interpret this in the context of a different reaction of children and adults to positive and negative evidence. We propose that a possible mechanism that contributes to the children's ability to regularize an inconsistent input is related to their heightened sensitivity to positive evidence rather than the (implicit) negative evidence. (Received September 06, 2015)

1116-VM-739 **Julia Walk***, 14 MacLean Hall, Iowa City, IA 52242. *Modeling the Effects of Multiple Myeloma on Kidney Function.* Preliminary report.

Multiple myeloma, a type of plasma cell cancer, is associated with many health challenges, including kidney damage caused by tubulointerstitial fibrosis. The damages caused by tubulointerstitial fibrosis increase the chances of development of end-stage renal disease. Interactions between proximal tubule cells, free light chains, and monoclonal protein produced by the myeloma cells determine the amount of kidney damage present. Using power law approximations, we develop a mathematical model that captures the biology of the interactions between these cells. The goal of this work is to create a model with prognostic capabilities that could be calibrated with a specific patient's data to predict likelihood of renal function recovery following myeloma therapy. (Received September 11, 2015)

1116-VM-937 **Sunnie Joshi*** (`sjoshi@temple.edu`). *A Computational Model for the Simulation of Atherosclerotic Plaques.*

Atherosclerosis is a chronic inflammatory process in which the arterial wall develops a plaque as a result of the build up of cholesterol and other fatty materials in the interior surface of the wall, and is the most common disease of the arterial system. This study focuses on the implementation of a coupled reaction diffusion model in two dimensions with a cross-sectional geometry of the artery which reveals the interaction between various factors that affect the growth of the plaque. The Darcy equations are implemented to model the intramural flow through the arterial wall. The interaction between the macrophages and the oxidized LDLs are modeled by a system of coupled reaction diffusion equations. A pseudo-Stokes equation is used to compute the long term growth velocity field of the wall, which is then used for the evolution of the geometry of the plaque. (Received September 15, 2015)

1116-VM-1072 **Kokum R. De Silva*** (`kdesilva@vols.utk.edu`), **Shigetoshi Eda** and **Suzanne Lenhart**. *A model of Johne's disease with the disease transmission through the environment.* Preliminary report.

Johne's disease is a bacterial infection caused by Mycobacterium avium subspecies paratuberculosis (MAP). It is a chronic, progressive, and infectious disease which has a long incubation period and probably not curable. One main problem with the disease is the reduction of milk production in infected dairy cows. In our study we develop a deterministic model to describe the dynamics of the Johne's disease in a dairy farm. In this model we use a system of ordinary differential equations to describe the behavior of Johne's disease among dairy cows considering the progression of the disease and the age structure of the cows. We analyze the behavior of the Johne's disease by taking the environmental persistence of the bacteria into account. (Received September 16, 2015)

1116-VM-1077 **Nar Rawal*** (nar.rawal@hamptonu.edu) and **Arun Verma**, Hampton University, Hampton. *Coexistence and Extinction of Competing Species in the Time-Periodic Volterra-Lotka type Systems with Nonlocal Dispersal.*

This talk will address the coexistence and extinction of two competing species sharing the same domain D in the time periodic Volterra - Lotka type competing system with non-local dispersal. Such issues have already been studied for the time independent cases. This talk extends some similar results which are already proved for time independent cases to the periodic time dependent cases. In this talk, the relation ensuring the coexistence and extinction between the coefficients representing Malthusian growths, self regulations and competitions of the two species will be mentioned for the time dependent case of Volterra-Lotka type system with nonlocal dispersal. (Received September 16, 2015)

1116-VM-1094 **Taylor M. Posey*** (taylor_p94@hotmail.com), Seattle, WA 98105, and **Kelsey Kalmbach** (kelsey.kalmbach@gmail.com), Golden, CO 80401. *Exploring Transcranial Stimulation in a Cognitive Learning Model.* Preliminary report.

We develop and test a biologically-based model of cognition that allows for determining the effects of transcranial stimulation on learning tasks. Learning is tested through pattern recognition of images. Using a modified Hodgkin–Huxley model, this model contains multiple interconnected brain regions with the ability to model stimulation from different sources of electrical current. New measures of discriminability between neural responses are also explored and detailed. (Received September 16, 2015)

1116-VM-1415 **Ryan M Evans*** (rmevans@udel.edu), University of Delaware, Mathematics Department, 15 Orchard Rd, Newark, DE 19716, and **David A Edwards**, University of Delaware, Mathematics Department, 15 Orchard Rd, Newark, DE 19716. *Overview of Multi-Component Surface-Volume Reactions.*

A surface-volume reaction occurs when a chemical flows through a channel, and then diffuses to the floor where it can react with immobilized receptors. Scientists study these reactions experimentally using optical biosensors. Chemists are currently running biosensor experiments in which there are multiple types of chemical reactants flowing through the channel of the biosensor, or multiple receptors at the floor.

Correctly interpreting biosensor data relies on having a mathematical model. Our model for multi-component reactions in a biosensor takes the form of a convection-reaction system. Using asymptotic analysis we are able to simplify the full system into a coupled set of nonlinear integro-differential equations for the reacting species concentration. In physically relevant asymptotic limits, this system further reduces to a nonlinear set of ODEs. This renders our asymptotic approximations useful for data analysis.

The exact values of the involved reaction rates are unknown to date. These rates can't be measured experimentally, and the problem of fitting the parameters to data is ill-posed. We discuss a curve-fitting algorithm we are developing to fit the constants, and an experimental design algorithm we are working on to resolve the ill-posedness. (Received September 19, 2015)

1116-VM-1586 **Hwayeon Ryu*** (ryu1@stolaf.edu) and **Anita T. Layton** (alayton@math.duke.edu). *Synchronization of tubular pressure oscillations by vascular and hemodynamic coupling in interacting nephrons.*

The kidney plays an essential role in regulating the blood pressure and a number of its functions operate at the functional unit of the kidney, the nephron. To understand the impacts of internephron coupling on the overall nephrons' dynamics, we develop a mathematical model of a tubuloglomerular feedback (TGF) system, a negative feedback mechanism for nephron's fluid capacity. Specifically, each model nephron represents a rigid thick ascending limb only and is assumed to interact with nearby nephrons through vascular and hemodynamic coupling along the pre-glomerular vasculature. We conduct a bifurcation analysis by deriving a characteristic equation obtained via a linearization of the model equations. To better understand the impacts of parameter variability on TGF-mediated dynamics, we investigated five cases with two coupled nephrons when i) vascular coupling is absent, ii) hemodynamic coupling is absent, iii) vascular and hemodynamic coupling strengths are identical, iv) vascular coupling is stronger, and v) hemodynamic coupling is stronger. Our model results show that the coupled-TGF system with two coupling effects can produce in-phase and anti-phase (out-of-phase) synchronization of tubular pressure oscillations in two nephrons, as has been reported in experimental studies. (Received September 20, 2015)

1116-VM-1590 **David S Torain, II*** (david.torain@hamptonu.edu). *A Deeper Study of a Mathematical Model Using Torain's Equations.*

Torain's mathematical model is mainly used as an analytical tool while computer software, like Mathematica or MatLab, is used to crosscheck the predictions given by the analytical tool. This analytical tool, which also represents a mathematical model, offers a global view that computer calculations cannot provide. The mathematical model reduces to a set of parametric coupled non-linear differential equations. The equations depend on sixteen parameters and all the parameters must be fixed in order to arrive at a computer solution. A different and new point of view consists of letting all of the parameters be free and getting a panoramic view of all possible solutions. It is possible to achieve this goal by using "Dimensional Analysis". (Received September 20, 2015)

1116-VM-1614 **Molly Monk***, 701 North C Street, #3903, Indianola, IA 50125, and **Teig Loge**, **Park Ellis Mikels** and **Maggie Long**. *Using Modeling and a Community Based Participatory Research Strategy to Stop the Spread of Palmer Amaranth in Iowa.* Preliminary report.

Palmer amaranth, an herbicide resistant superweed, recently began spreading across Iowa. Weed experts say that if left unchecked, Palmer will devastate many sectors of Iowa's economy. An undergraduate research team modeled the spread of the weed over a 21 year period using NetLogo software. Consultations with local community members and experts in the field helped determine the factors in the model. The model results are an integral part of an awareness campaign targeting a diverse group of stakeholders. The research team will give an overview of their work to date and explain the impact math modeling can have on agricultural decision making. (Received September 20, 2015)

1116-VM-1623 **Brendan C. Fry*** (brendan.fry@colorado.edu). *Impact of kidney structural architecture on oxygen transport: A mathematical model.*

A theoretical model is presented to analyze the impact on oxygen distribution of the heterogeneous organization of the inner part of the rat kidney – called the medulla – revealed in anatomical studies. Model PDEs are based on active and passive transmural transport processes, as well as conservation of water and solutes (NaCl, urea, O_2, HbO_2, Hb), and are solved to steady state. Results of the model suggest that the structural organization of the renal medulla produces marked axial and radial tissue PO_2 gradients. In addition, the heterogeneous structure preserves oxygen delivery deep into the kidney, but significantly increases the likelihood of O_2-limiting tissue injury. (Received September 20, 2015)

1116-VM-1676 **Chris McCarthy*** (cmccarthy@bmcc.cuny.edu), Department of Mathematics, Borough of Manhattan Community College, City University of New York, New York, NY 10007.
Modeling Adsorption Kinetics (Bio-remediation of Heavy Metal Contaminated Water).

Heavy metals, such as Cobalt, Copper, and Zinc, are often present in industrial waste waters. These pollutants can cause environmental degradation and pose health risks. It is possible to use spent tea leaves to filter heavy metals from contaminated water. The spent tea leaves are available in large quantities as a result of the industrial production of tea beverages. The heavy metals bond with the surfaces of the tea leaves (adsorption). Our interdisciplinary lab group (Chemistry, Environmental Engineering, and Mathematics) is conducting research on this process.

My talk will focus on modeling the kinetics of the adsorption and filtering process using differential equations, stochastic methods, and recursive functions. (Received September 22, 2015)

1116-VM-1701 **Bryan A Dawkins*** (bdawkins@uco.edu) and **Sean M Laverty**. *Modeling Effects of Regulatory T Cells in Antitumor Laser Immunotherapy.*

Antitumor laser immunotherapy is a promising approach for completely eradicating primary and metastatic tumors. We present a mathematical model consisting of a system of first order, ordinary differential equations that explicitly includes populations of dendritic cells, cytotoxic T cells, primary tumor cells, and metastatic tumor cells. One of the primary obstacles to achieving the desired clinical outcome for immunotherapy of cancerous tumors is the suppressive activity of regulatory T cells (Tregs) as a result of self-tolerance. We present our analysis of the effects of Tregs by considering simulated treatment outcome as a function of Treg immunosuppressive activity. Using model results, we outline a systematic method for assigning a patient's clinical outcome for a simulated treatment. Ultimately this will show how modulation of immunosuppressive Treg activity during laser immunotherapy determines clinical outcomes in treated patients. (Received September 21, 2015)

1116-VM-1748 **Christina L. Hamlet*** (chamlet@tulane.edu), **Kathleen A. Hoffman**, **Eric D. Tytell** and **Lisa J. Fauci**. *A central pattern generator-driven integrative multi-scale model of lamprey locomotion with sensory feedback.*

The lamprey is a vertebrate organism and a model for both neurophysiology and locomotion studies. Here a 2D, integrative, multi-scale model of the lamprey's anguilliform (eel-like) swimming is driven by neural activation from a central pattern generator (CPG) modeled as a chain of coupled oscillators. The CPG in turn drives muscle kinematics and fully coupled fluid-structure interactions implemented in an immersed boundary framework to produce the emergent swimming mode. Body curvature and rate of curvature change provide feedback to the CPG. Effects of nonlinear dependencies associated with muscle force development combined with feedback to the neural activation on the speed, stability and cost (metabolic work) of swimming are estimated and examined. (Received September 22, 2015)

1116-VM-1819 **Cody A Palmer***, cody.palmer@umontana.edu. *Dynamics of Vector-borne Relapsing Diseases.*

The dynamics of vector-borne relapsing diseases, such as Tick-Borne relapsing Fever (TBRF) and Equine Infectious Anemia Virus (EIAV) are affected by the number of relapses that occur over the course of infection. In this talk we will be investigating the relationship between the number of relapses and latent states and the fundamental reproductive number R_0. We will also be considering how the existence of endemic equilibria can be affected by relapse and latent states. (Received September 21, 2015)

1116-VM-1861 **Caleb L Adams*** (cadams5@radford.edu), Department of Mathematics and Statistics, Radford University, PO Box 6942, Radford, VA 24142. *An Extensible Mathematical Model of Glucose Metabolism.*

The impact of diabetes in the United States is immense. An estimated 29.1 million individuals, or 9.3 percent of the population, have diabetes. Nearly one-third of the cases is undiagnosed. The total of the direct and indirect medical costs associated with diabetes in 2012 was projected to be $245 billion. With the percentage of individuals being diagnosed with diabetes on a continual rise, one study estimates as many as one in three adults in the United States could have diabetes by 2050.

One must understand the glucose regulatory system of the healthy body to understand diabetes. Presented is the evolution of a model of ordinary differential equations beginning with a three-variable model of glucose, insulin, and glucagon mimicking the return of blood glucose levels to a constant, or basal, state. The extension includes the effects of a finite store of hepatic glycogen and whose solution demonstrates the short-term return of glucose concentration to near basal levels despite the constant energy usage which draws upon the glycogen stores. Long-term glucose homeostasis is explained by investigating the storage of a glucose load in the postprandial period and dispersion of stored glucose during the extended postprandial period. (Received September 21, 2015)

1116-VM-1890 **Christopher David Mitchell*** (mchris@uta.edu), 411 S. Nedderman Drive, 478 Pickard Hall, Arlington, TX 76019. *A comparison of methods to calculate the basic reproductive number for periodic systems.*

Many diseases exhibit seasonality, such as influenza and malaria, and so many models must incorporate this into their parameters. This leads to a non-autonomous model with periodic coefficients. The standard methods for calculating the basic reproductive number, or BRN, for autonomous models do not transfer to periodic systems. Here we review and compare two methods for calculating BRNs for periodic epidemic models, the time-average method and the linear operator method. We consider the simplest possible model where the two methods differ, and establish sufficient conditions for them to agree. (Received September 22, 2015)

1116-VM-1951 **Megan O Powell*** (mpowell@stfrancis.edu), 500 Wilcox St., Joliet, IL 60435. *Modeling in vitro studies of anthrax spore and macrophage interactions.* Preliminary report.

In vitro studies of the interaction between anthrax spores and macrophages yield varying results due to differences in uses of spore strains, macrophage cell lines, medium, as well as lab protocol. While *in vitro* studies often give definitive numerical results that help determine phagocytosis, germination, and spore killing rates, we must consider how well these results translate *in vivo*. We will offer models of *in vitro* studies and discuss relevant factors when trying to estimate parameters for *in vivo* models. (Received September 21, 2015)

1116-VM-1956 **Mitchell Eithun**, **McKenzie Lamb*** (lambm@ripon.edu) and **Andrea Young**. *Short-Term vs Long-Term Strategy in the Game of Monopoly.* Preliminary report.

Using a computer model, we analyze and compare various types of strategies for the game of Monopoly. Using an elementary hill-climbing algorithm and the linear algebra behind the Google PageRank algorithm, we identify several aspects of effective game play. In particular, we identify a ranking of the property groups from most to least desirable and give evidence that this ranking yields a highly effective strategy. We also demonstrate that it seldom pays to ignore the long-term goals determined by this ranking in order to maximize short-term gains. (Received September 21, 2015)

1116-VM-2000 **Margaret Elizabeth Swift*** (meswift@email.wm.edu), **Leah Shaw** and **Junping Shi**.
Dispersal-Induced Global Extinction in Two-Patch Model under the Allee Effect.

Centuries of overfishing and the gradual destruction of habitat have led to the rapid devastation of the Chesapeake Bay's oyster supply. We study asymmetric dispersal between two coupled patches (oyster reefs) under the Allee effect. This effect is displayed by many species, and is one under which initial populations below a certain threshold decline, while those above the threshold can persist. We extend a previous ordinary differential equation model with symmetric dispersal rates between patches (Kang & Lanchier, Bull. Math. Biol. 2011), and explore the steady state bifurcation structure while varying the dispersal rates and Allee threshold. We also show analytically that there are no periodic orbits. At high Allee thresholds, we find large parameter ranges in which the extinction state is the only fixed point. Previous symmetric models did not uncover this behavior, and it raises concerns for environmental restoration of other species that may exhibit the Allee effect and asymmetric dispersal, such as in estuarine and marine systems. (Received September 21, 2015)

1116-VM-2063 **Iftikhar Ali*** (iali@kfupm.edu.sa), King Fahd University of Petroleum and Mineral, Department of Mathematics and Statistics, KFUPM Box 5046, Dhahran, Eastern 31261, Saudi Arabia, and **Nadeem A Malik**, King Fahd University of Petroleum and Mineral, Department of Mathematics and Statistics, Dhahran, Eastern 31261, Saudi Arabia.
Numerical Investigation of Nonlinear Transport Models describing Gas Flow through Tight Porous Media.

Mathematical modelling of gas flow through tight porous media results into time-dependent advection-diffusion equations, with highly nonlinear diffusion and advection coefficients. These coefficients depend on the unknown variable p and its spatial derivative, and also on the several reservoir parameters, such as, gas density, permeability, porosity, together with their compressibility coefficients. An accurate and precise determination of these coefficients play crucial role in the success of the mathematical model describing gas flow through reservoirs. In this study, we numerically investigate the effects of reservoir parameters and their compressibility coefficients on the model outcomes and also perform the sensitivity analysis with respect to several parameters. (Received September 21, 2015)

1116-VM-2074 **Mark J Panaggio*** (panaggio@rose-hulman.edu) and **Daniel M Abrams**. *Not so sinister after all: How mathematical models can explain the resilience of the left-handed minority.*

Every human population in recorded history has been predominantly right-handed, and although numerous explanations for individual handedness have been proposed, none of these explanations can account for this population-wide bias. In this talk, I will present a mathematical model of competition between social groups that can explain why most humans are right-handed, why most animals are not, why left-handed athletes overachieve in baseball and why they underachieve in golf. This model approximates a population of left- and right-handed individuals as a dynamical system. I will analyze the equilibrium states in this system and demonstrate that mathematical models balancing competition and cooperation can provide insight into our right-handed world.
(Received September 21, 2015)

1116-VM-2087 **Austin States*** (statesar17@mail.vmi.edu), 1340 Windsor Road, Red Lion, PA 17356, **Bradley Lipscomb** (lipscombbs16@mail.vmi.edu), 1185 County Home Road, Blanch, NC 27212, and **Dimplekumar Chalishajar**. *On Applications of Generalized Functions in the Discontinuous Beam Bending Differential Equations.* Preliminary report.

Abstract:

This paper discusses the mathematical modeling for the mechanics of solid using the distribution theory of Schwarz to the beam bending differential equations. This problem is solved by the use of generalized functions, among which the well known Dirac delta function. The governing differential equation is Euler-Bernoulli beams with jump discontinuities on displacements and rotations. Also, the governing differential equations of a Timoshenko beam with jump discontinuities in slope, deflection, flexural stiffness, and shear stiffness are obtained in the space of generalized functions. The operator of one of the governing differential equations changes so that for both equations the Divac delta function and its first distributional derivative appear in the new force terms as we present the same in an Euler-Bernoulli beam. Examples are provided to illustrate the abstract theory. This research is useful to Mechanical Engineering, Ocean Engineering, Civil Engineering, and Aerospace Engineering.

Key words: Mechanics of solids, Discontinuities in a beam bending differential equations, Generalised functions, Jump discontinuities (Received September 21, 2015)

1116-VM-2102 **Long Le*** (longl@uca.edu), University of Central Arkansas, 201 Donaghey ave., Conway, AR 72035. *An epidemic model with exposed and treatment components.* Preliminary report.

Epidemics have had great effects throughout the course of human history. To be able to describe and predict the behavior of an epidemic is essential to prevent its spreading and to provide understanding of underlying mechanisms of a disease. One of the earliest models that successfully described and predicted behaviors of an epidemic is called the SIR model, in which the population is divided in three groups: susceptible (S), infected (I), and recovered(R). In this paper, a model in which exposed and treated groups are considered. An endemic equilibrium is found and its stability is analyzed. (Received September 21, 2015)

1116-VM-2209 **Bruce Pell*** (bepell@asu.edu), **Javier Baez**, **Gerardo Chowell**, **Yang Kuang**, **Daozhou Gao** and **Tin Phan**. *Implications of Logistic Equation Based Spatial and Behavioral Ebola Forecasting Models.*

Mathematical models are essential in the efforts to forecast the course of the West Africa Zaire ebola virus (EBOV) epidemic that started in December 2013. Here, we validate a family of logistic patch models for use in disease modelling and forecasting. In particular, we derive the well known logistic equation in an infectious disease context and forecast the trajectories of the EBOV epidemic in parts of West Africa. We also derive the basic reproduction number in this context. We then extend the logistic model by fitting the total reported case numbers at different geographical scales using multi-patch models that incorporate migration and logistic growth. The patch models show an improvement over the logistic model in short term forecasting, but produce erratic behavior for long term forecasting due to too many parameters. To circumvent this issue, we provide preliminary results of a continuous modeling effort using a partial differential equation model. This work contributes to the mathematical forecasting of disease outbreaks and extends a recent modeling effort reported in the PLoS Currents Outbreaks in 2014 by including spatial heterogeneity. (Received September 22, 2015)

1116-VM-2236 **Bradley Michael Stiefel*** (bstiefel@asu.edu), 630 E Jensen St., Unit 158, Mesa, AZ 85203, and **Zach Kenyon**, **Tin Pham**, **Eric Kostelich** and **Yang Kuang**. *Ensemble Kalman Filter for Prediction of Treatment Response in Metastatic Prostate Cancer.* Preliminary report.

