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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
1146	March 15–17, 2019	Auburn, AL	January 29	Vol 40, No. 2
1147	March 22–24, 2019	Honolulu, HI	January 29	Vol 40, No. 2
1148	April 13–14, 2019	Hartford, CT	February 5	Vol 40, No. 2
1149	June 10–13, 2019	Quy Nhon City, Vietnam	TBA	NONE
1150	September 14–15, 2019	Madison, WI	July 16	Vol 40, No. 3
1151	October 12–13, 2019	Binghamton, NY	August 20	Vol 40, No. 3
1152	November 2–3, 2019	Gainesville, FL	September 10	Vol 40, No. 4
1153	November 9–10, 2019	Riverside, CA	September 3	Vol 40, No. 4
1154	January 15–18, 2020	Denver, CO	TBA	TBA

BALTIMORE, MD, January 16–19, 2019

Abstracts of the 1145th Meeting.

00 ► General

1145-00-2 **Steven W Davis*** (sdcomet900@att.net), 864 South Wildflower Lane, Anaheim, CA 92808. *Competitive Math Problems made Simple.* Preliminary report.

When faced with competitive math problems we usually attack it with all our mathematical knowledge and skill and hammer it down solid, but with a little clever insight some problems which look hard are easily solved using simple techniques. We will look at a few of these competitive math problems and their amazing simple solutions. (Received March 08, 2018)

1145-00-9 **Peter Oszvath***, Princeton University, Princeton, NJ 08544. *From knots to symplectic geometry and algebra.*

Heegaard Floer homology is an invariant for three-manifolds which is inspired by gauge theory and defined using the theory of pseudo-holomorphic curves. Knot Floer homology is a variant of this construction, giving an invariant for knots in three-space. It has the form of a bigraded vector space, encoding interesting topological information about the knot. After explaining the basic form of knot Floer homology, and giving some of its applications, I will present a recent algebraic description of knot Floer homology, discovered in joint work with Zoltan Szabo, building on earlier joint work with Robert Lipshitz and Dylan Thurston. (Received May 31, 2018)

1145-00-10 **Lior Pachter***, California Institute of Technology, Pasadena, CA. *A Mathematical Introduction to the Molecular Biology of the Cell.*

Since the beginning of molecular biology in the 1930s, there has been great interest in developing mathematical models of the workings of the cell. During the past 50 years the molecular components of the cell have increasingly come into view, and during the past decade high-throughput sequencing based technologies have provided the opportunity to measure cell states in unprecedented resolution. Together, these developments have resulted in increasingly accurate mathematical models of the molecular biology of the cell. These promise to not only enhance our understanding of gene regulation, but also to allow for the prediction of the effect of perturbations in disease states. The current challenges for mathematics are exciting, and I will review the necessary background needed to engage in the field. (Received May 31, 2018)

1145-00-39 **Sergey Goncharov*** (s.s.goncharov@math.nsc.ru), Novosibirsk State University. *Some questions and results for classical algebraic structures.*

One of important directions in the study of computable structures deals with the problems related to autostability of algebraic structures and autostability relative to decidable presentations [1]. We will present results of this direction which are obtained in general computable model theory [2], and results on classical algebraic classes of structures: in particular, abelian groups, fields, linear orders, etc. Furthermore, some related problems [3, 4] will be discussed.

[1] Yu. L. Ershov and S. S. Goncharov, Constructive models, Kluwer Academic/Plenum Publishers, New York, 2000.

[2] S. S. Goncharov, N. A. Bazhenov, and M. I. Marchuk, The index set of Boolean algebras autostable relative to strong constructivizations, Siberian Mathematical Journal, vol. 56 (2015), no. 3, pp. 393–404.

[3] M. V. Korovina and O. V. Kudinov, Spectrum of the field of computable real numbers, Algebra and Logic, vol. 55 (2016), no. 6, pp. 485–500.

[4] N. Bazhenov, Prime model with no degree of autostability relative to strong constructivizations, Evolving Computability (A. Beckmann, V. Mitrana, and M. Soskova, editors), Lecture Notes in Computer Science, vol. 9136, Springer, Cham, 2015, pp. 117–126 (Received June 29, 2018)

1145-00-361 **Rachid Ait Maalem Lahcen***, 4000 Central Florida Blvd, MSB 221, Orlando, FL 32816, and **Ram Mohapatra** (ram.mohapatra@ucf.edu), 4000 Central Florida Blvd, MSB 412, Orlando, FL 3216. *UAVs Mesh Network Survivability Against Cyber Attacks: A Simulation Study.* Preliminary report.

In the absence of manual control and unmanned aerial vehicles (UAVs) dependence on communication links to do their duties, the attacker can hack the UAVs sensitive sensory data and feed them malicious information or jam their communication links. Consequently, a UAV node can fail and/or cause other nodes to fail due to inter-connectivity. Barabsi gave the typical example of 2003 blackout that is a cascading failure. The blackout illustrated the vulnerability due to inter-connectivity. Hence, there are several challenges that need to be resolved to improve survivability of multi-UAV flying ad hoc networks (FANET) including the structure of the network, the connectivity, and the management algorithm. In this presentation, we explore the cascading effect over different types of network structures to measure survivability based on loss of nodes and links. (Received September 04, 2018)

1145-00-383 **Rodrigo Banuelos***, Purdue University, West Lafayette, IN. *On the discrete Hilbert transform.*

The discrete Hilbert transform, acting on the space of (doubly infinite) sequences, was introduced by David Hilbert at the beginning of the 20th century. It is the discrete analogue of the continuous Hilbert transform (conjugate function) acting on functions on the real line. In 1925, M. Riesz proved the L^p boundedness, for p larger than one and finite, of the continuous version, thereby solving a problem of considerable interest at the time. From this he deduced the same result for the discrete version. Shortly thereafter, E.C. Titchmarsh turned this around. He gave a direct proof of the boundedness of the discrete Hilbert transform on ℓ^p and from it deduced the same for the continuous version. Further, he showed that the discrete and continuous versions have the same p-norms. Unfortunately, the following year Titchmarsh pointed out that his argument for equality of the norms was incorrect. The problem of equality has been a long-standing conjecture since. In this lecture we describe—taking a historical point of view and avoiding technicalities as much as possible—some tools from probability theory that lead to a proof of this conjecture. The talk is based on joint work with Mateusz Kwasnicki of Wroclaw University, Poland. (Received September 04, 2018)

1145-00-456 **Mason Remington*** (mason.remington@my.simpson.edu), **Levi Lefebure** and **Graham Brooks**. *Counting Sheep: Why Sleep Apnea is a Real Concern for Individuals with Down Syndrome.* Preliminary report.

Down syndrome Disintegrative Disorder (DSDD) is newly emerging in clinical literature. Most of the studies only focus on the appearance of this disorder, and not the etiology. Our objective is to explore the relationship between sleep apnea and DSDD. A survey monkey survey was emailed out to patients at Massachusetts General Hospital's Down syndrome (DS) clinic and posted on Facebook. The survey gathered mostly qualitative data with yes/no, multiple choice, and open-ended questions. Of the 191 respondents (27%), 115 were aged 10-35. These are the ages where DSDD is commonly diagnosed. For these two groups, we saw a statistically significant difference in the number of hospitalizations, whether they have regressed, and their mean age of regression. There is a relationship between sleep apnea and DSDD. (Received September 06, 2018)

1145-00-482 **Cheng Cheng***, 4225 Larchmont RD, Apt 935, Durham, NC 27707, and **Qiyu Sun**. *Phaseless sampling