Prostate-specific androgen (PSA) measurements are commonly used to predict tumor progression in prostate cancer patients. An Ensemble Kalman Filter was applied to an ordinary differential equation model of androgen deprivation therapy for metastatic prostate cancer. The sensitivity of the models to errors in parameters and measurements will be characterized, and the accuracy of the models' predictions compared to observations will be assessed. (Received September 22, 2015)

1116-VM-2250 **Yusuf Sofuoglu*** (ysofuoglu@yahoo.com), 56100 Siirt, Turkey. *Mathematical Models on Language Competition and Bilingualism.*

In this study general mathematical models on language competition and bilingualism are investigated. Also an application of the bilingualism model is given in the context of numerical simulation. (Received September 22, 2015)

1116-VM-2269 **Laura K. Gross*** (laura.gross@bridgew.edu), Mathematics Department, Bridgewater State University, Bridgewater, MA 02325, and **Jun Yu**, **Yi Yang** and **Kewang Chen**. *On a generalized free-interface model of solid combustion.*

We develop a generalized free-interface model to describe the propagation of a reaction such as solid combustion, explosive solidification, and certain other exothermic phenomena. In particular, from a reaction-diffusion model we derive a system of heat equations in the reacted and unreacted zones, subject to boundary conditions, including conditions posed at a sharp reaction front. This model contains a ratio of thermal diffusivities in the product and reactant and has limiting cases that reproduce two models from the literature. We present numerical studies of the nonlinear dynamics of the generalized model. (Received September 22, 2015)

1116-VM-2389 **Michael R Kelly*** (kelly.1156@osu.edu) and **Joseph H Tien**. *Preemptive vaccination strategies for disease outbreaks in community networks.* Preliminary report.

The risk of disease outbreaks within a network is important when considering where intervention strategies should be focused. The problem is intensified when considering uncertainty among regions within a network. We investigate questions of disease intervention, given uncertainty about the regions and where an outbreak occurs. We first investigate scenarios where intervention is fast, not dependent on time. We seek answers to the

the problem of minimizing the costs while also lowering the expected network reproduction number below some desired threshold. We compare results to outbreak scenarios with intervention. This problem is relevant due to the current debate on vaccination campaigns and vaccine stockpiles, with questions on how many doses to be requested and where vaccines should be deployed. (Received September 22, 2015)

1116-VM-2399 **Jacqueline M Dresch*** (jdresch@clarku.edu), Mathematics and Computer Science Department, Clark University, 950 Main Street, Worcester, MA 01610, and **Robert A Drewell** and **Gregory D McCarthy**. *Global Parameter Sensitivity Analysis on a Dynamic Model of Gene Regulation.*

The study of gene regulation has been an important topic in biology for decades, and it is well known that this activity is tightly controlled during early organismal development. However, the roles of key processes involved in this regulation, such as transcription and translation, are less well understood. Using a discretized reaction-diffusion model incorporating terms for each of the key processes involved, we perform global sensitivity analyses using various different initial conditions and spatial and temporal outputs. Our numerical results indicate that transcription and translation are often the key parameters driving protein abundance; an observation that is in close agreement with the experimental results from mammalian cells for various initial conditions at particular time points. These results suggest that a simple dynamic model is capable of capturing the intricate behavior of a gene. (Received September 22, 2015)

1116-VM-2479 **Tao Pang** and **Azmat Hussain*** (ahussai@ncsu.edu), North Carolina State University, 2152 Burlington Labs, 2500 Stinson Drive, Raleigh, NC 27695. *An Infinite Time Horizon Portfolio Optimization Model with Delays.*

In this paper we consider a portfolio optimization problem of the Merton's type over an infinite time horizon. Unlike the classical Markov model, we consider a system with delays. The problem is formulated as a stochastic control problem on an infinite time horizon and the state evolves according to a process governed by a stochastic process with delay. The goal is to choose investment and consumption controls such that the total expected discounted utility is maximized. Under certain conditions, we derive the explicit solutions for the associated Hamilton-Jacobi-Bellman (HJB) equations in a finite dimensional space for exponential, logarithmic and power utility functions. For those utility functions, verification results are established to ensure that the solutions are equal to the value functions, and the optimal controls are derived, too. (Received September 22, 2015)

1116-VM-2518 **Baoling Ma*** (baoling.ma@millersville.edu), **Azmy S Ackleh** and **Xinyu Li**. *Fitting structured population dynamics models for the green treefrog (Hyla cinerea) to population estimates from field data.* Preliminary report.

Major declines of many amphibian populations have been reported around the world and led to numerous research efforts. Many of these efforts focus on monitoring amphibian populations to better understand their dynamics. Estimates for an urban population of greentree frogs (Hyla cinerea) from capture-mark-recapture field data during the years 2006-2009 were obtained. To describe the population dynamics, structured mathematical models with distributed recruitment and distributed states-at-metamorphosis were developed and compared to the time-series obtained from the weekly population estimates using a least-squares approach. The results of the model-to-data fit are very good and suggest that mathematical models can be used as an important tool to predict the long term dynamics of this population and to understand conditions for its persistence. (Received September 22, 2015)

1116-VM-2522 **Cameron Harvey** and **Amy Buchmann***, Department of Mathematics Gibson Hall 424, Tulane University, 6823 St. Charles Avenue, New Orleans, LA 70118, and **Scott Christley**, **Joshua Shrout**, **Aboutaleb Amiri**, **Jianxu Chen**, **Danny Chen**, **Igor Aronson** and **Mark Alber**. *Mathematical and Computational Modeling of Bacterial Motility and Swarming.* Preliminary report.

Computational models play an important role in understanding bacterial movement. For example, the very social Myxococcus xanthus, a bacterium commonly found in soil and known for its multicellular interactions, can be modeled using the subcellular element method. I will present an implementation of this model and show how it can be used to study the effects of cell flexibility, cell-cell adhesion, and cellular reversal periods on cell-cell interactions. To characterize cell-cell interactions, the contacts between cells in simulations are analyzed to determine how these properties influence the populations' ability to form and keep cell-cell connections. (Received September 22, 2015)

1116-VM-2563 **Zachary Dean Kenyon*** (zkenyon@asu.edu), 1900 E Apache Boulevard, Apt 4040, Tempe, AZ 85281. *Uncertainty Quantification in Model of Treatment for Metastatic Prostate Cancer.* Preliminary report.

The Intermittent Androgen Suppression (IAS) treatment system from prostate cancer puts patients through on and off drug treatment cycles. When the patient is on their medication, their androgen and prostate specific androgen (PSA) levels decrease. Our objective is to use a method in the vein of weather forecasting to predict a patients response to the treatment: given data up to time tn, what will the PSA levels be at tn+1? The model developed by Portz et al. (2012), adequately represents the patient's PSA after going through the treatment cycles. Combining the Portz model with Local Ensemble Forecasting via Kalman Filtering, our objective is to predict a patient's PSA during off-treatment cycles. This would allow for updates with the inclusion of every new data point collected and ultimately, it would give doctors a tool to estimate the duration of the patient's off-treatment phases. (Received September 22, 2015)

1116-VM-2680 **Torrey A Johnson*** (johnsotor@science.oregonstate.edu), Department of Mathematics, Oregon State University, Kidder Hall 368, Corvallis, OR 97331-4605. *Urn Models for Honeybee Swarm Site-Selection.* Preliminary report.

When a colony of honeybees outgrows a hive, it will swarm for the purpose of selecting a new home. The swarm engages in a fascinating process, during which the swarm's scout bees examine the surrounding environment for new homes and report back on quality and location. This "house-hunting" process continues until a sufficient number of scouts agree on a site. Swarms will very often choose the best site when many are available .

In this talk I will describe a discrete-time urn model for this process. In the most basic version, a single bee finds one of a number of potential sites (idealized as the colors of balls in an urn), and either recruits another bee to it or switches to another site. Recruitment or switching occurs according to site-dependent probabilities that encode site quality. The number of bees (balls) grows until a quorum threshold is reached, and the process terminates in a decision for the site with the most bees. Natural questions for such a model include whether or not the process finds the best site, the rate at which decisions are reached, and to what extent the speed of the decision impacts the quality of the site ultimately selected. This is based on work from my Ph.D. thesis and continuing work with my thesis adviser, Edward Waymire. (Received September 22, 2015)

1116-VM-2802 **Ariel Cintron-Arias*** (cintronarias@etsu.edu), ETSU, Department of Mathematics and Statistics, Box 70663, Johnson City, TN 37614. *Post-Secondary Enrollment in the United States: Model Validation and Student Life Tables.* Preliminary report.

Mathematical models of demography are revisited in the context of student enrollment at postsecondary institutions across the United States (US). More specifically, matrix population models with constant and time-dependent coefficients are implemented.

Longitudinal datasets for a regional public university were employed as a case study. Additional datasets were obtained from public archives maintained by the US Department of Education. At each year, there were four measurements of enrollment corresponding to student classification: freshman, sophomore, junior, and senior.

Ordinary least squares (OLS) methods, together with bootstrap sampling were applied while estimating model parameters. Akaike information criterium (AIC) was calculated to select one of five mathematical models best suited to describe the longitudinal observations of enrollment.

An ultimate goal of this project is the estimation of life tables in the context of enrollment, also known as "tables of school life" or "student life tables". Model parameter estimates were transformed and evaluated to approximate student life table functions such as: student life expectancy, probability of school departure, average number of years in each school group (e.g. sophomore). (Received September 22, 2015)

1116-VM-2841 **Qing Wang*** (qwang@shepherd.edu), **Zhijun Wang** and **David J Klinke**. *Tumor Control Strategies for a Mixed Immuno-Chemotherapy via Impulsive Control.*

In this study, we developed a multi-scale impulsive ODE model to describe the effect of a chemotherapy agent Oxaliplatin in combination with Interleukin-12 treatment on pre-existing liver metastatic colorectal cancer in mice. Model parameters were calibrated to published experimental data. Criteria on stabilization of the tumor-free equilibrium were established via impulsive control. Treatment strategies to control tumor growth for the mixed immuno-chemotherapy were discussed based on impulsive stabilization results. This research has been supported by the NIGMS of the NIH grant as part of the WV-INBRE (P20GM103434). (Received September 22, 2015)

1116-VM-2904 **Michelle L Isenhour*** (michelle.isenhour@usma.edu), United States Military Academy, West Point, NY 10996, and **Rainald Löhner** (rlohner@gmu.edu), Center for Computational Fluid Dynamics, George Mason University, Fairfax, VA 22030. *Pedestrian Speed on Stairs: A Mathematical Model Based on Empirical Analysis for use in Computer Simulations.* Preliminary report.

A critical component of building evacuation simulations is pedestrian ascent and descent on stairs. Several researchers have conducted controlled laboratory experiments and performed observational studies in an effort to obtain empirical data and develop models that can be used to accurately predict the walking speed of pedestrians on stairs. Most recently, Qu et al. (2014) compiled an extremely thorough state-of-the-art summary of past experimental and observational data collection efforts, highlighting the studies of flow characteristics and evacuation processes. The availability and use of empirical data is essential to the calibration and validation of mathematical models used in computer simulations of pedestrian movement. This paper will describe the mathematical model used in our simulation code's subroutine (PEDFLOW) which adjusts a simulated pedestrian's velocity to account for movement on stairs. In addition, the paper will demonstrate how empirical data was used to determine individual step frequency on stairs, how the model was verified within PEDFLOW, and how the model performed against a newly collected set of empirical data. (Received September 23, 2015)

General Session on Number Theory

1116-VN-42 **Erhan Gurel*** (egurel@metu.edu.tr), Middle East Technical University, Northern Cyprus Campus, TZ-32, Guzelyurt, KKTC, Mersin 10, Turkey. *On the Products* $\prod_{k=1}^{n}(4k^4+1)$ *and* $\prod_{k=1}^{n}(k^4+4)$.

It is proven that the product $\prod_{k=1}^{n}(4k^4+1)$ is a perfect square infinitely often whereas, the product $\prod_{k=1}^{n}(k^4+4)$ is a perfect square only for $n=2$.
(Received June 16, 2015)

1116-VN-504 **Lee Troupe*** (ltroupe@math.uga.edu), Department of Mathematics, Boyd GRSC, University of Georgia, Athens, GA 30602. *Orders of reductions of elliptic curves with many and few prime factors.*

Let $E/\mathbb{Q}$ be an elliptic curve with complex multiplication and consider the quantity $\omega(\#E(\mathbb{F}_p))$, where $\omega(n)$ denotes the number of distinct prime factors of n and p is a prime of good reduction for E. Independent work of Cojocaru and Liu shows that the normal order of $\omega(\#E(\mathbb{F}_p))$ is $\log\log p$, and moreover that there is an elliptic curve analogue of the celebrated Erdős - Kac theorem: The quantity

$$\frac{\omega(\#E(\mathbb{F}_p))-\log\log p}{\sqrt{\log\log p}}$$

has a Gaussian normal distribution. In this talk, we will discuss the frequency with which $\omega(\#E(\mathbb{F}_p))$ is much larger or smaller than expected. For fixed $\gamma>1$, we have

$$\#\{p\le x:\omega(\#E(\mathbb{F}_p))>\gamma\log\log x\}=\frac{x}{(\log x)^{2+\gamma\log\gamma-\gamma+o(1)}}.$$

The same result holds for the quantity $\#\{p\le x:\omega(\#E(\mathbb{F}_p))<\gamma\log\log x\}$ when $0<\gamma<1$. (Received September 04, 2015)

1116-VN-553 **Beth Romano*** (romanob@bc.edu). *The Local Langlands Correspondence: New Examples for Small Residue Characteristic.*

The structure of reductive p-adic groups arises from the interaction of Euclidean geometry and the arithmetic of p-adic fields. Reeder and Yu have drawn upon this interaction to construct certain "epipelagic" representations using Geometric Invariant Theory (GIT). In recent work, Jessica Fintzen and I have built on their methods to find new supercuspidal representations of p-adic groups when p is small. For each of these representations, the Local Langlands Correspondence predicts the existence of a corresponding field extension of $\mathbb{Q}_p$, whose Galois theory reflects the structure of the representation. In my talk, I will give explicit examples of representations and corresponding field extensions for the group G_2. (Received September 06, 2015)

1116-VN-606 **Duff G Campbell*** (campbell@hendrix.edu), Hendrix College, Mathematics Department, 1600 Washington St., Conway, AR 72032. *Minkowski's Theorem (Geometry in the Aid of Algebra).*

An important result in number theory is that a prime integer $p > 2$ can be written as a sum of squares, $p = a^2+b^2$, if and only if $p \equiv 1 \pmod 4$. Many proofs exist. Minkowski proved this in a novel way, using the geometry of lattices. His proof may be modified to apply to other quadratic forms such as $p = a^2 + 2b^2$, $p = a^2 - ab + b^2$, . . . even $p = a^2 + 43b^2$. (Received September 08, 2015)

1116-VN-988 **Darin Orrie Brindle*** (dabri8@morgan.edu), 2900 Dunleer Rd, Dundalk, MD 21222. *Continued Fractions: Methods and Applications, including finding Epsilon Periods of Almost Periodic Functions.*

The three forms of continued fractions are: terminating (which relate to simple fractions), repeating (which involve square roots) and non-repeating (all other irrationals). They have applications ranging from Diophantine equations to almost periodic functions.

Herein the well-known simplest algorithm for continued fractions is defined along with its equivalent algorithms of direct recursion of numerators and denominators.

The limit for continued fractions can be proved using standard real analysis.

And from this a major consequence is that continued fractions can be used to find actual almost periods and more for any given epsilon when combining some continuous periodic functions that result in almost periodic functions. That is there are almost periodic functions defined as $\forall\epsilon > 0\ \exists P$ such that $\sup|f(x) - f(x - P)| < \epsilon$ that have algorithms to find P fitting the conditions. Which allows one to compose definitive graphs that illustrate major properties of almost periodic functions.

These graphical shifts are illustrated with their actual maximum differences that are within ϵ (Received September 15, 2015)

1116-VN-996 **Qingquan Wu*** (qingquan.wu@tamiu.edu), 5201 University Blvd, TAMIU, Math & Physics, Laredo, TX 78041. *Certain number fields with an explicit integral basis.* Preliminary report.

It is known that an explicit integral basis is rare for number fields, except for certain types. Based on the previous work on radical function fields, we anticipate that there are certain number fields K with explicit integral bases. The construction is based on a technique to calculate the ramification indices for various primes in the absolute field extension $K/\mathbb{Q}$. (Received September 15, 2015)

1116-VN-1410 **Joshua Zelinsky*** (joshua.zelinsky@maine.edu). *Counting Artin representations with bounded conductor.*

We present upper bounds on certain sums which are related to a an average version Artin's primitive root conjecture and are also used in counting ray class characters. Define $\mathrm{ord}_n(a)$ for the order of a in the multiplicative group of invertible residue classes modulo n when $(a, n) = 1$. Let

$$G(x) = \sum_{n\le x,(n,a)=1} \frac{\phi(n)}{\mathrm{ord}_n(a)}.$$

Then our primary result is any α, we have $G(x) = O(x^2/\log^\alpha x)$. An analogous result for number fields is also obtained. (Received September 19, 2015)

1116-VN-1421 **Samuel Gross** and **Joshua Harrington*** (joshua.harrington@cedarcrest.edu), Cedar Crest College, 100 College Drive, Allentown, PA 18104. *Special Numbers in the Ring $\mathbb{Z}_n$.*

In a recent article, Andrzej Nowicki introduced the concept of a special number. Specifically, an integer d is called *special* if for every integer m there exist solutions in non-zero integers a, b, c to the equation $a^2 + b^2 - dc^2 = m$. In this talk we investigate pairs of integers (n, d), with $n \ge 2$, such that for every integer m there exist units a, b, and c in $\mathbb{Z}_n$ satisfying $m \equiv a^2 + b^2 - dc^2 \pmod n$. Upon refining a recent result of Harrington, Jones, and Lamarche on representing integers as the sum of two non-zero squares in $\mathbb{Z}_n$, a complete characterization of all such pairs is established. (Received September 19, 2015)

1116-VN-1591 **Dominic Lanphier***, Department of Mathematics, 1906 College Heights Blvd., Bowling Green, KY 42101, and **Mahannah El-Farrah**, Departmetn of Mathematics, 1906 College Heights Blvd., Bowling Green, KY 42101. *Subgroups of Cyclic Groups and Values of the Riemann Zeta Function.*

The average order of the elements of a cyclic group have been well-studied in recent years. We consider the average order of the subgroups of a cyclic group which are generated by a fixed number of elements. Values of the Riemann zeta function arise in expressing the expected size of such subgroups. (Received September 20, 2015)

1116-VN-1647 **Jeremy Newton*** (jnewto02@leeu.edu). *Predicting the Sequence of Non-Truncated Tetrahedron Numbers.*

Arising from Eike Hertel's paper, {Reguläre Dreieckspflasterungen konvexer Polygone}, we discuss tiling a regular tetrahedron with unit tetrahedrons and octahedrons. Ordering the tetrahedral constructions by size produces the sequence of tetrahedron numbers, which represents the number of unit tetrahedron volumes in a tetrahedral construction, which is the sequence of cubic integers. Truncating a tetrahedron by cutting away its corners, we discover a new sequence of integers. The sequence can be understood from various mathematical perspectives, and its complement is seemingly finite. Using methods of estimation and the squeeze theorem, a range can be given for the largest element in the sequence's complement. Further explorations would include proving a surjection from the sequence to the natural numbers. (Received September 20, 2015)

1116-VN-1873 **Jonathan Gerhard***, James Madison University. *Conjugacy classes in $GSp_6(\mathbb{F}_q)$ and an application to abelian varieties.* Preliminary report.

The finite matrix group $\mathrm{GSp}_{2n}(\mathbb{F}_q)$ is the subgroup of $\mathrm{GL}_{2n}(\mathbb{F}_q)$ consisting of matrices that preserve an anti-symmetric bilinear form up to scalar multiple. In $\mathrm{GL}_{2n}(\mathbb{F}_q)$, the characteristic polynomial and some additional partition data completely determine a conjugacy class. However, in $\mathrm{GSp}_{2n}(\mathbb{F}_q)$, this is still not enough to uniquely identify a conjugacy class in every case. In $\mathrm{GSp}_6(\mathbb{F}_q)$, we use a parameterization of Shinoda (1980) to construct representatives of certain conjugacy classes and then determine the sizes of those conjugacy classes. As an application, inspired by work of Gekeler (2003) and Achter and Williams (2015), we share progress towards constructing a product formula related to class numbers of number fields of degree 6 and conjecturally to sizes of isogeny classes of abelian varieties of dimension 3. (Received September 21, 2015)

1116-VN-1875 **Nicolas Allen Smoot*** (ns02570@georgiasouthern.edu). *Enumerating the Partitions of the Göllnitz–Gordon Theorem.* Preliminary report.

Nearly a century ago, the mathematicians Hardy and Ramanujan established their celebrated circle method to give an exact asymptotic expression for the unrestricted partition function. Following later improvements by Rademacher, the method was utilized by Niven, Lehner, Iseki, and others to develop rapidly convergent series representations of various restricted partition functions. Following in this tradition, we use the circle method to develop formulæ for counting a restricted class of partitions that arise in the Göllnitz–Gordon identities. We then derive and compare the asymptotic behavior of such formulæ. (Received September 21, 2015)

1116-VN-1930 **Mits Kobayashi*** (mkobayashi@cpp.edu), Department of Mathematics and Statistics, Cal Poly Pomona, Pomona, CA 91768, and **Berit Givens**. *A Notorious Problem in Silverman's* A Friendly Introduction to Number Theory. Preliminary report.

When I teach introductory number theory, I enjoy challenging my students with the following exercise from Silverman's book:

The first two numbers that are both squares and triangles are 1 and 36. Can you figure out an efficient way to find triangle-square numbers?

Although this problem out of Chapter 1 is not intended to be completely solved at that point in the book, we present a solution using only the elementary knowledge acquired in that chapter, albeit in a sophisticated way. (Received September 22, 2015)

1116-VN-1965 **Harris B. Daniels**, **Jeffrey Hatley** and **James Ricci*** (jricci@daemen.edu), Daemen College, Department of Mathematics, 4380 Main Street, Amherst, NY 14226. *Elliptic curves with maximally disjoint division fields.*

One of the many interesting algebraic objects associated to a given rational elliptic curve, E, is its full-torsion representation $\rho_E : \mathrm{Gal}(\bar{\mathbf{Q}}/\mathbf{Q}) \to \mathrm{GL}_2(\hat{\mathbf{Z}})$. Generalizing this idea, one can create another full-torsion Galois representation, $\rho_{(E_1,E_2)} : \mathrm{Gal}(\bar{\mathbf{Q}}/\mathbf{Q}) \to \left(\mathrm{GL}_2(\hat{\mathbf{Z}})\right)^2$ associated to a pair (E_1, E_2) of rational elliptic curves. The goal of this talk is to provide an infinite number of concrete examples of pairs of elliptic curves whose associated full-torsion Galois representation $\rho_{(E_1,E_2)}$ has maximal image. (Received September 21, 2015)

1116-VN-2002 **Frank Fuentes** (frank@francizco.com) and **Monta Meirose*** (msm011@morningside.edu). *Quadratic Prime-Generating Polynomials Over $\mathbb{Z}[i]$.*

The quadratic polynomial $x^2 + x + 41$ is prime for $x = 0, 1, \ldots, 39$. For this reason, it is called a prime-generating polynomial. Many other prime-generating polynomials have been discovered by computer searches, and their efficiency at producing primes can be predicted in some special cases. In this talk, we find and classify prime-generating polynomials $f(z)$, where the variable and coefficients are permitted to be Gaussian integers. Many of the same criteria for efficiency may be generalized from integer polynomials, though without a natural ordering of Gaussian integers there are some surprising differences. Since Gaussian polynomials live in a two-dimensional space, some symmetry can be observed—rotations and reflections, as well as translations, dilations, and combinations of these create more complicated families of polynomials. Our results so far have led us to polynomials that have a high efficiency on a region near 0. (Received September 21, 2015)

1116-VN-2028 **Scott Zinzer*** (zinzer_s@wvwc.edu), 59 College Avenue, Buckhannon, WV 26201. *Iwasawa λ-invariants of p-adic product measures.* Preliminary report.

We explore the product measure construction on p-adic measures. As an application, we describe the multivariate Iwasawa λ-invariants of sums of certain product measures. (Received September 21, 2015)

1116-VN-2053 **Jonathan Douglas Chan*** (jdchan@princeton.edu), **Soonho Kwon** and **Michael Seaman**. *On the distribution of discriminants over a finite field.*

For a prime power q, we show that the discriminants of monic polynomials in $\mathbb{F}_q[x]$ of a fixed degree m are equally distributed if $\gcd(q-1, m(m-1)) = 2$ when q is odd and $\gcd(q-1, m(m-1)) = 1$ if q is even. A theorem in the converse direction is proved when $q-1$ is squarefree. (Received September 21, 2015)

1116-VN-2190 **Michael Wijaya*** (michael.wijaya.gr@dartmouth.edu). *A function-field analogue of Conway's topograph.*

In *The Sensual (Quadratic) Form*, Conway introduces a visual method to display values of an integral binary quadratic form $Q(x,y) = ax^2 + bxy + cy^2 \in \mathbb{Z}[x,y]$. This topograph method, as he calls it, leads to a simple and elegant method of classifying integral binary quadratic forms and answering some basic questions about them. In particular, Conway uses his climbing lemma to show that the topograph of any definite (respectively, indefinite) integral binary quadratic form has a unique "well" (respectively, "river").

We will present an analogue of Conway's topograph method in the function-field setting, that is, for binary quadratic forms with coefficients in $\mathbb{F}_q[T]$, where q is an odd prime power. Our starting point was the connection between Conway's topograph method and hyperbolic geometry; this led us to consider the Bruhat–Tits tree of $\mathrm{SL}_2\big(\mathbb{F}_q((T^{-1}))\big)$ as the natural setting for our work. After we formulate and prove an analogue of Conway's climbing lemma, we establish that just as in the classical setting, there is a unique "well" (respectively, "river") on the topograph of any definite (respectively, indefinite) binary quadratic form with coefficients in $\mathbb{F}_q[T]$. (Received September 22, 2015)

1116-VN-2214 **Brandon Rafal Epstein*** (brandonmath774@gmail.com), 47 Hunting Hollow Court, Dix Hills, NY 11746. *Maximizing the Number of Lattice Points on a Strictly Convex Curve.*

We obtain an upper bound for the maximum number of integral lattice points on the graph of a twice differentiable convex function $f : [0, N] \to [0, N^\gamma]$, where $\gamma > 0$ by generalizing an argument for $\gamma = 1$ to all γ between $\frac{1}{2}$ and 2. This method was based on the asymptotes of sums involving the Euler totient function, which we extended to prove the general case. Moreover, we also strengthen upper bounds for smooth convex functions $f : [0, N] \to [0, N]$ with restrictions on higher derivatives. Specifically, we tighten an upper bound on the number of lattice points on a curve with positive first, second, and third derivatives by modifying a method of Bombieri and Pila. We also examine the problem of finding the maximal number of lattice points on a smooth convex curve $y = f(x)$, subject to the condition $1 < f''(x) < 2$. We conjecture that this maximum is attained for the curve $y = \frac{3}{4}x^2$, which has $2\sqrt{\frac{N}{3}} - O(1)$ lattice points. (Received September 22, 2015)

1116-VN-2430 **Paul A Kinlaw*** (kinlawp@husson.edu). *Explicit Bounds on Several Sums and Functions Arising in Elementary Analytic Number Theory.*

We consider solutions of $\varphi(n) = \varphi(n+1)$ and $\sigma(n) = \sigma(n+1)$. Both equations are conjectured to have infinitely many solutions. Work of Erdős, Pomerance and Sárközy shows that the sum of reciprocals of solutions is convergent.

We will discuss recent joint work with Jonathan Bayless, including explicit bounds on the counting functions of smooth numbers, as well as numbers with k distinct prime factors. We use these results as tools to put explicit numerical bounds on the sum of reciprocals of solutions of $\varphi(n) = \varphi(n+1)$ and $\sigma(n) = \sigma(n+1)$. (Received September 22, 2015)

1116-VN-2456 **Shannon R Lockard*** (slockard@bridgew.edu) and **Timothy Flowers**. *Hyper $m-$ary partition sequences.* Preliminary report.

Hyper $m-$ary partitions are integer partitions whose parts are powers of m and where each part appears at most m times. Several authors have found congruences and other arithmetic properties of this family of restricted partitions. Recently we have shown that the hyperbinary partition sequence can be found within the hyper m-ary partition sequence for any m. In this talk, we will show that this result can be extended to say that the hyper m_1-ary partition sequence is a subsequence of the hyper m_2-ary partition sequence for any $m_1 < m_2$. (Received September 22, 2015)

1116-VN-2458 **Don Vestal*** (donald.vestal@sdstate.edu) and **Tristin Lehmann**. *A Set of Two-Color Rado Numbers for $x_1 + x_2 + \cdots + x_m + c = ax_0$.*

In this talk, we'll summarize a set of two-color discrete and continuous Rado numbers for the equation $x_1 + x_2 + \cdots + x_m + c = ax_0$. In the discrete case, a, m, and c denote positive integers and the Rado number is the smallest positive integer R such that for any 2-coloring of the integers in $\{1, 2, \ldots, R\}$ there exists a monochromatic solution to the given equation. In the continuous case, a and m will denote positive integers, and c and γ will denote real numbers. The Rado number $R = R_\gamma(m, c; a)$ is the smallest real number with $R \geq \gamma$ such that for any 2-coloring of the real numbers in the interval $[\gamma, R]$, there exists a monochromatic solution to the given equation. (Received September 22, 2015)

1116-VN-2566 **Elijah Miguel Allen*** (pupilofyah@gmail.com). *Getting prime numbers from polynomials.*

Given an admissible set, $\mathcal{F}$, of polynomials and a positive integer k, there exist an integer n such that for each prime $\leq k$ that prime is not a divisor of $f(n)$, for all $f \in \mathcal{F}$. Further more, if n is less than a bound calculated from the first prime larger than k then the each $f(n)$ is a prime number.

In this talk we will discuss how the author plans to show that for large enough k that there will exist n that gives us a set of primes for $\mathcal{F}$. (Received September 22, 2015)

1116-VN-2624 **William C. Linderman*** (wclinder@king.edu), 1350 King College Road, Bristol, TN 37620. *Runs of Consecutive Abundant Numbers.* Preliminary report.

A natural number n is said to be **abundant** if the sum of its positive proper divisors is greater than n. Long runs of abundant numbers exist, but they are scarce. For example, the starting term of the smallest known set of four consecutive abundant numbers has 39 digits. We present a method for constructing runs of abundant numbers. (Received September 22, 2015)

1116-VN-2660 **Shawn Michael Elledge*** (shawn.elledge@asu.edu), Wanner Hall 301J, 6073 S. Backus Mall, Mail Code 2780, Mesa, AZ 85212-2780. *On Minimal Levels of Iwasawa Towers.*

In 1959, Iwasawa proved that the size of the p-part of the class groups of a $\mathbb{Z}_p$-extension grows as a power of p with exponent $\mu p^m + \lambda m + \nu$ for m sufficiently large. Broadly, we explore algebraic conditions necessary for a given m to be sufficiently large.

More precisely, let CG^i_m (class group) be the ϵ_i-eigenspace component of the p-Sylow subgroup of the class group of the field at the m-th level in a $\mathbb{Z}_p$-extension; and let $IACG^i_m$ (Iwasawa analytic class group) be $\mathbb{Z}_p[[T]]/((1+T)^{p^m} - 1, f(T, \omega^{1-i}))$, where f is the associated Iwasawa power series. It is expected that CG^i_m and $IACG^i_m$ be isomorphic; however, as of yet, this isomorphism is unestablished in general.

We consider the existence and the properties of an exact sequence

$$0 \to \ker \to CG^i_m \to IACG^i_m \to \operatorname{coker} \to 0,$$

primarily focusing on verifying if m is sufficiently large that the kernel and cokernel of the above exact sequence have become well-behaved, providing similarity of growth both in the size and in the structure of CG^i_m and $IACG^i_m$. (Received September 22, 2015)

1116-VN-2746 **James M Hammer*** (jmhammer@cedarcrest.edu) and **Joshua Harrington** (joshua.harrington@cedarcrest.edu). *Counting the Number of Pythagorean Triples in a Finite Field of Odd Characteristic.*

The Pythagorean identities date back to antiquity. In recent times, the Pythagorean theorem has been generalized to higher dimensions and even to non-Euclidean spaces. This presentation studies the Pythagorean theorem in finite fields. Specifically, this presentation will enumerate the number of Pythagorean triples in all finite fields of odd characteristic. (Received September 22, 2015)

1116-VN-2763 **Reyes M Ortiz-Albino*** (reyes.ortiz@upr.edu), 1011 Sonsire Chalets, Mayaguez, PR 00682, and **Carlos Molina**. *On the number of $\tau_{(n)}$-factors.* Preliminary report.

The notion of a τ-factorization or τ-products in the general theory of (nonatomic) factorization was defined in 2006. Since, several results have been done in general, but there is been a small interest study such type of factorization when considering the set of integers as the integral domain and τ as the equivalence relation modulo n. In this talk, we will present some preliminary results about the number of τ-factors of a nonzero nonunit integer. As expected, when considering the equivalence relation modulo n and $\phi(n) \geq 4$, the problems becomes more complicated. Hence we give a flavor of what to expect when the Euler number gets bigger. Also, as a consequences we could characterize some elements that are τ-irreducible. (Received September 22, 2015)

1116-VN-2884 **Julian H Rosen*** (julianrosen@gmail.com). *Multiple harmonic sums in number theory.* Preliminary report.

Multiple harmonic sums are rational numbers generalizing the partial sums of the harmonic series. These numbers have rich arithmetic structure and are connected in surprising ways to many areas of number theory. I will describe some of these connections, and outline an algorithm for using multiple harmonic sums to find/prove congruences involving a wide variety of other quantities, including binomial coefficients, Fermat quotients, and values of p-adic L-functions. I will also describe a Galois theory for congruences involving these quantities. (Received September 22, 2015)

General Session on Outreach

1116-VO-1872 **Meghan M De Witt*** (mdewitt@stac.edu), St Thomas Aquinas College, 125 Route 340, Sparkill, NY 10976. *Girls Exploring Mathematics: A female-centric outreach program.* Preliminary report.

We report on the progress of a new outreach program for female high school students. GEM consists of a double-layer of mentoring: the professor mentors several undergraduates, and they in-turn mentor high school students. We explore various subjects in mathematics, including tessellations and fractals, from a mathematical and an artistic point of view in the hope that more female students will become interested in pursuing mathematical studies. (Received September 21, 2015)

1116-VO-2158 **Jerry F. Dwyer*** (jerry.dwyer@ttu.edu) and **Aimee M. Cloutier** (aimee.cloutier@ttu.edu). *Combining sports and STEM in activity-based lessons for middle school students.*

Active STEM was a 5-day summer program designed to enhance interests in STEM. The program's focus was the math, science, and engineering that undergird the sports most popular among its prospective participants (middle school males from underrepresented populations in STEM). The program was designed by a mathematics professor and an engineering graduate student, while active presentations were enhanced by graduate students in exercise science. Program activities were equally divided between interactive lectures (students constantly participating) and active lessons (involving lots of movement or exploration of patterns, math, engineering principles, etc.). Pre-to-post survey results were studied to measure increases in self-efficacy in that area of STEM. The program provided an opportunity to explore the effectiveness of different types of activity-based lessons for encouraging student engagement. Program highlights included an active engineering design lesson with an inquiry-based approach and a series of math games, which involved high levels of mental engagement without any physical activity. These observations provide a basis for future studies focused on the nature of interactive lessons that may be most effective for STEM learning among underrepresented groups. (Received September 21, 2015)

1116-VO-2571 **John Hall*** (john.hall@yale.edu), **James S Rolf**, **Sara Epperson**, **Jennifer Frederick**, **James Kim**, **Edward O'Neill** and **Frank Robinson**. *Beyond Grades: Motivation in a Not-For-Credit Online Bridge Program.* Preliminary report.

As part of a 2014 commitment to President Obama to recruit and graduate more STEM majors, Yale developed a not-for-credit course, Online Experiences for Yale Scholars (ONEXYS), to boost the quantitative reasoning skills of selected incoming freshmen. Not granting course credit meant that the ONEXYS team had to think hard about motivation. We discuss extrinsic and intrinsic motivators including social relationships, learning communities, badging software, progress bars, a leader-board, a "completion" metric, and post-program celebrations to encourage student engagement. We examine performance data, survey data and focus group feedback to assess the success of each of these elements. (Received September 22, 2015)

1116-VO-2754 **Sofia Agrest*** (agrests@cofc.edu), College of Charleston, Math. Dept., 175 Calhoun St., Robert Scott Small Bld., Rm 329, Charleston, SC 29401, and **Debby Jeter** (jeterd@cofc.edu). *Cougar Math Advanced Project (C-MAP) Summer Camp: A Hands-On-Approach to Mathematical and Critical Thinking for High School Students.*

This session will highlight a week-long summer modeling mathematical camp for rising high school juniors, run by College of Charleston, and founded by Tensor-SUMMA Foundation: Strengthening Underrepresented Minority Mathematical Achievement. We will talk about the structure, recruitment, mathematical content, as well as what we have learned about the students and how to more effectively run this summer math camp. (Received September 22, 2015)

General Session on Probability and Statistics

1116-VP-37 **Juming Pan*** (panj@bgsu.edu), Department of Mathematics and Statistics, Bowling Green State University, Bowling Green, OH 43402. *Adaptive Lasso for Linear Mixed Model Selection via Profile Log-Likelihood.*

Mixed models accommodating both fixed effects and random effects are widely utilized to describe the complicatedly correlated data in a variety of fields. However, mixed model selection poses an intricate challenge in that both the set of covariates for the fixed effects and the structure for the random effects are taken into account of selection procedure. For effectively selecting both the fixed and random effects, we propose a two-stage mixed model selection procedure based upon the penalized profile log-likelihood. In the first stage, the random effects are selected using the adaptive lasso penalty term. After the completion of the random effects selection, in the second stage, the fixed effects are selected using another penalized term. In each stage, the Newton-Raphson algorithm is carried out to implement parameter estimation. We prove that the proposed procedure possesses consistency and the oracle properties. For illustration of the performance of proposed selection procedure, we conduct the simulations and an application of a real data example. The simulation results and the application show that the proposed two-stage procedure perform effectively in selecting the best covariates and random covariance structure. (Received June 09, 2015)

1116-VP-284 **Toyin O Alli*** (toalli@crimson.ua.edu), 7651 Highway 69 N, Apt. 1412, Northport, AL 35473. *Building Large Financial and Economic Networks.*

The study of high dimensional networks has increased dramatically. Group wise information from large datasets can be used to build networks where nodes represent variables and edges represent the conditional dependency between two variables. Economic policy makers use these networks to measure impulse responses and determine how an economy will react over time. Networks can be used to illustrate the trade and exchange of goods in non-centralized markets, the provision of mutual insurance in developing countries, alliances among corporations, and trading agreements. Two approaches for determining grouping information to build networks are large covariance matrix estimation and regularization. The purpose of this research is to investigate whether large covariance matrix estimation or nodewise l_1-regularization will give more interpretable results when building a high dimensional network through group wise information. (Received August 21, 2015)

1116-VP-364 **Dawit G Tadesse*** (tadessdt@ucmail.uc.edu), Dept. of Math Sciences University of Cincinna, 2815 Commons Way, 5411 French Hall, Cincinnati, OH 45221, and **Mark Carpenter**. *A Method for Selecting the Relevant Dimensions for Text Classification in Singular Vector Spaces.*

In this paper, we give a new feature selection algorithm for the text mining problem in sparse high-dimensional spaces. Singular Value Decomposition (SVD) is a popular dimension reduction method in higher-dimensional text classification. The traditional SVD method begins by ranking the Singular Dimensions (SDs) from largest singular value to the smallest. However, when the signal is sparse and the signal-to-noise ratio low, the first few ranked SDs are not necessarily the best for classification. We demonstrate, theoretically and empirically, that our method efficiently selects the SDs most appropriate for classification and significantly reduces the misclassification error. We also apply our method to a real data text mining application. (Received August 28, 2015)

1116-VP-389 **Qasim M Al-Shboul*** (z9889@zu.ac.ae), Zayed Universit, University College, Department of Mathematics and Statistics, Dubai, 19282, United Arab Emirates, and **Elies Kouider**. *Best linear invariant estimators using both double ranked set sampling and a modified double ranked set sampling procedures.*

The use of ranked set sampling for estimating the mean and its advantage over the use of a simple random sampling for the same purpose has become known in the literature. The best linear invariant estimators of the location and scale parameters and consequently the population mean when using both the double ranked set sampling (DRSS) and a modified double ranked set sampling (MDRSS) techniques are introduced. The relative precisions of the best linear invariant estimators (BLIEs) using both DRSS and MDRSS relative to the best linear unbiased estimators (BLUEs) using DRSS are obtained for some selected distributions and sample sizes. Computations indicate that regardless of the sample size or distribution being used, the BLIEs using MDRSS outperform the BLIEs using DRSS, which in turns do better than the BLUEs using DRSS for estimating the mean, location, and scale parameters. (Received August 30, 2015)

1116-VP-402 **Tvrtko Tadić*** (tvrtko@math.hr), Department of Mathematics, University of Zagreb, Bijenicka cesta 30, 10000 Zagreb, Croatia. *Can one make a laser out of cardboard?*

We consider two dimensional and three dimensional semi-infinite tubes made of “Lambertian” material, so that the distribution of the direction of a reflected light ray has the density proportional to the cosine of the angle with the normal vector. If the light source is far away from the opening of the tube then the exiting rays are (approximately) collimated in two dimensions but are not collimated in three dimensions. An observer looking into the three dimensional tube will see “infinitely bright” spot at the center of vision. In other words, in three dimensions, the light brightness grows to infinity near the center as the light source moves away. (Joint work with Krzysztof Burdzy.) (Received August 30, 2015)

1116-VP-524 **Karen M Holmes*** (kholmes@butler.edu). *A Few Game Examples from Win, Lose, or Draw an Analytic Reasoning Course.*

Win, Lose, or Draw is a course created to fulfill the Analytical Reasoning requirement in the core at Butler University. The course covers many topics from logic puzzles to combinatorics to probabilities and expected value with an emphasis on games. The talk will concentrate on logic in the game Bulls and Cows and probability in both Risk and Poker. Bulls and Cows is a paper and pencil game version of Mastermind and examples of class logic problems will be presented. For Risk, the focus will be on dice and the probabilities of an attack ending in different outcomes depending on how an unknown die falls. Then the probabilities for the different Poker hands will be discussed, and then using a deck of pinochle cards, the probabilities will be reevaluated to emphasize the method. (Received September 05, 2015)

1116-VP-568 **Fan Ny Shum*** (fan.shum@uconn.edu). *Stability of a $\mathbb{C}^2$-valued Coupled System.*

This is a report on the results of the NSF-supported REU program at the University of Connecticut, Summer 2015. Namely, we present numerical results on the complex-valued ODE

$$\begin{cases} \dot{z}_t = -\nu z_t + \alpha z_t w_t \\ \dot{w}_t = -\nu w_t + \beta z_t w_t \quad \text{ where } \nu \in \mathbb{R}^+, \alpha, \beta \in \mathbb{R}. \\ z_0, w_0 \in \mathbb{C}, \end{cases}$$

We show this ODE has solutions that blow up in finite time and can be stabilized by the addition of a Brownian term. Furthermore, we numerically computed the steady-state distribution of the system with an additive Brownian term. This is a higher-dimensional example of the system studied by David Herzog and Jonathan Mattingly. They showed an explosive system of ODEs in the form of a complex-valued polynomial is stabilized by an isotropic Brownian term. (Received September 07, 2015)

1116-VP-714 **Ivan Rodriguez*** (rodriguez108@outlook.com), 207 W 28TH ST, Tucson, AZ 85713-2847, and **Claressa L. Ullmayer**. *Survival Analysis Dimension Reduction Techniques: A Comparison of Select Methods.*

Although formal studies may obtain copious data, most can be collinear/‘redundant’ in terms of explaining pertinent outcomes. Thus, dataset dimensionality reduction becomes imperative for easily expressing this relationship. Principal Component Analysis (PCA) and Partial Least Squares (PLS) are established methods used to obtain ‘components’—eigenvalues of the given data’s variance-covariance matrix—such that the covariance and correlation is maximized between linear combinations of predictor and response variables. PCA employs orthogonal transformations on covariates to reduce dataset dimensionality by producing new uncorrelated variables. PLS projects both predictor and response variables into a new space to model their covariance structure. Additionally, three Johnson-Lindenstrauss Euclidean-space embeddings were investigated. These techniques’ performance was explored via 5,000 simulated datasets in R. The semi-parametric Accelerated Failure Time model was used to obtain predicted survivor curves; then, bias and mean-squared error between true and estimated survivor curves was obtained to find all methods' error distributions. The results herein indicate that PCA outperforms PLS, random matrices are comparable, and random matrices outdo both PCA and PLS. (Received September 10, 2015)

1116-VP-793 **Khairul Islam*** (khairul.islam@tamuk.edu), Mathematics Department, Texas A&M University-Kingsville, Kingsville, TX 78363, and **Mian Arif Shams Adnan**, Department of Mathematical Sciences, Ball State University, Muncie, IN. *Tossing a Coin and Characteristics Assessment in R.*

Tossing a coin is a very common practice to introduce probability. Very often, we wish to establish if the coin is unbiased by the repetitive tosses of the coin. How can we implement the process via a technology? In particular, how can we do it in an open source software at a no-cost platform? In this presentation, we intend to implement an open source software R for tossing of a coin. Specifically, we would like to address the concept of the law of large numbers, central limit theorem, and sampling distribution in R, empirically, along with the demonstration of flexibility of using R in teaching and learning. (Received September 22, 2015)

1116-VP-879 **Steven B Kim*** (stkim@csumb.edu), Department of Mathematics and Statistics, 100 Campus Center, Building 53 - S116, Seaside, CA 93955. *A Semi-Parametric Approach to Hypothesis Testing for Hormesis.*

Several animal-based studies in toxicology have shown that low exposures to a toxic agent may lower the risk of cancer outcome which is known as a hormetic effect. Some authors, however, have pointed out a lack of formal hypothesis testing procedures. There are some parametric methods for modeling a hormetic effect at low doses; however we concern about the regression approaches to the hypothesis testing. In particular, due to the impact of model misspecification and leverage effect, a regression model may favor monotonicity despite an empirical trend of a hormetic effect at low doses. To address this issue, we propose a semi-parametric approach to detect a hormetic effect which better tolerates model misspecification and leverage effect at high doses. (Received September 14, 2015)

1116-VP-971 **Khyam Paneru*** (paneruk@uww.edu), Department of Mathematics, University of Wisconsin-Whitewater, Whitewater, WI 53190. *Empirical non-coverage rate in interval estimation of expected response in ZIM regression.*

ZIM regression refers to zero-inflated mixture (ZIM) regression under complex probability sampling designs. It describes zero-inflated generalized linear models under unequal probability sampling designs via two-component mixture models where the probability distribution of non-zero component is known. In many applications such as insurance, auditing, and manufacturing, a common problem known as zero-inflation, is caused by the presence of a large proportion of zero values. Maximum pseudo-likelihood ratio statistic and its limiting distribution are used to estimate confidence intervals for expected responses at "future" covariate values/vectors using ZIM regression models. Monte Carlo simulations are carried out to calculate non-coverage probability for the parameter of interest using maximum pseudo-likelihood procedure and the popular maximum likelihood procedure. Empirical non-coverage rates are compared with nominal level under both approaches. Simulation results show that empirical non-coverage rate under maximum pseudo-likelihood approach is close to nominal level. (Received September 15, 2015)

1116-VP-1002 **Mingwei Sun*** (msun5@crimson.ua.edu), Department of Mathematics, The University of Alabama, Box 870350, Tuscaloosa, AL 35487, and **Yuhui Chen** and **Timothy Hanson**. *Bayesian Nonparametric Multivariate EWMA Control Chart for Process Changepoint Detection.*

Multivariate control charts for monitoring multivariate process commonly assume that the observations are from multinormal distribution, which may not hold in many practical applications. And many multivariate control charts can only detect the shifts in mean instead of scale or both. In this paper, a Bayesian nonparametric multivariate exponentially weighted moving average control chart for sequential observations monitoring the process mean and variability simultaneously by a single control chart in phase II applications is proposed. We introduce a Bayesian nonparametric test statistic based on evolving density estimates. A novel evolving

exponentially-weighted density estimate based on a Polya tree predictive rule, which is centered at the widely-used normal families, is found to have excellent power and robustness to detect both location and scale shifts, as well as shifts in skew and modality in simulations. The procedure is further demonstrated on multivariate real data example.
(Received September 15, 2015)

1116-VP-1027 **Mehdi Razzaghi*** (mrazzagh@bloomu.edu), Department of Mathematics, Bloomsburg University, Bloomsburg, PA 17815. *Rosner's Mathematical Model of Ovarian Cancer and it Generalization.* Preliminary report.

The incidence of ovarian cancer in women has for a long time been the most common and one of the most problematic forms of cancer. Recently, Rosner et al (2005) made an attempt to develop a mathematical model that describes the incidence rate of ovarian cancer as a function of risk factors that are relevant at a given age. The model is based on the assumption that log cell proliferation depends on risk factors linearly. Based on a data set, several interesting conclusions are drawn. Although the model has several interesting properties, it has not been further explored or generalized. Here, we discuss the properties of this model and describe its components. We further consider the model assumptions and explore the possibilities of extending the model to more general situations. (Received September 16, 2015)

1116-VP-1097 **Dilli Bhatta***, University of South Carolina Upstate, Division of Mathematics and Computer Science, Spartanburg, SC 29303, and **Balgobin Nandram**, Worcester Polytechnic Institute, Department of Mathematical Science, Worcester, MA 01609. *A Bayesian Test of Independence in a Two-way Contingency Table with Covariates under Cluster Sampling.*

We consider a Bayesian approach for the test of independence to study the association between two categorical variables from a two-stage cluster sampling design. We incorporate the covariates at both unit and cluster levels in the test. Our main idea for the Bayesian test of independence is to convert the cluster sample with covariates into an equivalent simple random sample without covariates which provides a surrogate of the original sample. Then, this surrogate sample is used to compute the Bayes factor to make an inference about independence. We apply our methodology to the data from the Trend in International Mathematics and Science Study (2007) for fourth grade U.S. students to assess the association between the mathematics and science scores represented as categorical variables and also provide the simulation study. The result shows that if there is strong association between two categorical variables, there is no significant difference between the tests with and without the covariates. However, in the simulation study, we found noticeable difference in borderline cases (moderate association between the two categorical variables). (Received September 16, 2015)

1116-VP-1180 **Brice Merlin Nguelifack*** (bmn0003@auburn.edu), 610 Americana Dr. Apt 104, Annapolis, MD 21403, and **Guy-Vanie Miakonkana**. *Rank Based Group Variable Selection.*

A robust rank based estimator for variable selection in linear models, with grouped predic- tors, is studied. The proposed estimation procedure extends the existing rank based variable selection (Johnson and Peng (2008)) and the ww-scad (Wang and Li (2009)) to linear regres- sion models with grouped variables. The resulting estimator is robust to contamination or deviations in both the response and the design space.The Oracle property and asymptotic normality of the estimator are established under some regularity conditions. Simulation stud- ies reveals that the proposed method performs better than the existing rank based methods (Johnson and Peng (2008), and Wang and Li (2009)) for grouped variables models. This estimation procedure also outperforms the adaptive Hlasso (Zhou and Zhu (2010)) in the presence of local contamination in the design space or for heavy tailed error distribution. (Received September 17, 2015)

1116-VP-1325 **Miguel A Cerna*** (miguel.cerna01@utrgv.edu), School of Mathematical and Statistical Sc., The University of Texas Rio Grande Valley, 1201 West University Drive, Edinburg, TX 78539. *Attention Deficit Hyperactivity Disorder (ADHD) – a statistical analysis of incidence in Texas and other states.*

The percent of children estimated to have Attention Deficit Hyperactivity Disorder (ADHD/ADD) in Texas has increased over time. In 2007 4.8% of children in Texas were diagnosed ADHD, ranking them 46 in the nation. Just four years later (2011), the tally has risen to 9% ranking them 28. Clearly the diagnosis of ADHD/ADD is rising in Texas. What about the other states in USA? In our brief analysis, we will try to make a comparative study between Texas and other states in USA using standard statistical tools such as ANOVA, Multiple Linear Regression and some nonparametric techniques. Once we have some understanding of the situation in Texas, we extend our study to the other states. We will also study if the literacy level is going up with time in order to study the awareness and if the diagnostic techniques have improved over the years to keep track of more ADHD cases. It is also a question if the diagnosis is right in each and every situation. The intuition suggests that there could be a lot of cases of misdiagnosed children giving rise to study on misclassification of individuals but this we rather leave for future considerations. Our statistical study is based on the online data resources provided by Center of Disease Control and Prevention (CDC) website. (Received September 18, 2015)

1116-VP-1360 **Howard Troughton*** (htroughton@babson.edu), 374 GREAT ROAD, UNIT 12, Acton, MA 01720. *Using Minitab to Demonstrate the Central Limit Theorem (CLT).*

Many statistics students confuse sampling distributions with the distribution of the original data. This confusion prevents them from fully appreciating the importance of the CLT, causing later difficulties understanding the subtleties of inferential statistics. In this session I will demonstrate the method I use in my introductory statistics class to address this.

When introducing sampling distributions I start with a population parameter that is assumed to be known (for example height of students on a college campus), but the population distribution is not known. We use Minitab to generate hundreds of thousands of samples for a fixed sample size under three different assumptions for the population distribution (normal, uniform and strongly skewed).

Students generate the sampling distribution histograms and summary statistics to compare values of μ and σ with $\mu_{\bar{X}}$ and $\sigma_{\bar{X}}$ (actually they are comparing to $\bar{X}_{\bar{X}}$ and $s_{\bar{X}}$).

By generating samples students gain a better understanding of the difference between the underlying population and the distribution of sample means. Furthermore, using different hypothetical population distributions students gain insight into how the CLT can be applied to any population. (Received September 18, 2015)

1116-VP-1425 **Matthew L Wright*** (wright5@stolaf.edu). *Intrinsic Volumes of Random Cubical Complexes.*

How can we understand the size of noise in digital images? One way to answer this question involves studying intrinsic volumes of random sets. The intrinsic volumes generalize both Euler characteristic and Lebesgue volume, quantifying the size of a set in various ways. A random cubical complex is a union of (possibly high-dimensional) unit cubes, with vertices on an integer lattice, selected according to some probability model. I will describe a simple model of random cubical complex and provide exact polynomial formulae, dependent on a probability, for the expected value and variance of the intrinsic volumes of the complex. I will also give a central limit theorem and an interleaving theorem about the roots of the expected intrinsic volumes – that is, the values of the probability parameter at which an expected value is zero. Lastly, I will discuss applications such as image recognition. (Received September 19, 2015)

1116-VP-1706 **Netra Khanal*** (nkhanal@ut.edu), 401 W. Kennedy Blvd, Tampa, FL 33606. *Bayesian age-stratified joinpoint regression model: an application to lung and brain cancer mortality.*

Joinpoint regression model identifies significant changes in the trends of the incidence, mortality, and survival of a specific disease in a given population. The purpose of the present study is to develop an age-stratified Bayesian joinpoint regression model to describe mortality trend assuming that the observed counts are probabilistically characterized by the Poisson distribution. The proposed model is based on Bayesian model selection criteria with the smallest number of joinpoints that are sufficient to explain the Annual Percentage Change. The prior probability distributions are chosen in such a way that they are automatically derived from the model index contained in the model space. The proposed model and methodology estimates the age-adjusted mortality rates in different epidemiological studies to compare the trends by accounting the confounding effects of age. In developing the subject methods, we use the cancer mortality counts of adult lung and bronchus cancer, and brain and other Central Nervous System cancer patients obtained from the Surveillance Epidemiology and End Results data base of the National Cancer Institute. (Received September 21, 2015)

1116-VP-1744 **Paul H Bezandry*** (pbezandry@howard.edu), 2441 6th Street, NW, Washington, DC 20059. *Almost periodic random sequences in probability.* Preliminary report.

In this talk, we discuss almost periodic random sequences in probability. Some basic and fundamental properties of such sequences will be presented. (Received September 21, 2015)

1116-VP-1756 **Mavis Pararai*** (pararaim@iup.edu), 210 S 10 th Street, Stright Hall Rm 233, Indiana, PA 15705, and **Broderick Olusegun Oluyede** and **Gayan Warahena Liyanage**. *An extended Lindley Poisson distribution with applications.*

The Extended Lindley Poisson (ELP) distribution which is an extension of the extended Lindley distribution [**?**] is introduced and its properties are explored. This new distribution represents a more flexible model for the lifetime data. Some statistical properties of the proposed distribution including the shapes of the density, hazard rate functions, moments, Bonferroni and Lorenz curves are explored. Entropy measures and the distribution of the order statistics are given. The maximum likelihood estimation technique is used to estimate the model parameters and a simulation study is conducted to investigate the performance of the maximum likelihood estimates. Finally, we present applications of the model with a real data set to illustrate the usefulness of the proposed distribution. (Received September 21, 2015)

1116-VP-1900 **Ewa J Infeld*** (ewa.j.infeld.gr@dartmouth.edu), Dartmouth College, Department of Mathematics, 27 N Main St, Hanover, NH 03755. *Avoidance Coupling of Simple Random Walks: Graph Conditions.* Preliminary report.

A coupling of two Markov chains is an implementation of the chains on a common probability space, in such a way that each chain, viewed separately, is faithful to its transition matrix. An avoidance coupling of simple random walks on a graph can be represented by two tokens each taking a walk on a graph, such that they never collide and yet if viewed separately, each token appears to be taking a simple random walk. I will present some necessary and some sufficient conditions for a graph to admit an avoidance coupling of simple random walks. (Received September 21, 2015)

1116-VP-1972 **Budhinath Padhy***, University of Hartford, Hillyer College, Department of Mathematics and Science, 200 Bloomfiled Avenue, West Hartford, CT 06117, and **Gemechis Djira**, South Dakota State University, Department of Mathematics and Statistics, Brookings, SD 57007. *A Comparative Study of Structural Equation Models vs. Alternative Models for Multivariate Longitudinal Data.*

In the past few years, there has been a surge of research interest in modeling longitudinal data in a variety of fields including medicine, marketing research, psychology, social and behavioral sciences. As such, number of studies in multivariate longitudinal data is also growing. In this talk, among others, attention is placed on structural equation models (SEM) and linear mixed effect models (LME) because they are popular, flexible, and widely applicable. These models assume that measurements from a single subject share a set of latent or random effects which are used to generate an association structure between repeated measurements. The fact that latent structures generate associations implies that SEM and LME are very convenient for the joint or multivariate analysis of longitudinal data. The main research objective is to describe these multivariate longitudinal data analysis techniques that are easily accessible to a wider audience and then to compare and contrast the evolution of associations and the association of evolutions of the responses of these methodologies by giving a motivating example. (Received September 21, 2015)

1116-VP-2065 **Rebecca Rachan*** (rarachan@noctrl.edu), **Subodh Selukar**, **Trevor Adriaanse** and **Meshach Hopkins** (mhopk1@umbc.edu). *Statistical analysis of a case-control Statistical Analysis of a Case-Control Alzheimer's Disease: a Retrospective Approach with Sufficient Dimension Reduction.*

Alzheimer's Disease is a neurological disorder chiefly present in the elderly that affects functions of the brain such as memory and logic, eventually resulting in death. There is no known cure for Alzheimer's and evidence points to the possibility of a genetic link. This study analyzes microarray data from patients with Alzheimer's disease and disease-free patients in order to evaluate and determine differential gene expression patterns between the two groups. The statistical problem stemming from this data involved many predictor variables with a small sample size, preventing the use of classical approaches from being effective. We turn to a novel three-step approach: first, we screen the genes in order to keep only the genes marginally related to the outcome (presence of Alzheimer's); second, we implemented a sparse sufficient dimension reduction to retain only predictors relevant to the outcome; lastly, we perform a hierarchical clustering method to group genes that exhibit mutual dependence. We adapted this methodology from Adragni et. al and expand on their work by optimizing the existing R code with parallel capabilities in order to enhance performance speed. Thus, our results reflect both an analysis of the microarray data and a performance study of the modified code. (Received September 21, 2015)

1116-VP-2070 **Ann E Moskol*** (amoskol@ric.edu). *Using simulation to understand the Central Limit Theorem for Proportion.* Preliminary report.

Using MIT's Imagination Toolbox and Star Logo Nova, I wrote a program to help statistics students understand the central limit theorem for proportion. Students can use the program to experiment with different population and sample sizes, and with different population proportions of flowers. The program simulates finding the sample proportion of flowers by counting the proportion of times that a randomly moving graphic object (a Brown bear) collides with a flower (as opposed to grass). Besides demonstrating the software, I will provide information on how to access the program for use in a statistics class. (Received September 21, 2015)

1116-VP-2103 **Tiffany N. Kolba*** (tiffany.kolba@valpo.edu). *Probabilistic Analysis of Polyovulation.*

Polyovulation is the production of more than one ovum, or egg, during a single menstrual cycle. This talk examines the probability of the human ovarian system ovulating k eggs during a single cycle, for $k \geq 0$. In order to obtain precise estimates for the probability of polyovulation, we use U.S. birth data from the 1950's (before the introduction of artificial reproductive technologies). However, to utilize birth data, we model the various processes that eggs undergo in order to result in a live birth, including fertilization, possible division, implantation, and potential miscarriage. We also examine the distribution of the number of eggs ovulated from the left and right ovaries in order to analyze the probability of polyovulation resulting from within one ovary versus from both ovaries. (Received September 21, 2015)

1116-VP-2150 **Mathew Titus*** (titusm@math.oregonstate.edu), 258 Kidder Hall, Oregon State University, Corvallis, OR 97330. *Mixing Times for Markov Chains on Lattices via Weak Limits.* Preliminary report.

Mixing times for discrete time and space Markov chains describe how the system size affects the time required for the chain to approach its stationary distribution. Path coupling methods have been very effective for systems with rapid mixing, but for chains with $t_{mix} = O(n^{\rho} \log n)$ for $\rho > 1$ path coupling is no longer applicable. In this paper we use the weak limit of the Markov chain under a rescaling of the lattice to give a lower bound on the mixing time. Using a local limit law, we demonstrate that under certain conditions this result may be strengthened to prove convergence in total variation distance, proving the mixing time asymptotics. Applications to mean-field spin systems are given. (Received September 21, 2015)

1116-VP-2176 **Victor Villalpando*** (victor.villalpando01@utrgv.edu), School of Mathematical and Statistical Sc., The University of Texas Rio Grande Valley, 1201 West University Drive, Edinburg, TX 78539. *A Statistical Study to determine the criteria for winning in Mixed Martial Arts for the Ultimate Fighting Championship (UFC).* Preliminary report.

Mixed Martial Arts is the fastest growing sport with many organizations world wide. The biggest stage or biggest organization for mixed Martial Arts is the Ultimate Fighting championship(UFC). There are eight weight classes for men. The website www.fightmetric.com provides data on fighters in all these categories.This data measures aggression, octagon control, striking accuracy, take downs, reversals, knockout, etc.in each category. It is interesting to understand and interpret all these numbers and study their relationships. Statistical tools like both parametric and non parametric inference may give rise to such interpretations and provide explanations why a certain fighter is better than another in terms of aggression, octagon control etc.In this study we have selected 30 fighters per weight class and will do some comparative study among these fighters in terms of their strengths and weaknesses using regression, ANOVA, and non parametric techniques etc. We are also planning to do some Bayesian statistical study based on prior information about the fighters and there by obtaining posterior distribution. We believe that our study will give rise to many striking insights, which may be of help for future research. (Received September 22, 2015)

1116-VP-2277 **Keshav Pokhrel***, University of Michigan-Dearborn, Department of Mathematics and Statistics, 4901 Evergreen Road, Dearborn, MI 48128, and **Chris Tsokos**. *Age-Specific Variations in Cancer Mortality rates: A Functional Data Approach.*

We present cancer mortality rates as a function of age to explore variations in mortality rates of different age groups. Nonparametric smoothing methods are used to mitigate the existing randomness in the observed data. We present the disparity of cancer mortality rates among the age groups together with the rate of change of mortality rates. We apply principal differential analysis to measure the noisy features of the data in a single curve and the variations of the data are also measured across the curves. (Received September 22, 2015)

1116-VP-2311 **Mosisa G Aga*** (maga@aum.edu). *Bootstrapping Time Series Models.* Preliminary report.

The bootstrap is a general approach to statistical inference based on building a sampling distribution for a statistic by resampling from the data at hand. In this talk we will discuss the application of bootstrap to dependent data structures in general and to certain time series models in particular. (Received September 22, 2015)

1116-VP-2315 **James Matuk*** (matukj@duq.edu). *Adaptations to curvature based denoising.*

Image denoising techniques include tools from a number of fields of mathematics including partial differential equations, probability, linear algebra, and both convex and non-convex optimization. Recent work by Bertalmio and Levine has demonstrated that it might be more effective to denoise the curvature of the level lines of a noisy image and then use this 'denoised' curvature information to reconstruct an estimate of the original image. The goal of this research is to statistically analyze image curvature data in order to develop better denoising methods for this new framework. In this talk I will give a brief description of the problem: image noise. An analysis of the curvature noise distribution which motivates new techniques for denoising curvature data will follow. We use this information to generate a denoised image using a variational model that incorporates the smoothed level line curvature data while preserving level line contrast. Numerical results using this approach show improvement upon state-of-the art denoising methods. (Received September 22, 2015)

1116-VP-2353 **Doo Young Kim*** (dooyoungkim@mail.usf.edu), 1244 Standridge Dr., Wesley Chapel, FL 33543, and **Chris P. Tsokos**. *A Prediction-Based Time Series Clustering of Brain Cancer Mortality Rates in The United States.*

In the present study, we have developed an algorithm which enables us to model time series data in an objective way and cluster time series data based on predictions delivered from modeling procedures. Since time series prediction intervals tend to be wider as time goes further, we simulate prediction values based on prediction intervals with the variance as a weight factor so that we can assign a bigger weight value on a prediction with nearest observation. We apply this algorithm to cluster brain cancer mortality rates in the United States based on nine U.S. climate regions in order to identify the relation between climate conditions and brain cancer mortality rates. The developed algorithm is also applicable to other data in clustering times series such as economic data, environmental data, sports data, etc., (Received September 22, 2015)

1116-VP-2463 **Krishna Kaphle*** (krishna.kaphle@maine.edu). *Some Statistical Tools for Data in Hilbert Spaces.* Preliminary report.

Functional Data Analysis refers to the study of statistical methodology when data are in function spaces. With the advance of modern technology, attention on Functional Data Analysis has increased. We will discuss on simple statistical tools for estimation of the mean and the covariance operator when data are in a Hilbert space. We will also discuss the problem of testing various hypothesis using functional data. (Received September 22, 2015)

1116-VP-2514 **Ashley S Johnson*** (ajohnson18@una.edu). *Using Poker to Motivate Conditional Probability.*

In a general education math course, it always helps to be able to give students an interesting application of the material. While this may not always be possible with all topics, a section on probability lends itself well to applications. In this talk, I will include some examples of probability in the real world, including the World Series of Poker and the game show Let's Make a Deal. (Received September 22, 2015)

1116-VP-2579 **Jeffrey B Gaither*** (gaither.16@mbi.osu.edu), Mathematical Biosciences Institute, The Ohio State University, Jennings Hall 3rd Floor, 1735 Neil Ave, Columbus, OH 43210. *Rooted triplets in species tree inference: some new results on construction and application.*

We present some results on triplet-based methods for the inference of species trees. A triplet is a species tree which includes exactly three leaves; when rooted, it tells us which of the three pairs of species shares the most recent common ancestor. We present some new findings on how triplets can be computed from raw genetic data, and also about how a species tree can be inferred once we have the triplets. Our methodology depends ultimately on the stochastic process which underlies nucleotide substitution, and draws on techniques from both Bayesian and non-Bayesian reasoning. (Received September 22, 2015)

1116-VP-2651 **Brian R Zaharatos*** (brian.zaharatos@colorado.edu), Engineering Center, ECOT 331, Boulder, CO 80309-0526. *Clarifications and Caveats on Data Cloning.*

Mathematical and statistical models often contain model parameters that need to be estimated from data. Many estimation techniques require that a model satisfy certain structural properties. For example, parameter *identifiability* is a necessary condition for the consistency of the maximum likelihood estimator. A parameter is identifiable if there is a one-to-one correspondence between parameter values and density functions. It is also desirable that a parameter be *estimable*. A parameter is estimable if the maximum likelihood estimator yields a unique result (i.e., the likelihood function has a unique mode). The method of *data cloning* has been proposed as a way to diagnose structural deficiencies—such as non-identifiability and inestimability—in a model. However, the data cloning literature seems to conflate the concepts of identifiability and estimability. In this paper, we seek to clarify exactly what data cloning diagnoses by upholding the distinction between identifiability and estimability. Once these issues are made clear, we consider several examples in which data cloning can be misleading in practice. (Received September 22, 2015)

1116-VP-2693 **Steve S. Chung*** (schung@csufresno.edu), Department of Mathematics, CSU Fresno, Peters Business Bldg., Rm 341, 5245 N. Backer Ave. M/S PB108, Fresno, CA 93740, and **Xu-Feng Niu**. *Semiparametric models for financial volatility.* Preliminary report.

We propose a semiparametric method for modeling the autoregressive conditional heteroscedasticity for prediction of volatility in financial time series. With the generalized autoregressive conditional heteroscedasticity (GARCH) as an initial parametric estimate, we update the model based on bivariate Bernstein basis polynomials by using the functional gradient descent (FGD) algorithm with a normal likelihood loss function. We evaluate the model through simulated and real data. The results demonstrate its strong predictive potential for financial volatility. (Received September 22, 2015)

1116-VP-2711 **Khairul Islam**, Department of Mathematics, Texas A&M University-Kingsville, Kingsville, TX , and **Mian Arif Shams Adnan***, Department of Mathematical Sciences, Ball State University, Muncie, IN. *Generating Various Integral Representations of Beta and Gamma Functions and Their Individual Products.*

Several integral representation of beta function, gamma function and their products have been developed based on mixture distribution. These integrals are applied for finding the mathematical as well as statistical properties of the various gamma and beta behavioral populations. Several characteristics of the aforesaid distributions will be computed by means of simulation. (Received September 22, 2015)

General Session on Teaching and Learning Introductory Mathematics

1116-VQ-196 **Edward D Smith*** (edsmith@pima.edu), 2202 W Anklam Rd, Mail 0920, Tucson, AZ 85709. *Struggles of College Algebra Survival.* Preliminary report.

The evolution of college algebra at one community college campus has undergone a separation of STEM versus non-STEM and the Emporium. (Received August 13, 2015)

1116-VQ-323 **Qingxia Li*** (qli@fisk.edu), 411 Annex Ave, Apt B4, Nashville, TN 37209. *Integrating Case Studies in Teaching Developmental Mathematics Courses.*

This project integrates case studies in teaching developmental mathematics courses. This study uses a quasi-experimental non-equivalent control design comparing student's outcomes with and without implementing case studies in these courses. Data analysis shows that there is an increase in student's critical thinking ability, retention rate and success rate. (Received August 25, 2015)

1116-VQ-584 **Jenna P. Carpenter*** (carpenter@campbell.edu), PO Box 115, Buies Creek, NC 27506. *Using Coding Examples to Teach Inverse Functions: Helping Students Connect "Abstract" Mathematical Concepts to "Real" Life.*

Helping students see the connections (even if they are simple ones!) between what they view as "abstract" mathematical concepts and their world not only motivates them to learn the content, but also assists them with understanding concepts that otherwise become major stumbling blocks. One such concept (and application) is invertible functions and coding. Students are usually aware of the need to encrypt information sent via their cell phone, email, etc. One simple approach to encryption involves encoding the words of a message using numbers, then plugging the numbers into an invertible function and sending the resulting y-values. Starting with a simple coding example that utilizes non-invertible functions not only helps students understand the desired attributes of an invertible function, but also helps them grasp related concepts like composition of functions. We will look at a successful approach for introducing inverse functions via coding that works with any college algebra class, as well as some fun exercises that you will find your students requesting be on their exams! (Received September 08, 2015)

1116-VQ-1471 **Skona Brittain*** (skona@sbfamilyschool.com). *A Recipe to Infinity.*

I discovered this activity in the kitchen while homeschooling my own kids but I have since used it in the classroom with pre-calculus students and math circles. It's very appropriate for both non-majors and freshman survey classes.

Dividing recipes in half offers the opportunity for practicing trivial fraction arithmetic, of course. However, needing to make a third of a recipe, with teaspoons that only come in size $1/2^n$ (we have them for 7 values of n!), leads very naturally to the discovery of infinite series.

Math that is tangible, motivated, and related to food is particularly appetizing for the targeted students. (Received September 22, 2015)

1116-VQ-1817 **Peter T. Olszewski*** (pto2@psu.edu), 4205 College Drive, Erie, PA 16563. *Bringing College Algebra out of the Classroom.* Preliminary report.

At St. Vincent Medical Center in Erie, PA, there about 200 nurses who wish to obtain their BSN. One of the challenges faced by these prospective students is working around their tight schedules to come to campus for their education. While some classes, such as Chemistry, need to be taught on campus, other classes are being taught on sight. This talk will present how Math 21 was taught to nursing students in a hybrid format. In addition, this presentation will outline the good, the struggles, lessons learned, and future offerings of the course. (Received September 21, 2015)

1116-VQ-1897 **Frank Savina***, The Charles A. Dana Center, The University of Texas at Austin, 1616 Guadalupe, Suite 3.206, Austin, TX 78701, and **Stuart Boersma**, Central Washington University, 400 E. University Way, Ellensburg, WA 98926. *Preparing Students for Calculus: Function as Process and Covariational Reasoning.*

The STEM Prep Pathway is designed as a one-year course created by the New Mathways Project at the Charles A Dana Center that prepares students beginning at the elementary algebra level to succeed in college-level calculus. STEM Prep was designed by several leading calculus education researchers and experienced two-year college mathematics faculty. The curriculum is guided by four overarching principles: 1) developing a deep understanding of the function process, 2) emphasizing the ability to apply covariational reasoning, 3) stressing the facility to communicate about functions and use function notation, and 4) meaningful approaches are used to drive the algebraic content. In terms of content this means that the focus is to explore concepts with multiple representations. In particular functions are experienced as processes not just algebraic formulas, students develop the language and inclination to describe how one quantity changes with respect to another, students communicate orally and in writing, the curriculum is active and set within authentic STEM contexts and models. For this talk we will show examples from the curriculum that support these design principles. (Received September 21, 2015)

1116-VQ-1929 **Rodica Cazacu*** (rodica.cazacu@gcsu.edu), 231 W Hankock St., CBX 17, Milledgeville, GA 31061. *Why should I learn mathematics in college?*

Bringing real life examples in classroom could make students in introductory level classes see the necessity of learning mathematics even if they will not go for a science major. Asking and answering questions like WHY?, HOW?, or WHEN? could help them see that mathematics is not just a bunch of formulas and rules one can memorize to succeed, but a way of explaining and solving phenomena from nature and life. Introduction to Mathematical Modeling is a course where students can see that first hand and in my presentation I will bring a few examples on how I try to do that with my students and how I get them to work independently while I supervise and assess their work and give them on time feedback. (Received September 21, 2015)

1116-VQ-1985 **Karen Hulsebosch*** (khulsebosch@olympic.edu) and **James Howell** (jhowell@olympic.edu). *IMATH: Integrated Intermediate Algebra and College Level Mathematics.*

IMATH embeds prerequisite math skills in a college level introductory course. How does this impact student learning and success? Results from a two-year study of the strengths and weaknesses of an integrated Intermediate Algebra with Precalculus curriculum design and an integrated Intermediate Algebra with Liberal Arts Math in Society curriculum design at Olympic College will be shared. (Received September 21, 2015)

1116-VQ-2491 **T. C. Kull*** (kullt@winthrop.edu). *Explorations in Course Redesign.* Preliminary report.

The Mathematics Department at Winthrop University is exploring the incorporation of an emporium classroom model in certain introductory mathematics courses, including Applied College Algebra. Motivations include increased student involvement and learning, cost savings, and a better balance in faculty workloads. This talk will summarize our efforts to this point, share data and lessons learned, and attempt to help others considering similar course modifications. (Received September 22, 2015)

1116-VQ-2647 **Rachid Ait Maalem Lahcen*** (rachid@ucf.edu), 4000 Central Florida Blvd, Mathematics Department, MSB221, Orlando, FL 32816, and **Ram Mohapatra**. *Integrating Parallel Notes Delivery to Increase Success.*

Integrating parallel notes giving in teaching and learning helped students in introductory mathematics to organize notes and compare different discussed rules and examples. This technique of putting a lesson in one overall image helped students develop study skills, have meaningful notebooks and excel. The motivation was from Statistics that uses collecting data and organizing it before presenting it. Students were engaged with completing the worksheets and making similar examples. (Received September 22, 2015)

1116-VQ-2918 **Peter L Staab*** (pstaab@fitchburgstate.edu), Department of Mathematics, Fitchburg State University, 160 Pearl St., Fitchburg, MA 01420. *Preparing Elementary School Teachers: Techniques to aid Future Teachers.*

Fitchburg State University has a three-course sequence for Elementary Education majors that emphasizes the foundation of the mathematics in K-5. I will present a number of techniques that I have employed in the classroom that I have used in our Informal Number Theory class (first of the 3-course sequence) that has been effective. These include a variation of a flipped classroom, journals and a course project. I will cover these aspects of the course in detail in the talk. (Received September 23, 2015)

General Session on Teaching and Learning Calculus

1116-VR-34 **Ram Verma*** (verma99@msn.com). *Innovative and Alternate Methods to Chain Rules.* Preliminary report.

A class of innovative alternate methods to the traditional chain rules is developed, and then experimented during regular class-sessions. In general, students feel more comfortable learning it naturally rather than being burdened by the imposition - the derivative of a composition of two functions transforms into the regular multiplication of two derivatives. (Received June 05, 2015)

1116-VR-74 **Alexander Y Vaninsky*** (avaninsky@hostos.cuny.edu), 500 Grand Concourse, Room B409, Mathematics Department, Bronx, NY 10451. *On a misconception about alternative definition of the logarithmic function in Calculus.*

There is a misconception about an alternative definition of the logarithmic function y = ln(x) as an integral of 1/t from 1 to x that may be found in almost all standard calculus texts. The authors typically show that main properties of the logarithms are held, so that the "new" definition is equivalent to the "old" one. However, this is not true. No matter how many properties of the two functions are proved to be the same, there may exist other properties that may differ. Moreover, one can hardly list all properties of the logarithmic function and prove them. What is actually needed, is using the Cauchy functional equation stating that the only continuous function satisfying the condition f(x+y)=f(x)+f(y) is the function y=Cx, and its corollary that the only continuous function satisfying the condition f(xy)=f(x)+f(y) for x,y >0 is the logarithmic function y=Cln(x). It is not difficult to show that C=1. This analytical characterization of the logarithmic function is missing from the calculus textbooks that creates confusion for readers in regard to the "new" logarithmic function. All properties of the "new" logarithmic function follow automatically from the coincidence of the two functions. They may serve as examples of the properties of the corresponding definite integrals. (Received September 15, 2015)

1116-VR-310 **Jay M. Kappraff*** (kappraff@njit.edu), Department of Mathematics, NJIT, University Heights, Newark, NJ 07102. *Calculus and structures.*

Architectural structures is used to motivate the development of the calculus. Using the idea that the area under the curve of shear stress results in the bending moment and that the derivative of the bending moment equals the shear stress. Also when the shear stress goes from positive to negative or negative to positive the bending moment is a maximum or minimum and that the inverse of the bending moment curve gives a rough idea of the deflection of a beam. In this way the elements of calculus can be developed quite naturally. In the development of this approach to calculus it is natural to introduce the integral in the second week. Although the concept of a derivative is introduced in the third week computations of derivatives is not introduced until it is needed in the sixth week. I have had a good deal of success in teaching this approach to calculus to students of architecture. (Received August 24, 2015)

1116-VR-452 **Sharon S Vestal*** (sharon.vestal@sdstate.edu), Mathematics & Statistics, Box 2225, Brookings, SD 57007. *Helping Students Succeed in First Semester Calculus.*

As many of you know, most calculus students do not struggle with calculus concepts; they struggle with the algebra and trigonometry needed to complete calculus problems. We wanted to help students master these skills without delaying their entry into calculus the way traditional methods such as forcing them to take a pre-calculus course can. Our department created an alternative solution to this problem; a 1 credit co-requisite lab that aligns with any early transcendental first semester calculus course. This lab provides a review of algebra and trigonometry concepts that are needed to succeed in calculus. Using an electronic textbook with randomized problems through WebAssign, we are receiving positive results. Come find out how you may be able to implement this type of lab solution in your early transcendental first semester calculus course. (Received September 02, 2015)

1116-VR-474 **Matthew Cathey*** (catheyme@wofford.edu) and **Joseph Spivey**. *Breaking Free from Traditional Calculus Textbooks with Mathematica.* Preliminary report.

Wofford College, a 4-year liberal arts college with around 1500 students, faced particular challenges in its first-year calculus sequence: the semesters are 13 weeks long, and each class meets for only 2.5 hours each week. Thus, only differential calculus could be covered in the first semester, leaving integral calculus for the second. Students taking only Calculus I weren't seeing the whole picture; students with AP credit for one semester had seen much of our second semester and missed the rigor of the ϵ-δ formulation of limits. So, we redesigned the two-semester curriculum, presenting derivatives and integrals side-by-side in the first semester, and postponing formalities to the second. We created a digital book (using Wolfram CDF) that is appropriate for our new curriculum. This medium allows interactive figures, which illuminate the concepts of change much more effectively than static figures. Also, the cost to students is significantly lower than using traditional course materials, since the text itself is available at no cost. The presenters will talk about the advantages, disadvantages, and challenges involved in the creation of this digital text, along with a brief demonstration. Preliminary results will be shared. (Received September 03, 2015)

1116-VR-480 **Alexander J Hahn*** (hahn@nd.edu), Department of Mathematics, University of Notre Dame, Notre Dame, IN 46556. *Reverse Engineering as a Learning Strategy in the Calculus Classroom.*

The mathematical community has given the concepts "flipped classroom" and "project based learning" much attention. Indeed, such strategies have much to recommend them. They commonly include learning aids such as mini videos designed to get the students up to speed for their in-class activities. However, the textbook does not appear to play a significant role. This seems unfortunate. Does it not have to be one of the primary aims of a university education to get students to be able to extract the essence of sophisticated written materials and to present what they have analyzed articulately and confidently in front of an audience?

In the spirit and context of the flipped class room, I have recently been experimenting with the following approach. Small working groups of students (who as a rule come with calculus experiences from high school) are handed complete segments of applied topics of basic calculus and are asked by "reverse engineering" to reach an understanding of the relevant underlying facts and preliminaries. They do this under the guidance and with the assistance of the instructor. After they have gotten up to speed, they present the matter at the board. Succinctly put, this is the "flipped class room" based on meaningful texts. (Received September 03, 2015)

1116-VR-559 **John K Williams*** (jwilliams@hartford.edu), Mathematics Department, 200 Bloomfield Ave, West Hartford, CT 06117, and **Larissa Schroeder**. *Three Years of Flipping Calculus at the University of Hartford.*

Four years ago, the University of Hartford's mathematics department started flipping our Calculus I class. Now we have moved to flipping both Calc I and II in all our sections. We have developed videos, quizzes and classroom worksheets. The material for Calc I was supported by an NSF TUES grant and is available to the public via a website. In this talk we will discuss the process of moving all our classes to a new format including some data we have collected on how our students are affected. (Received September 07, 2015)

1116-VR-708 **Lance Burger*** (lburger@csufresno.edu) and **Marat Markin**. *On the Teaching of Calculus: A Deeper Look at a Derivative Sketching Activity.* Preliminary report.

One of the focal points for NSF-funded Calculus redesign at Fresno State is to include more active learning in the classroom. This paper resulted from discussions in our redesign group while working through an activity used at Colorado University, which involved coffee being poured at a constant rate into four different shaped cups. This activity asks students, working in groups, to produce sketches of graphs of the depth of coffee in a cup, h(t), as a function of time t; and of the rate of change of depth, dh/dt, verses time t. Here we examine two of the cup shapes and the solutions provided to us and explain why the solutions are problematical for some of the cups, yet also very instructive potentially for students or prospective teachers when looking deeper into the oftentimes usual underlying assumptions. (Received September 10, 2015)

1116-VR-1044 **Mylan Redfern*** (redfern_m@utpb.edu), Math & CS Dept., University of Texas, Permian Basin, 4901 E. University, Odessa, TX 79762, and **David Betounes** (betounes_d@utpb.edu), Math & CS Dept., University of Texas, Pemian Basin, 4901 E University, Odessa, TX 79762. *A Surprise Among the Trig Substitutions.* Preliminary report.

Having taught Calculus II for more years than we would like to count, we recently were stunned to learn an aspect of trig substitutions that has apparently gone unnoticed by calculus book authors for over three decades (maybe longer, but that's the oldest calculus book we could locate).

While we are not absolutely certain that these authors, and others, were unaware of it, or rather conveniently chose to overlook it, we do know that having it brought to light by one of our students was an unsettling revelation.

In our talk we will discuss this surprising (to us) aspect of trig substitutions: *half of them can be done another way without trig functions.* We suggest a way to revise our calculus books accordingly. (Received September 16, 2015)

1116-VR-1263 **Paul Sisson*** (paul.sisson@lsus.edu), One University Place, Shreveport, LA 71115, and **Tibor Szarvas** (tibor.szarvas@lsus.edu), One University Place, Shreveport, LA 71115. *The Unsung Heroes of Calculus: Mathematicians Before and After Newton and Leibniz.*

The development of Calculus is commonly associated with two justly-famous names: Newton and Leibniz. But the problems that motivated this development began to arise far before their time; some were tackled by ancient mathematicians with great success, while other partially-settled problems waited, primed and ready, for Newton, Leibniz, and those that followed. This talk will focus on some lesser-known mathematicians, both before and after the time of Newton and Leibniz, the unsung heroes whose work shaped the subject into the form we know today. We believe that the teaching of Calculus greatly benefits from such a historical context, which brings the subject to life for students by exposing its human side, as opposed to being presented as an unmotivated system of definitions, theorems, and techniques. (Received September 18, 2015)

1116-VR-1393 **Richard G Chandler*** (richard.chandler@mavs.uta.edu). *Enhancing the Instruction of Multivariable Calculus using Dynamic Visualizations.* Preliminary report.

The benefits of visualization in the teaching of calculus to undergraduates has been a topics of research for some time. In particular, it has been shown that dynamic visualizations have aided students in understanding the ideas of limits, derivatives and integration in single-variable calculus. However, the need for dynamic visualizations can be realized again when students begin studying multivariable calculus. In this settings, students must not only apply concepts they learned in single-variable calculus, but they must do so while visualizing and interpreting surfaces and curves in 3-space for the first time. In this talk, we will look at some specific dynamic visualizations and animations, created using the open-source software Geogebra, that were used in a multivariable calculus class and discuss how they improved the students understanding over the course of the semester. (Received September 19, 2015)

1116-VR-1710 **J.C. Price*** (jprice12@ggc.edu), 1600 Peachcrest Dr., Lawrenceville, GA 30043. *Teaching Calculus in the 21st Century.* Preliminary report.

In this talk we will discuss our efforts to redesign the traditional calculus experience by using 21st century technology to remove lectures from the classroom and replace them with an active learning experience. This entails students watching lectures outside of class at www.youtube/user/drprice765, and then working problems in class at a whiteboard and in small groups, while the instructor facilitates learning. Our classroom and instructional design draws upon elements from the laboratory sciences, studio arts, and other humanities courses. The main result is a course that offers an active learning experience that encourages students to engage in discovery, compare and contrast of ideas, and work together to solve problems. (Received September 21, 2015)

1116-VR-1815 **Younggon Bae*** (baeyoun3@msu.edu). *Inquiry-based learning activities in multivariable calculus.*

Multivariable calculus is often a challenging course for undergraduate students because of the simultaneous need for abstraction and argumentation in addition to computation. Research on teaching has established the value of inquiry-based learning activities with interactions among students within the classroom to balancing instructors' lectures. We designed and implemented an inquiry-based multivariable calculus at a university in South Korea. In the flipped classroom setting of the course, students watch short video clips before the class, while in-class times are devoted to exercises, activities or discussions. It enabled the instructor's explanatory lectures to be replaced by the online video clips and allowed the students to experience inquiry-based learning activities with mathematical modeling, mathematical proof construction through discussions with their peers. In this presentation, we aim to introduce the overall process of class implementation and practices of inquiry-based learning activities in multivariable calculus, and sharing students' performance on their in-class writing and reflective journals. (Received September 22, 2015)

1116-VR-1996 **Ian Pierce*** (ian.pierce@usafa.edu). *Not ready for calculus? What we've tried. . . .* Preliminary report.

Students at the United States Air Force Academy must complete two semesters of calculus and a number of other technical classes to earn their degree. What is the best way to help the students who arrive with the weakest algebra skills? Is it better to place them in a separate algebra class or to develop their algebra skills while they take calculus? If they are in a separate algebra class, what should be the goals of that class (technical acuity versus problem-solving)? We consider four approaches: a computational-intensive ("traditional") pre-calculus and algebra class, a modelling-based pre-calculus and algebra, an integrated approach (which included extra algebra support in first-semester calculus), and a "mainstreaming" approach. (Received September 21, 2015)

1116-VR-2369 **Nicholas Gorgievski*** (nick.gorgievski@nichols.edu), Center Road, P.O. Box 5000, Dudley, MA 01571, and **Kimberly S. Sofronas**, **Thomas C. DeFranco**, **Hariharan Swaminathan**, **Charles I. Vinsonhaler** and **Samantha A. MacMillan**. *Calculus Instructors' Reported Use of Technology to Teach Approximation Concepts in First-Year Calculus Courses.*

This paper discusses the ways in which calculus instructors in higher education institutions throughout the United States use technology to teach approximation concepts in first-year calculus courses. This research is part of a larger study designed to investigate calculus instructors' perceptions of approximation as a unifying thread of the first-year calculus. A survey was administered to 279 calculus instructors. Qualitative measures were employed to extract themes and patterns from the data regarding those calculus instructors' use of technology to teach approximation concepts in first-year calculus courses. Three major themes emerged which focused on (a) the types of technology currently being used by college and university calculus instructors to teach approximation concepts, (b) the frequency with which calculus instructors report using technology to teach approximation concepts, and (c) calculus instructors' perceptions of the role of technology in the teaching and learning of approximation concepts. The findings of this research are of significance to all instructors of first-year calculus courses and may have implications for their instructional practices. (Received September 22, 2015)

1116-VR-2396 **Matthew J Haines*** (haines@augsburg.edu), Augsburg College, 2211 Riverside Ave S, Minneapolis, MN 55454. *An application of 3D printing in Calculus 3.*

Tangible surfaces can be used to assist students in their understanding of multivariable calculus. Summaries of Calculus 3 lessons will be presented. For these lessons, pairs of students work together on surfaces different than their classmates' surfaces. (Received September 22, 2015)

1116-VR-2402 **Cameron O'Neill Byerley*** (cameron.byerley@asu.edu). *The impact of Calculus students' understanding of quotient on their understanding of rate of change functions.*

Students' understandings of fractions in 5th grade is predictive of their overall mathematics achievement in high school (Siegler et. al. 2012). However, there is little research on university Calculus students' meanings for fraction and quotient and the impacts of these meanings on understanding derivatives. Understanding derivative as a function whose values are rate of changes requires students to understand fractions, quotients and constant rate of change. I investigated these issues with student interviews and a diagnostic measure of 112 Calculus students at a large southwestern public university. Many students could not place fractions on a number line or find a change in y given a constant rate of change and a change in x. Variation in students' responses to items about fraction, quotient and rate was predictive of variation in success on test questions about rate of change functions ($n = 112$, $p = .0001$). In particular, the ability to estimate a slope of a line on a blank graph with equally scaled x and y axes was predictive of success on tests in Calculus. I will present items, distributions of student responses and the relationship between students' success in the course and their performance on the diagnostic items. (Received September 22, 2015)

1116-VR-2597 **Skyler C Simmons*** (simmons@mathematics.byu.edu), 275 TMCB, Brigham Young University, Provo, UT 84602. *Using and Creating 3D Printed Models in Calculus Teaching.*

Modern 3D-printing technology enables the construction of a wide variety of objects, and has been used in fields such as art, medicine, and industry. This naturally has applications in mathematics and mathematics teaching as well. I will give a brief overview of my experiences using 3D printing in teaching, as well as some resources that I found helpful in getting started. (Received September 22, 2015)

1116-VR-2658 **Rebecca Glover*** (rebecca.glover@stthomas.edu), University of St. Thomas, Saint Paul, MN 55105, and **Nicholas Hammond**, **Justin Smith** and **Dalyana Guerra**. *Peer-Led Team Learning in Calculus.*

Research has shown that Peer-Led Team Learning (PLTL) is an effective recitation model for students to learn various STEM subjects. However, this model is not commonly used in mathematics courses at research institutions. In this talk, we will outline a large-scale implementation of a PLTL workshop model in a first-semester calculus course at the University of Rochester. We will describe the workshops themselves as well as the training class for the peer-leaders, and will discuss the effectiveness of this model as observed through improved student performance and leader growth. (Received September 22, 2015)

1116-VR-2694 **Jason Samuels** (jsamuels@bmcc.cuny.edu), **Aaron Wangberg** and **Brian Fisher***. *Developing Deep Student Understanding of the Partial Derivative using 3D Manipulatives.*

Most students know how to calculate derivatives in single and multivariable calculus, but many cannot explain their meaning. We have designed and implemented an innovative curriculum for Calculus III in which students use plastic surfaces, measurement tools, and group activities in order to explore and uncover many of the key ideas and formulas of multivariable calculus. In this talk we will describe how students explore the partial derivative. Some initial results demonstrating student growth will be presented. This research is part of the project Raising Calculus to the Surface, funded by the National Science Foundation DUE #1246094. (Received September 22, 2015)

1116-VR-2696 **Ziyue Guo*** (zoeyguo@gmail.com), 2582 South Road, Marlboro, VT 05344. *Using 3D-Printing in Teaching Multi-variable Calculus.* Preliminary report.

In this talk, we present student activities in a multi-variable calculus course using a 3D-printer and Mathematica to create surfaces that demonstrate limits and differentiability. We start with classic examples of surfaces that are not differentiable at the origin, such as the graph for $f(x, y) = (xy^2)/(x^2 + y^4)$ and the graph for $f(x, y) = (xy^2)/(x^2 + y^2)$. By working together on the Mathematica code, students practice using polar coordinates and observe the difference between pathological limits, continuity, and differentiability. Later in the course, students are also assigned a project to design a surface that is smooth on its domain except at one point, and 3D-print the surface with its tangent plane at a differentiable point. (Received September 22, 2015)

1116-VR-2758 **Jesse W Johnson*** (jwjohnson@westfield.ma.edu), Westfield State University, Department of Mathematics, 577 Western Ave., Westfield, MA 01086. *Teaching Calculus Through "Astronomical" Mistakes.* Preliminary report.

We all make mistakes, even the brilliant ones. In this talk, I will share my experiences in a Calculus 1 classroom where we learned differential and integral calculus by examining some of the earlier, erroneous models of the solar system. I will focus on the students' reception of the material and the pedagogical benefits of this experience. (Received September 22, 2015)

1116-VR-2878 **Paul E. Seeburger*** (pseeburger@monroecc.edu), Monroe Community College, 1000 E. Henrietta Rd., Rochester, NY 14623. *Playing with Multivariable Calculus Concepts Wearing 3D Glasses.* Preliminary report.

A tour of an NSF-funded project that seeks to develop geometric intuition in students of multivariable calculus. CalcPlot3D, an online exploration environment, allows students (and instructors) to create and freely rotate the graphs of functions of two variables, contour plots, vectors, plane and space curves, regions of integration, vector fields, parametric surfaces, implicit surfaces, etc. 3D glasses can be used for a real 3D perspective! Come get a pair and try it out! A series of four assessment/exploration activities has also been created to help students "play" with the 3D concepts themselves and to assess improvements in geometric understanding gained from these activities. Topics of these explorations include Dot Products, Cross Products, Velocity and Acceleration Vectors, and Lagrange Multiplier Optimization, and more are being developed. The grant project is titled, Improving Conceptual Understanding of Multivariable Calculus Through Visualization Using CalcPlot3D (NSF-DUE-IUSE # 1524968). See http://web.monroecc.edu/calcNSF/. (Received September 22, 2015)

1116-VR-2961 **William C Kronholm*** (wkronholm@whittier.edu), Whittier College, Department of Mathematics, Whittier, CA 90608. *Integration by the Wrong Parts.*

Integration by parts is a standard technique for determining antiderivatives for functions. Typically, students learning this technique are encouraged to make the "right" choice of parts. In this talk we explore what happens when the "wrong" choices are made. Perhaps surprisingly, making the "wrong" choices can still lead to closed form solutions to antiderivatives for some elementary functions. (Received September 23, 2015)

1116-VR-2962 **Jian He*** (hexiaodong9@163.com), Department of Mathematics, Northeastern University, No.11, Lane 3, WenHua Road, Shenyang, Liaoning 110819, Peoples Rep of China, and **Aihua Li** (lia@mail.montclair.edu), Department of Mathematics, Montclair State University, 1 Normal Avenue, Montclair, NJ 07043. *Mathematics and art meet at a beautiful bridge - a calculus problem derived.*

A calculus problem is derived based on the shape and projection of a well-known bridge, Sanhao Bridge, located in the city of Shenyang, China. Sanhao bridge has won the world's highest prize for bridge design, the "Eugene C. Figg Medal", and the Global Road Achievement Award in 2009. The biggest characteristic of the bridge is its two large skew arches, shaped like the wings of a butterfly from afar. Seen from one end of the bridge, the outlines of the two skew arches reflect two intersecting curves. The beautiful shape of each arch can be viewed as a combination of a partial circle and a segment of a parabola. How to get the mathematical expression of the outline curve? This article creates a problem that asks students to model the outline of one arch with an optimized enclosed area or arc length. Real date on measurement of the bridge is used. The problem is approachable by college students and advanced high school students. It also can be used by calculus instructors as a real world model. This project presents a great example of beautiful combination of mathematics and art. (Received September 23, 2015)

General Session on Teaching and Learning Advanced Mathematics

1116-VS-79 **Pablo Ulises Suarez Joya*** (psuarez@desu.edu), Department of Mathematical Sciences, Delaware State University, 1200 N Dupont Hwy, Dover, DE 19901. *MATLAB simulation an aid for teaching probability.*

In an introductory course of probability students are typically taught the theory and no simulation methods. For the most part, textbooks and instructors will mention briefly that one can conduct simulations based on the empirical probability but that is it! Few elaborate on this topic. Using simulation to illustrate concepts of probability may lead undergraduates to understand topics better and tackle problems that otherwise might no be possible. In this talk we illustrate how using MATLAB simulation can be used as complementary tool to study probability. Computer simulations of classical results are presented and difficult problems are tackled. We hope this talk will encourage other instructors and authors to discuss computer simulations early on their respective courses. (Received July 14, 2015)

1116-VS-357 **Russell R Coe*** (coer@sunysuffolk.edu), 110 Moonlight Walk, Holbrook, NY 11741. *Behind the Scene: What the Brain Thinks the Eyes Are Seeing.*

Most students trying to solve a mathematics problem want to see a problem that looks exactly like the one they saw their instructors do in class. So when they see a problem that looks different than the ones they saw in class, many of them simply give up. Often a student will have become difficulty solving a problem in mathematics simply because when he or she looks at the problem, the student either thinks he or she sees something that isn't there and then uses the wrong approach to solve the problem, or the student does not see something that is staring the student in the face. For example, when given the problem of solving the equation $\sin^2\theta - \cos^2\theta = 0$, a student may think he or she is seeing a trigonometric identity and not realize he or she is seeing a difference of squares. A student needs to be flexible enough in the way he or she views a problem in order to be able to find the solution. In this talk I will discuss the need to teach students to be flexible in the way they think and present several examples of where this applies. (Received August 27, 2015)

1116-VS-588 **Eric Errthum*** (eerrthum@winona.edu), Winona State University, 175 West Mark Street, Winona, MN 55987. *Publishing or perishing in an intro-to-proof course.* Preliminary report.

Many online forums rely on reputation to rank contributors and reward them for activity. Similarly, in the mathematical research community one builds up prestige through publishing and presenting material. In this talk, I will report on my experience with awarding reputation points and using a publish-or-perish scheme in an intro-to-proof class. I will explain how student work was evaluated like submissions for publication and how reputation was earned. Student feedback will also be shared. (Received September 08, 2015)

1116-VS-1543 **Mary K. Flagg*** (flaggm@stthom.edu), Department of Mathematics, 3800 Montrose, Houston, TX 77006. *Applied Abstract Algebra.*

An Introduction to Abstract Algebra course seems an unlikely place to include undergraduate research. After all, the standard material on groups, rings and fields with an emphasis on learning to write proofs is nothing new. However, it is the perfect place to share the connections between abstract theory and applications that captivated me as a graduate student and still excite my passions. My class, although small, is made up of students with a very diverse range of interests and career goals. I recently decided to celebrate that diversity and let the students choose the application topic they were most interested in as a semester project in the course. Half of the fall 2015 students chose to try an undergraduate research project instead of a standard fundamentals of public key cryptography or introduction to coding theory option. I will report on the projects "Evaluating Online Resources for Polynomial Functions from a Polynomial Ring Perspective" and "Power Domination, Zero Forcing and Graphs of Rings and Groups". The class includes pre-service secondary education majors, and one question I will report on is how the experience changed heir perception of mathematics and mathematics teaching. (Received September 20, 2015)

1116-VS-1738 **Danny T Lau*** (danny.lau@ung.edu), PO Box 1358, Gainesville, GA 30503. *Suitable Topics and Appropriate Depth in a Junior/Senior Level Elementary Number Theory Course.* Preliminary report.

Elementary Number Theory is considered as the oldest branch of mathematics interchangeable with the study of Integer Arithmetic. Its problems are usually easy to state but often challenging to do. As an elective course for our Math majors, I have seven students enrolled in this Fall 2015 course where the prerequisite is successful completion of a "How to do proofs" math course. Since there are many fine free online electronic resources, I have created my own class notes based on "The Theory of Numbers" by Robert D. Carmichael, a monograph from the Project Gutenberg, and supplemented them with other online or printed books. The grading of the course consists of homework, tests, a final exam and a five-page expository term paper. By the January 2016 Joint Meeting, I would have finished the course and may reflect and assess how well I had conducted the course. I thus like to share information on the topics and the depth that I have covered with the hope of getting feedback from the audience in terms of their suitability and appropriateness. In the long run, I hope that we can establish a more standardized 80/20 undergraduate Number Theory course with 80% of its content as required and 20% as optional. (Received September 21, 2015)

1116-VS-2064 **David W Mauro*** (david.mauro@trincoll.edu). *Bridge Courses for Undergraduates – What May Be Missing.* Preliminary report.

A bridge course is a course that is designed to ease the student's transition from lower-level computational courses to upper-level theoretical courses. Aimed at inculcating a mathematical mindset, textbooks and syllabi typically include inferential logic and an introduction to proof techniques, followed by an emphasis on proof-writing within the areas of sets, relations, and functions. Tracing my own students' struggles in proof-writing to their origins has led to a bridge course at Trinity College (CT) in which the art and the science of reading and writing mathematical *definitions* stands not only as a precursor to reading and writing proofs, but as an equal. I describe the exposition of mathematical definition that has evolved, the types of exercises that students encounter, and the responses I am likely to see as students are put to the tests of reading, applying, and ultimately writing their own definitions. (Received September 21, 2015)

1116-VS-2259 **Timothy B Flowers*** (flowers@iup.edu). *Connecting Collegiate Mathematics to Secondary Mathematics for Pre-service Teachers.*

Several recent reports and studies have indicated that secondary mathematics education majors should have (at least) one course which connects the topics they will teach at the high school level to the material in undergraduate mathematics courses. The author will share experiences from teaching such a course for the first time. This will include reports on approaches and assignments that worked well and others that did not. We will also comment on the students' desire to focus on method above content and how this was addressed by the instructor and students. (Received September 22, 2015)

1116-VS-2477 **Alyssa M. Armstrong*** (armstronga@wittenberg.edu). *Using Proof Portfolios in an Introduction to Proofs Course.* Preliminary report.

In a typical Introduction to Proofs course, students first learn to write formal mathematical arguments using common techniques such as proof by contradiction, proof by cases, and mathematical induction. In most cases, students write a proof and never get a chance to revise and polish their arguments. This hinders the traditional writing process seen in other fields and as well as when writing proofs for publication. By introducing a semester-long proof portfolio project, these students learn that mathematical writing is a continual process by writing proofs, receiving feedback from the instructor, and then refining their work in a final portfolio format. The portfolio also allows students to witness their improvement as they continue to learn to write proofs. In this talk, I will provide details regarding the proof portfolio I used in the Introduction to Proofs course at Wittenberg University in the fall 2015 semester, and I will reflect on students' experiences regarding the portfolio. (Received September 22, 2015)

General Session on Teaching and Learning Developmental Mathematics

1116-VT-595 **Vlajko L Kocic*** (vkocic@xula.edu), **Gurdial Arora** (gdial@xula.edu), **Andrew Klimas** (aklimas@xula.edu), **Donna Sutson** (dstutson@xula.edu) and **Sindhu Unnithan** (sunnitha@xula.edu). *Comprehensive Reform of Developmental Math at Xavier University of Louisiana.*

The reorganization and consolidation of the developmental mathematics course MATH 0990D Preparation for College Math, has been one of the highest priorities of the Mathematics Department at Xavier University of Louisiana in the past four years. Low passing rate (51% at the end of fall 2011 semester) was a major concern for both the department and the University. During the spring of 2012 an ad-hoc committee, developed a comprehensive plan (approved by the department and the administration) for reorganization of the course. The plan addressed several areas that needed intervention such as: restructuring and reorganizing the course, placement policy, development of new course materials, student support, selection of teachers, coordination of the course, development of assessment tools, etc. The plan was implemented for the first time in fall 2012. The passing rate at the end of fall 2012 was 72% and since then remained on that level. The whole process of reorganization was supported by the NSF grant Critical Juncture, STEM Educational Innovations Driven by Holistic, Integrative Evaluation Systems (I-3) (Award # 0963641). (Received September 08, 2015)

1116-VT-1010 **Shumei C. Richman*** (richmansmc@gmail.com). *Using Word Problems as a Bridge to Learn Linear Equations.* Preliminary report.

Most college students in a beginning algebra class are afraid of word problems. This research rose from a question: Is it possible to change the situation by adding the role of word problems in algebra, besides as applications? Our strategy is to use word problems to serve as a bridge, from everyday life to math and from arithmetic to algebra. For example, when first introducing a linear equation, instead of rules and algorithms, we give students some simple and concrete word problems, which can be solved by the equation, are familiar to them and they can solve easily by arithmetic methods with visual drawings. This is to help students 1. interpret the meaning of the equation, especially the meanings of operations involved, from what they have known about the word problems, and 2. solve the equation, without any algebraic rules, but with what they have known about the arithmetic solutions of the given word problems. We have found that this alternative approach helps students make sense of equations, and thus increases not only their comfort in solving word problems, but also their understanding of algebraic rules, such as the distributive law. In this talk, we will discuss the design of bridging word problems and their impacts on students. (Received September 21, 2015)

1116-VT-1870 **Katy Bird**, **Sarah Cordell** and **Joseph Hibdon*** (j-hibdonjr@neiu.edu), Northeastern Illinois University, Mathematics Department, 5500 N. St. Louis Ave., Chicago, IL 60625. *The EMERGE Summer Program at Northeastern Illinois University: Supporting Incoming Freshmen in Strengthening their Mathematical Identities and Succeeding in Mathematics Development Coursework.* Preliminary report.

This paper describes the development, results, and future directions of the mathematics component of the English & Math Enrichment, Readiness & Growth Experience (EMERGE) Summer Program at Northeastern Illinois University (NEIU), a Hispanic serving institution in Chicago, Illinois. During summers 2014 and 2015, the EMERGE Summer Program offered a 3-week English session and a 3-week math session for new incoming freshmen at NEIU. To participate in the math session, students must have completed NEIU's math placement exam and placed into math development course. The math session aimed to help students strengthen their mathematical foundation, gain confidence in their mathematical abilities, and gain the skills needed to successfully place into a higher-level math course. The mathematical learning environment was enhanced by a modified peer led team learning environment, in which current NEIU math majors served as peer leaders that collaborated with classroom instructors and actively engaged with and mentored EMERGE students. EMERGE math students attended mini-lectures, participated in structured group activities, and completed online MyMathLab modules. Results for the 2014 and 2015 EMERGE Program mathematics component indicated a 73% and 70% success rate respectively. (Received September 21, 2015)

1116-VT-2906 **Alvina J. Atkinson*** (aatkinso@ggc.edu), 1000 University Center Lane, School of Science & Technology, Lawrenceville, GA 30043, **Aris B. Winger** (awinger@ggc.edu), 1000 University Center Lane, School of Science & Technology, Lawrenceville, GA 30043, **Sarah H. Park** (spark3@ggc.edu), 1000 University Center Lane, School of Science & Technology, Lawrenceville, GA 30043, **Lee Ann Roberts** (lrobert2@ggc.edu), 1000 University Center Lane, School of Science & Technology, Lawrenceville, GA 30043, and **Angela Lively** (alively@ggc.edu), 1000 University Center Lane, School of Science & Technology, Lawrenceville, GA 30043. *Ready or Not, Here We Go!: Using A Corequisite Approach to Prepare Students for College Level Math.*

In Fall 2011, a grant was awarded to Georgia to produce a model that would "fast-track" learning support students through developmental courses and college algebra in a single semester. The authors' institution created the new "Access" course and launched it in the spring semester of 2012. Over the last 3 years, the course and has been modified and expanded to include two corequisite courses designed to fast-track slightly underprepared students though College Algebra and Quantitative Reasoning. Access Algebra and Access Reasoning are both 2-hour courses that are paired with a traditional college algebra course and a traditional quantitative reasoning course to deliver prerequisite content. Both courses are taught in a computer classroom. The model for the course and results will be presented. This presentation is designed for educators with an interest in innovative models in developmental mathematics. (Received September 23, 2015)

1116-VT-2974 **Grazyna Badowski*** (gbadowski@uguam.uog.edu), P.O. Box 21831, Barrigada, GU 96921. *Developmental Mathematics Redesign.* Preliminary report.

University of Guam is an open enrollment university with about 70% of students being placed in developmental mathematics. Recently Math Development Program was completely changed from self-paced courses to lecture/workshop format. In self-paced classes the students were supposed to study mostly on their own and take test when they were ready. This format failed most of the students. In this paper, we will discuss the transition to a new lecture/workshop format that proved to be highly successful in the first year of implementation. The pass rate increased from around 20-30% in self-paced classes to 60%-70% in lecture/workshop classes. (Received September 23, 2015)

General Session on Topology

1116-VU-302 **Kathryn Bryant*** (kbryant01@brynmawr.edu), kbryant01@brynmawr.edu. *Determining Sliceness in 5-Stranded Pretzel Knots: The Single-Pair Case.*

Within any infinite family of knots, a compelling question to ask is which members of the family hold certain knot theoretic properties and which do not. One such property of interest is that of being *smoothly slice*, which means that the knot bounds a smoothly embedded disk in the 4-ball. This talk will focus on the problem of determining the slice knots within the family of 5-stranded pretzel knots, specifically of those with exactly one pair $(k, -k)$ of canceling twist parameters. The result builds on work of Lisca with 2-bridge knots, and on work of Greene and Jabuka with 3-stranded pretzel knots. The conditions for sliceness used to get results for 2-bridge knots and 3-stranded pretzel knots are necessary but *insufficient* for 5-stranded pretzel knots with one or two pairs of canceling twist parameters. Thus, a new technique is implemented to obtain results in the single-pair case. This is joint work with Paul Melvin. (Received September 21, 2015)

1116-VU-536 **Jay Stine*** (jstine@misericordia.edu). *A New Characterization of Clopen Sets.* Preliminary report.

We characterize clopen (both open and closed) sets in a topological space in terms of functions and discrete spaces. Accordingly we can define clopen (sub)objects in any topological category. We give some simple examples and discuss a very general Theorem which has an interesting interpretation in general topology. (Received September 06, 2015)

1116-VU-828 **Liljana Babinkostova*** (liljanababinkostova@boisestate.edu), Boise, ID 83725, and **Marion Scheepers**. *Selective strong screenability and a game.*

Selective versions of screenability and of strong screenability coincide in a large class of spaces. We show that the corresponding games are not equivalent in even such standard metric spaces as the closed unit interval. We identify sufficient conditions for ONE to have a winning strategy, and necessary conditions for TWO to have a winning strategy in the selective strong screenability game. (Received September 13, 2015)

1116-VU-1638 **Mia Smith*** (mcs3@williams.edu) and **Gregory Kehne**. *Volume and Determinant Densities of Hyperbolic Links.*

Hyperbolic volume has proven to be a powerful invariant for distinguishing links. Somewhat surprisingly, there is a related combinatorial invariant, the determinant of a link, which appears to be deeply connected to volume. In particular, it is conjectured that for any hyperbolic link L, $vol(L) < 2\pi \log det(L)$. To better understand this conjecture, we study the sets of volume and determinant densities of hyperbolic links. We construct sequences of knots that approach any $x \in [0, v_{oct}]$ in both volume and determinant density. Additionally, we use geometric and combinatorial techniques to prove that in the case of rational links, these sets are dense subsets of two subintervals of $[0, v_{oct}]$. These are results from our SMALL 2015 knot theory group. (Received September 22, 2015)

1116-VU-1716 **Mehmet Emin Aktas*** (maktas@math.fsu.edu), 208 Love Building, 1017 Academic Way, Tallahassee, FL 32306. *Classification of Dessins D'Enfants of the Completely Reducible Trigonal Curves.*

In recent years, topology of singular plane algebraic curves has been an area of active research. Especially, there is a huge effort on the computation of the fundamental group of plane curve complements. However, there is a geometric approach, which is developed by A. Degtyarev, to the study of such plane curves with using the representation of curves via trigonal curves in Hirzebruch surfaces and Grothendieck's *dessins d'enfants*. Via dessin d'enfants, we can compute the braid monodromy of the complement of the trigonal curve C and the exceptional section E, *i.e.*, $\Sigma_1 \setminus (C \cup E)$. In this study, we work on the topology of the completely reducible trigonal curves i.e. the curves in the form $(y - p_1)(y - p_2)(y - p_3) = 0$ where $p_1, p_2, p_3 \in \mathbb{C}[x]$. We give the classification of Dessin d'enfants of these curves up to ambient isotopy for some certain degrees and work on the topology of each class. (Received September 21, 2015)

1116-VU-1848 **A. Overbay*** (aoverbay@austincollege.edu) and **K. Van Dinh**. *New Knot Invariants in an Expansion of the Colored Jones Polynomial.*

Both the Alexander polynomial and the Jones polynomial are two well-known knot invariants. The Melvin-Morton conjecture, proved by Bar-Natan and Garoufalidis, provides a relationship between these two invariants. It states that the bottom 'line' in a certain expansion of the colored Jones polynomial generates the inverse of the Alexander polynomial. Rozansky later proved that the upper lines in this expansion generate rational functions with powers of the Alexander polynomial in the denominator with polynomial invariants of the knot in the numerator. In this talk, we will describe our methods used to calculate the third term in the expansion and present new polynomial invariants that occur in this term. We will also discuss how these results support a conjecture concerning amphichiral knots. (Received September 21, 2015)

1116-VU-1924 **Deborah Vicinsky*** (vicinskd@wabash.edu). *Some nontrivial model categories with trivial associated stable categories.*

We study two pointed model categories. The first is the category of small categories with the canonical model structure, and the second is the category of directed graphs with the Bisson-Tsemo model structure. For each category, we construct the suspension functor and use it to show that the associated stable category is homotopically trivial. (Received September 21, 2015)

1116-VU-2125 **John E Mosley*** (john.mosley@uky.edu). *The Image of the Witten Genus.*

The Witten genus is a variant of Ochanine's elliptic genus and can be interpreted as the index of the Dirac operator on the free loop space of a manifold. The natural domain of the Witten genus is string cobordism. The image of this ring under the Witten genus is difficult to compute, but is of some interest. A more tractable problem may be to compute the image of Spin- and SU-cobordism under the Witten genus. In this talk, we will discuss recent progress on this question. (Received September 21, 2015)

1116-VU-2142 **Will Murray**, Department of Mathematics and Statistics, 1250 Bellflower Blvd, California State University, Long Beach, Long Beach, CA 90840, **Joshua Sack*** (joshua.sack@csulb.edu), Department of Mathematics and Statistics, 1250 Bellflower Blvd, California State University, Long Beach, Long Beach, CA 90840, and **Saleem Watson**, Department of Mathematics and Statistics, 1250 Bellflower Blvd, California State University, Long Beach, Long Beach, CA 90840. *P-spaces and intermediate rings of continuous functions.*

A completely regular topological space is a P-space if every zero-set is open. A ring of real-valued continuous functions on X is an intermediate ring if it contains all the bounded functions. This talk examines the relationships between P-spaces and intermediate rings. There are a number of characterizations of P-spaces involving properties of the ring $C(X)$ of all continuous functions on X. We show that some of these properties still characterize P-spaces when we consider the corresponding property of an intermediate ring $A(X)$ strictly contained in $C(X)$, and other properties characterize $C(X)$ among intermediate rings when X is a P-space. For example, the property $M_A^p = O_A^p$ for all $x \in X$ characterizes X as a P-space, while the property that $M_A^p = O_A^p$ for all $p \in \beta X$ characterizes $C(X)$ among intermediate rings when X is a P-space. (Received September 21, 2015)

1116-VU-2206 **Colin Murphy*** (murphyc6@seattleu.edu), **McKenna Renn** (mrswiss@comcast.net), **Ra'Jene Martin** (martin_r7@denison.edu) and **Jennifer Townsend**. *The Applications of Region Almost Alternating Knots.*

Colin Adams introduced the notion of almost alternating knots, which are non-alternating knots that have a projection in which one crossing change is required to create an alternating diagram. We extend this notion in conjunction with Ayaka Shimizu's work on region crossing changes to develop the idea of a region almost alternating knot. This is defined as a knot where there exists a diagram such that a single region crossing change will produce an alternating diagram and no alternating projection exists. We discuss families of knots that are region almost alternating and their characteristics, such as their relation to almost alternating knots, their behavior in a connected sum, bounds on region dealternating numbers, and warping span. Our results resolve an open question about the maximum warping span of knots. (Received September 22, 2015)

1116-VU-2240 **Dean Matthew Menezes*** (dean.menezes@utexas.edu), 7309 Elm Hollow Dr, Corpus Christi, TX 78413. *Rational knots and their canonical triangulations.*

We study a contruction of a "canonical triangulation" for rational knots described by Sakuma and Weeks and use it to provide a useful presentation of the fundamental group for these knots. (Received September 22, 2015)

1116-VU-2584 **Ik Jae Lee***, Department of Mathematics, Rowan University, 201 Mullica Hill Rd., Glassboro, NJ 08028, and **David N Yetter**. *Dijkgraaf-Witten Type Invariants of Seifert Surfaces in 3-Manifolds.* Preliminary report.

In this talk, we introduce defects, with internal gauge symmetries, on a knot and Seifert surface to a knot into the combinatorial construction of finite gauge-group Dijkgraaf-Witten theory. The appropriate initial data for the construction are certain three object categories, with coefficients satisfying a partially degenerate cocycle condition. (Received September 22, 2015)

1116-VU-2859 **Gangadhar R Hiremath*** (gangadhar.hiremath@uncp.edu), Dept of Math/comp Sci, PO Box 1510, One University Drive, UNCP, Pembroke, NC 28372. *Pseudometrizability in the Class of Essentially Hausdorff Spaces.*

Essentially Hausdorff axiom is shared by the Hausdorff spaces and regular spaces. Interesting observations are first countable countably paracompact spaces and paracompact spaces in the class of essentially Hausdorff spaces are regular. Among many interesting results established in the class of essentially Hausdorff spaces are the following:

A topological space is pseudometrizable 1. if and only if the space is essentially Hausdorff semistratifiable wM-space; 2. if and only if the space is the space is essentially Hausdorff submetacompact quasi-developable wM-space (Received September 22, 2015)

Assorted Topics

1116-VW-136 **Jathan W. Austin*** (jwaustin@salisbury.edu), Department of Mathematics & Computer Science, Salisbury University, 1101 Camden Avenue, Salisbury, MD 21801. *Exploring Hall's Genealogy of Pythagorean Triads.* Preliminary report.

In 1970, Hall published a short paper showing that primitive Pythagorean triples can be sorted into sets of three according to matrix multiplication by three given matrices and discussed patterns that appear in this sorting. In this talk, I will discuss additional patterns that appear, with connections to Fibonacci and Pell numbers. (Received August 04, 2015)

1116-VW-188 **Nicole R Juersivich*** (njuersi9@naz.edu). *Design and Implementation of a Mathematics Education Undergraduate Research Course.*

Undergraduate research provides many opportunities for students and faculty members; however, not much information exists on how to create and run an undergraduate research course in K-16 mathematics education. In this session, I will present how I designed and implemented the course, and then re-designed and re-implemented the course based on feedback and reflection. Some topics addressed will be (1) form and intensity of the experience, (2) determination of project needs, expectations, structure, and support to produce original work, (3) assessments used (4) student perceptions, and (5) future plans. The goal of this presentation is the share a model and to promote discussion on creating undergraduate research experiences in K-16 mathematics education to enhance pre-service teachers' understanding of content pedagogy. (Received August 12, 2015)

1116-VW-269 **Marshall Hampton*** (mhampton@d.umn.edu), Duluth, MN 55812. *Probabilistic models of Trypanosome RNA tails.*

Trypanosomes cause a variety of diseases, most notably sleeping sickness and Chagas disease. Trypanosomes are very unusual unicellular parasitic flagellate protozoa; one of the strangest features being that their mitochondrial genome is essentially encrypted, requiring massive editing by their minicircle DNA. In addition, mitochondrial RNA transcripts have complicated 3' tail additions incorporating uridine (U) as well as adenine (A). Unique features of these parasites are important as they could provide good novel drug targets.

Based on new circularized RNA deep sequencing data, we present different probabilistic approaches to modeling the structure of these RNA tails, and how the models can inform biological interpretation. (Received August 19, 2015)

1116-VW-283 **Ralph P. Grimaldi*** (grimaldi@rose-hulman.edu), 5500 Wabash Ave, Terre Haute, IN 47803. *Compositions with Descents at Odd Plus Signs.*

For a positive integer n, a composition of n is an ordered summation $x_1 + x_2 + \cdots + x_r$, where $1 \leq r \leq n$, and $x_1 + x_2 + \cdots + x_n = n$. In general there are 2^{n-1} such compositions for n. We want to consider those compositions of n where $x_{2i-1} > x_{2i}$ for $i \geq 1$. For example, for $n = 9$, of the 256 compositions of 9, only 34 satisfy this condition. Three such compositions are $3+2+2+1+1$, $3+1+2+1+2$, and $4+3+2$. In general the number of such compositions is F_n, the n^{th} Fibonacci number.

For a given n, results derived for these compositions include:
(1) the total number of summands that occur;
(2) the number of summands in even and odd positions;
(3) the sums of all first, second, third, and fourth summands;
(4) the number of compositions with three and four summands; and,
(5) the number of times 1 occurs as a summand. (Received August 21, 2015)

1116-VW-295 **Brian G. Kronenthal*** (kronenthal@kutztown.edu). *An Integer Sequence Motivated by Generalized Quadrangles.*

Can you fill in the blanks in the following sequence of integers? No internet please!

$$2, 6, 8, 10, 32, 84, 128, 186, \_\_\_\_\_, \_\_\_\_\_, 2048, 3172, 8192, 19816, \ldots$$

In this talk, we will explain how this sequence relates to incidence geometry (generalized quadrangles in particular) and algebraically defined graphs. Don't worry, we will also fill in the blanks, and moreover discuss a closed form for the n^{th} term of the sequence. (Received August 23, 2015)

1116-VW-299 **Alperen S Sirin*** (saidsirin@gmail.com), 57 West Squire Dr Apt 7, Rochester, NY 14623, and **Maria Lema** and **Maximillian Bender**. *Properties of m'th Level Triangle Numbers in Second Order Recursive Polynomials.*

Through the application of Budan's Theorem, which relates the number of roots of a polynomial in a given interval to the sign changes in the sequence of coefficients of that polynomial, we present analytic and combinatorial properties of a generalized sequence of recursive polynomials. Here, we follow the standard initial conditions for a recursive polynomial $G_n(x)$ with $G_0(x) = -1$ and $G_1(x) = x - 1$. We consider the generalized recurrence relation $G_n(x) = x^k G_{n-1}(x) + x^\ell G_{n-2}(x)$, where ℓ and k are natural numbers. Our results include properties of the roots, the growth of the sequence of derivatives, and general structure of these polynomials. In particular, we prove that the maximal roots of the polynomials generated in the case where $\ell = k$ converge to 2 and all non zero roots of G_n for any k are irrational for $n > 2$. We also discuss the relevance of the triangle numbers in the formation of these polynomials and present a game theoretical application along with modular identities evaluating $G_n(x)$ modulo $G_1(x)$, $G_2(x)$. (Received August 23, 2015)

1116-VW-348 **Nitya Mani***, nityam@stanford.edu, and **Simon Rubinstein-Salzedo**. *N-Division Points of Hypocycloids.*

One of the most famous mathematical problems concerns constructing figures with an unmarked straightedge and compass, specifically regular polygons. Such construction problems concerning regular n-gons can be generalized to consider the n-division points of any closed curve C (n points dividing C into pieces of equal arc length).

Here, we will discuss two theorems we proved concerning the constructible n-division points of a family of closed hypotrochoids called the hypocycloids. These theorems and their proofs will provide insight into 2 major problems in this field: characterizing the constructible n-division points of families of curves and understanding the difference in the constructible n-division points of a closed curve C depending on whether C is drawn or not.

We will show that the n-division points of all rational hypocycloids are constructible with a straightedge and compass for all integers n, given a pre-drawn hypocycloid. We will also consider the problem of constructibility of n-division points of hypocycloids without a drawn curve. Here, we will examine the hypocycloid with 3 cusps and prove that only the 1, 2, 3, and 6-division points of an undrawn tricuspoid are constructible in this manner. (Received August 26, 2015)

1116-VW-361 **Bryan Dawson*** (bdawson@uu.edu), Union University, Jackson, TN. *Infinitesimals, Point Nine Repeating, and One.*

Many students do not believe that $.\overline{9} = 1$, even after seeing a proof. It has been conjectured that for some students the reason lies in their intuition about the infinitely small, that they perceive an infinitesimal difference between the two numbers. Does such a difference actually exist? This presentation explores the question of whether or not $.\overline{9}$ and 1 are equal in the hyperreal numbers. (Received August 27, 2015)

1116-VW-391 **Omer Yildiz*** (omeryildiz2018@gmail.com), 3 sudbury dr, Rochester, NY 14624. *Applications of Quadratic Reciprocity to Finite Diophantine Equations.*

Quadratic reciprocity theorem has a lot of applications in pure mathematics and especially number theory. It has been studied all the way since Gauss till today's most prominent number theorists. The law of quadratic reciprocity is a theorem that provides conditions on the solvability of quadratic equations modulo prime numbers. In this talk, we present the applications of quadratic reciprocity to two types of Diophantine equations. One is in the form $ax_1 + bx_2 = c$ where a, b, c are constants with variables x_1, x_2. The other is in the form of $c_1x_1^2 + c_2x_2^2 + ... + c_nx_n^2 = k$ for some k where $c_1, ..., c_n$ are sums of two squares with variables $x_1, ..., x_n$ for some n. (Received August 30, 2015)

1116-VW-460 **J. Alan Alewine*** (jaalewine@mckendree.edu), 701 College Road, Lebanon, IL 62254. *Childhood Memories: Using the Inner Child to Teach Mathematics.*

Where do homemade chocolate chip cookies, Lego sets, M&M's, and Sudoku fit into the college mathematics curriculum? In linear algebra, modern algebra, and introduction to proofs courses (of course)! Revisit your childhood and learn how to incorporate comfort and a bit of fun into post-calculus courses. (Received September 02, 2015)

1116-VW-596 **Bryan Nankervis*** (bn10@txstate.edu). *Accountability and the Texas Miracle.*

Texas has moved to the head of the class in terms of mathematical proficiency due to accountability. This talk will examine the evolution of the accountability movement, include comparisons of students from Texas to their national and international counterparts, and examine the strategy behind what has been referred to as the 'Texas Miracle.' (Received September 08, 2015)

1116-VW-893 **Lee N. Collins*** (ncollins@ccm.edu), County College of Morris, Department of Mathematics, 214 Center Grove Road, Randolph, NJ 07869. *Extracting Square Roots of Power Series by Hand.*

Over the past 35 years, the process of extracting the square root of a number has become a job for the calculators. Once a familiar hand calculation in grade school mathematics, the division-like algorithm used for extracting square roots is virtually non-existent in classrooms today. In this talk, we discuss the algorithm, the theory behind it, and consider a generalization for extracting nth roots. By extending the argument, we show it is possible to extract the square root of any power series by hand. (Received September 14, 2015)

1116-VW-1093 **C. Berge-Sisneros*** (carissa.berge-sisneros@nsc.edu), Henderson, NV. *Probability of Integer Area Lattice Figures.* Preliminary report.

We prove that lattice triangles have integer area with probability $\frac{5}{8}$. We use this result to show that any lattice polygon has a greater than 50% probability of having integer area. We then show that if a lattice polygon has integer area, the probability that the area is an even number is greater than 50%. After establishing these two-dimensional results, we prove similar results for lattice pyramids in higher dimensions.
Keywords: lattice n-gons, lattice pyramids (Received September 16, 2015)

1116-VW-1476 **Ian Nicolas*** (nico6473@pacificu.edu), 1509 22nd Ave, Apt 4, Forest Grove, OR 97116, and **Melody Bruce**, **Michael Dougherty**, **Max Hlavacek** and **Ryo Kudo**. *A Decomposition of Parking Functions by Undesired Spaces.*

There is a well-known bijection between the set of parking functions of length n (denoted PF_n) and the maximal chains of the lattice formed by the noncrossing partitions on $n+1$-elements (denoted NC_{n+1}). Using this bijection we explore a particular decomposition of PF_n and the posets formed by the corresponding maximal chains in NC_{n+1}. We show the these decomposed posets preserve several interesting properties of NC_{n+1} such as self-duality. We also enumerate these decompositions and posets into formulas using the Catalan numbers. In addition, we provide interpretations of this particular decomposition in other objects such as labeled Dyck paths, labeled rooted forests, and nonnesting partitions. (Received September 20, 2015)

1116-VW-1578 **Padraig M. McLoughlin*** (mcloughl@kutztown.edu), 265 Lytle Hall, Department of Mathematics, Kutztown University of Pennsylvania, Kutztown, PA 19530. *The Moore Method: A Decidedly American Educational Philosophy.*

The author of this paper argues that the Inquiry-Based Learning (IBL) methodology, the Moore Method (and modified Moore methods), is distinctly American and individualist as opposed to post-modern European and communistic pedagogy.
We argue that the pedagogy of the Moore Method is a realisation of a decidedly American adaptation or interpretation of the Socratic Method. At the core of the pedagogy is exploration, discovery, conjecture, hypothesis, thesis, and synthesis such that the experience of doing an argument, creating a model, or synthesising ideas is reason enough for the exercise.
We argue that the Moore Method has manifestly American aspects which differentiate it from more collectivist critical-theory educational methods. The manner in which the pedagogy is applied has individual presentations of work students themselves create, reason, and construct that are as practically independent of material from outside influence as is possible; with the instructor donning the role of mentor to apprentices (students) . We submit the Moore Method prepares the student for advanced work or studies and is a pedagogical approach that is a 'percolation-up' creative model of learning in an increasingly 'bottom-down' information (just 'Google' it) society. (Received September 22, 2015)

1116-VW-1615 **Maria Neophytou*** (maria.neophytou@belmont.edu). *Helping students see connections between mathematics and other disciplines through a fun teaching exchange project.*

Being a part of a peer teaching group consisting of six colleagues from six different disciplines has been one of the most rewarding experiences I have had as a mathematics assistant professor at Belmont University. In this session I will discuss the impact an innovative (and fun) trans-disciplinary teaching exchange project we have implemented has had on, not just the members of the group, but also our students. In particular, I will explain how three specific classroom swaps have helped students see connections between mathematics and art, mathematics and pharmacy, and even mathematics and law, and how that promoted the students' learning and interest in the course, as well as their general appreciation of mathematics. (Received September 20, 2015)

1116-VW-1648 **Soowhan Yoon*** (10916858@live.mercer.edu). *Polynomials of Binomial Type: an Analytic Connection between the Fibonacci Recurrence and the Binomial Coefficients.*

The Fibonacci sequence and Pascal's triangle are closely related due to their recursive properties. Although these two are often viewed as discrete objects, both can be studied at the analytic level. This talk presents an outline of the proof of the identity $\sum_{n=0}^{\infty}\binom{\frac{n+z}{2}}{n} = \left(1+\frac{1}{\sqrt{5}}\right)\phi^z$ and its consequence $\sum_{n=0}^{\infty}\binom{\frac{n+k}{2}}{n} = L_{k+1} + \frac{F_{k+1}}{\sqrt{5}}$ where $\phi = \frac{1+\sqrt{5}}{2}$ and L, F each denote Lucas sequence, Fibonacci sequence, respectively. The proof uses notable properties of the polynomials of binomial type. (Received September 20, 2015)

1116-VW-1651 **Noureen Khan*** (noureen.khan@unt.edu), 7400 University Hills Blvd., Dallas, TX 75241. *Obstacles in Implementation of a successful undergraduate research program.*

Recruiting students from underrepresented groups to pursue a career in mathematics continues to be a challenge. Early exposure to scientific research is often cited as a powerful means to attract research scholars with the research mentor being critical in facilitating the development of an individual's science identity and career; however, most mentors in the STEM fields have had little formal training in working with research mentees. We explore and identify the obstacles in implementing a successful research program focused on undergraduate student research in mathematics. (Received September 20, 2015)

1116-VW-1699 **Roman Wong*** (rwong@washjeff.edu), Mathematics Department, Washington & Jefferson College, 60 South Lincoln Street, Washington, PA 15301. *Connectivity of One Step Apart Integers.*

Inspired by the Fibonacci identity $f_{n-1}f_{n+1}+1=f_n^2$ for odd n, we define a relation $\sim$ on $\mathbb{Z}^+$ by $a\sim b$ if and only if $ab+1=k^2$ for some k. The relation results in an undirected infinite graph G with vertex set $\mathbb{Z}^+$ and an edge between a and b if $a\sim b$. We investigate the connectivity of G. By using Pell's equations and Bhaskara Lemma, we show that G has finite diameter and that every edge in G belongs to a 3-cycle and a 4-clique. We also find explicit formulas for any element in $N(a)$, the neighbor of a. (Received September 21, 2015)

1116-VW-1820 **Erin Denette*** (edenette@uri.edu) and **Araceli Bonifant** (bonifant@math.uri.edu). *On the Existence of a Semi-Conjugation Between Certain Combinatorially Obtained Minimal Cantor Sets.*

A Cantor set is a perfect, zero dimensional, compact metric space. Given a Cantor set X, a continuous map $f: X\to X$ is called a minimal Cantor set if every orbit of f is dense in X. In 2006, Gambaudo and Martens gave conditions under which it can be guaranteed that a minimal Cantor set can be obtained as the inverse limit of certain directed topological graphs. This talk will use the projection maps between each of these graphs in order to prove the existence of a semi-conjugation between two combinatorially obtained minimal Cantors sets that are related by a specific property. (Received September 21, 2015)

1116-VW-2039 **Mohamed Allali*** (allali@chapman.edu). *Partial Differential Equations and Digital Image Processing.*

Digital image processing is becoming a strong application area of modern mathematics. In this talk, I will show strong connections between partial differential equations and digital image processing through practical examples that can be incorporated into many mathematics courses. This approach makes the courses more visual and interesting for instructors and students. (Received September 21, 2015)

1116-VW-2041 **Karen McCready***, King's College, Mathematics Dept., 133 N. River St., Wilkes-Barre, PA 18711. *Role Reversal: Student Learning through Teaching.* Preliminary report.

There are many facets to a well rounded learning experience. Lecture, flipped classrooms, and group work can be effective uses of class time that help students to grasp new ideas. A potential learning method that could also be incorporated into the classroom is that of peer tutoring. In this talk we will consider how students can benefit from the opportunity to lead problem review sessions for small groups of their classmates. (Received September 21, 2015)

1116-VW-2263 **Tomas J McIntee*** (tomas.mcintee@gmail.com), 1120 East Main Street, Radford, VA 24141. *A Geometric Classification of Strategic Effects Resembling Duverger's Law.* Preliminary report.

A method of geometrically analyzing the vulnerability of elections to strategic manipulation is demonstrated and used to compare all possible positional voting systems, with and without majority runoff stages, for $n=3$ candidates. An informational response dynamic is exhibited, which shows an effect reminiscent of Duverger's Law for plurality elections, and also for antiplurality elections with a majority runoff stage. A corresponding opposite dynamic is found for antiplurality elections and plurality elections with majority runoff stages. Further results are given for $n \geq 3$ candidates qualitatively via inductive arguments. (Received September 22, 2015)

1116-VW-2509 **Yun Myung Oh*** (ohy@andrews.edu), Department of Mathematics, 4260 Administration Dr., Andrews University, Berrien Springs, MI 49104-0350. *Riemannian submersion and Lagrangian isometric immersion II.*

For a Riemannian submersion $\pi : M^n \to B^b$ with totally geodesic fibers, the invariant $\check{A}_\pi = \sum_{i=1}^{b} \sum_{s=b+1}^{n} ||A_{e_i} e_s||^2$ was introduced using the integrability tensor of the submersion. B. Y. Chen has provided the inequality on this invariant if the manifold M admits an isometric immersion into a Riemannian manifold $\tilde{M}^m$. In this talk, we will discuss on the recent work on this invariant if M admits a Lagrangian isometric immersion. (Received September 22, 2015)

1116-VW-2570 **Aimee M. Cloutier*** (aimee.cloutier@ttu.edu) and **Jerry F. Dwyer** (jerry.dwyer@ttu.edu). *Exploration of some dynamics of the iteration of the complex sine function.*

The complex sine function is iterated using Newton's method. The generated fractal images display vertical strips of width pi centered at the roots, n*pi. Further observation of the images reveals nontrivial dynamics about the boundaries of the basin of attraction of each root. The fractal properties at these boundaries, located at ((2n+1)*pi)/2, are displayed. The fixed points are classified as attracting or repelling. Some bounds are proven for the basins of attraction of the fixed points. Several symmetries are verified around the x and y axes as well as symmetry about the roots and fractal boundaries. These properties are compared to those obtained through iteration of other common trigonometric functions. (Received September 22, 2015)

1116-VW-2605 **Carl Olimb*** (carl.olimb@augie.edu), Augustana University, Sioux Falls, SD 57106. *Divisibility rules in different bases: an opportunity for discovery.*

When teaching preservice teachers it is common to use other bases as a pedagogical tool to strengthen their understanding of place value and operations. Also, divisibility rules are explained. In this talk we show results when combining these topics by having students search for divisibility rules in other bases. (Received September 22, 2015)

1116-VW-2610 **William Johnston** and **Amber Russell*** (acrusse3@butler.edu). *Introducing Undergraduates to Research Though a One-Week Mathematics Research Camp.* Preliminary report.

Mathematics Research Camp is an intensive summer eight-day mathematics research experience at Butler University open to its undergraduate majors. Students work one-on-one with research faculty mentors in an introduction to research. This summer marked the second annual camp, with quite strikingly strong results. Eight students participated, and each developed a poster to present at the Camp's capstone poster session. Though new results were not required or necessarily expected, nearly every student came away with a proof of a new theorem. This presentation outlines the Research Camp and details the features that seem critical to its success—features that could commonly be adapted to fit at any institution. (Received September 22, 2015)

1116-VW-2709 **Jason Samuels*** (jsamuels@bmcc.cuny.edu). *The Partial Differential: A New Operator in Multivariable Calculus.*

The partial derivative $\frac{\partial f}{\partial x}$, compared to the derivative $\frac{df}{dx}$, is troublesome. It likewise represents a rate of change. However, it is limited in that it cannot be separated like a fraction since ∂, ∂f and ∂x have no individual meaning. I will present a new differential operator on multivariable functions. It is consistent with all of the known properties and operations for derivatives and differentials, it admits new ones as well, and it solves the limitation above. The benefits for calculation and for instruction as well as extensions to differential geometry will be discussed. (Received September 22, 2015)

Pure and Applied Talks by Women Math Warriors Presented by EDGE (Enhancing Diversity in Graduate Education)

1116-Z1-332 **Laurel A Ohm*** (ohmxx039@umn.edu). *A mathematical model of broad-spectrum antibiotic treatment of leptospirosis: the risk of antibiotic resistance.*

Leptospirosis, a zoonotic infection affecting people globally, presents unique epidemiological challenges as disease propagation depends on local environmental conditions rather than direct human-to-human contact. *Leptospira* *interrogans* is spread via urine of infected animals and can survive for months without a host in aquatic environments. Outbreaks in Southeast Asia and Latin America are often combatted by widespread distribution of broad-spectrum antibiotics among residents in the vicinity of the outbreak. While leptospirosis itself has thus far not demonstrated resistance to antibiotics, the presence of other strains of virulent bacteria, especially MRSA, in the surrounding environment indicates that antibiotic resistance may threaten public health. To analyze the effects of mass, non-targeted antibiotic administration following a leptospirosis outbreak, we develop an ODE model of leptospirosis transmission coupled with the dynamics of antibiotic-resistant bacterial infections. Uncertainty and sensitivity analyses of model parameters highlight the prominent role environmental factors play in the persistence of leptospirosis and antibiotic-resistant infections, indicating that disease control efforts may need to focus on addressing unsanitary living conditions. (Received August 25, 2015)

1116-Z1-866 **Amy Veprauskas*** (aveprauskas@math.arizona.edu) and **J M Cushing**. *Evolutionary Dynamics of a Multi-trait Semelparous Model.*

We consider a multi-trait evolutionary (game theoretic) version of a two class (juvenile-adult) semelparous Leslie model. Unlike matrix models with primitive projection matrices, semelparous Leslie models have imprimitive projection matrices. Consequently, the direction of bifurcation does not solely determine the stability of a bifurcating continuum. When the net reproductive number R_0 increases through 1, the extinction equilibrium destabilizes resulting in the simultaneous bifurcation of both a continuum of positive equilibria and a continuum of synchronous 2-cycles. Only forward bifurcating branches can be stable and which of the two is stable depends on the intensity of between-class competitive interactions. We give criteria for the direction of bifurcation and for the stability or instability of each bifurcating branch in this evolutionary setting. These results generalize earlier results for single trait models. (Received September 14, 2015)

1116-Z1-1071 **Craig Guilbault**, **Christopher Mooney**, **Molly Moran*** (molly.moran@coloradocollege.edu) and **Carrie Tirel**. *Boundaries of Baumslag-Solitar Groups.*

Boundaries of CAT(0) groups and Hyperbolic groups have proven to be very useful and interesting objects to study. For this reason, Bestvina introduced the notion of a Z-structure on a group so that a wider class of groups could be studied by examining the group's boundary. One of the simplest examples of a group that is neither CAT(0) nor Hyperbolic is the Baumslag-Solitar group, $\mathrm{BS}(1,2)$. While Bestvina asserts that $\mathrm{BS}(1,2)$ admits a Z-structure, we will discuss how to construct Z-structures on all Baumslag-Solitar groups $\mathrm{BS}(m,n)$. (Received September 16, 2015)

1116-Z1-1151 **Shelby N Wilson*** (shelby.wilson@morehouse.edu), **Selenne Banuelos**, **Janet Best**, **Gemma Huguet**, **Alicia Prieto-Langarica** and **Pamela Pyzza**. *Temperature Effects on REM/non-REM Sleep Dynamics.*

Sleep is a behavioral state in which we spend nearly one third of our lives. While much effort has been put forth in understanding the nature of sleep, many aspects of this phenomenon are still not well understood. Several studies have been done on human patients that suggest that changes in ambient temperature may have important effects on sleep patterns. We present a mathematical model consisting of a system of non-linear ordinary differential equations that describes numerous features of the human sleep/wake cycle and aspects of REM/non-REM dynamics. The model simulates temperature changes detected by neurons in the POAH that, in turn, affect the REM/non-REM cycles during sleep through a state-dependent homeostatic process. This model enables us to better understand temperature and sleep relationships and support experimental findings. (Received September 17, 2015)

1116-Z1-1502 **Jamye Nichelle Curry*** (jcurry4@ggc.edu). *A Test for the Two-sample Problem using a Rank-based Approach.*

Rank-based formulations are investigated for the two-sample problem. Two nonparametric statistical procedures are proposed. One formulation is based on the average of between-group distances of ranks. The second formulation includes the difference between the average of between-group distances of ranks and the average of within-group distances of ranks. Each formulation is closely related to the two-sample Cramér-von Mises criterion. The proposed tests are strictly nonparametric as there is no assumption made on the distribution of the populations from which the samples are drawn. The bootstrap and permutation procedures are used to estimate consistently the null distribution. A numerical study is performed to compare power performance of the rank formulations with other commonly used nonparametric and parametric procedures. An application of the proposed test is presented using microarray data for identifying differentially expressed genes across two samples in replicated microarray experiments obtained under two experimental states. (Received September 20, 2015)

1116-Z1-2549 **Karamatou A Yacoubou Djima***, kyacoub1@swarthmore.edu, **Wojciech Czaja**, wojtek@math.umd.edu, and **Lucia D Simonelli**, lsimonel@umd.edu. *Analysis of Retinal Images Via Dimension Reduction on Graphs.*

First, we present a novel method for automated anomaly detection in auto-fluorescent retinal images provided by the National Institute of Health (NIH). This work is motivated by the need for new tools to improve the capability of diagnosing macular degeneration in its early stages, track the progression over time, and test the effectiveness of new treatment methods. The method that we propose is a combination of a nonlinear dimensionality reduction on graphs, Laplacian Eigenmaps, along with a new classification method, Vectorized Matched Filtering. Comparison to other schemes shows that this novel method yields the highest rate of accurate anomaly detection. Next, we describe a set of Harmonic Analysis tools, which comprises Laplacian Eigenmaps, so-called kernel-based techniques on graphs. Finally and as an example, we introduce a new system in this family. (Received September 22, 2015)

1116-Z1-2747 **Anisah Nabilah Nu'Man*** (`anisah.numan@trincoll.edu`), 534 Prospect Ave., Hartford, CT 06105. *Intrinsic Tame Filling Functions.* Preliminary report.

Let G be a group with a finite presentation $\mathcal{P} = \langle A|R \rangle$ such that A is inverse- closed. Let $f : \mathbb{N}[\frac{1}{4}] \to \mathbb{N}[\frac{1}{4}]$ be a nondecreasing function. Filling invariants are quasi-isometry invariants for groups with finite presentations defined using properties of van Kampen diagrams. Loosely, f is an intrinsic tame filling function for $(G, \mathcal{P})$ if for every word w over A that represents the identity element in G, there exists a van Kampen diagram Δ for w over $\mathcal{P}$ and a continuous choice of paths from the basepoint $*$ of Δ to the boundary of Δ such that the paths are steadily moving outward as measured by f. Tame filling functions are a recent pair of asymptotic invariants that are a strengthening of the intrinsic diameter (i.e., isodiametric) function and the extrinsic diameter function. In contrast to diameter functions, it is unknown if every pair $(G, \mathcal{P})$ has a finite-valued tame filling functions. In this talk I show that two group constructions, namely graph products and certain free products with amalgamation, preserve finite-valued intrinsic tame filling functions. (Received September 22, 2015)

2010 MATHEMATICS SUBJECT CLASSIFICATION

Compiled in the Editorial Offices of MATHEMATICAL REVIEWS and ZENTRALBLATT MATH

00 General
01 History and biography
03 Mathematical logic and foundations
05 Combinatorics
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08 General algebraic systems
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15 Linear and multilinear algebra; matrix theory
16 Associative rings and algebras
17 Nonassociative rings and algebras
18 Category theory; homological algebra
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20 Group theory and generalizations
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43 Abstract harmonic analysis
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60 Probability theory and stochastic processes
62 Statistics
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68 Computer science
70 Mechanics of particles and systems
74 Mechanics of deformable solids
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78 Optics, electromagnetic theory
80 Classical thermodynamics, heat transfer
81 Quantum theory
82 Statistical mechanics, structure of matter
83 Relativity and gravitational theory
85 Astronomy and astrophysics
86 Geophysics
90 Operations research, mathematical programming
91 Game theory, economics, social and behavioral sciences
92 Biology and other natural sciences
93 Systems theory; control
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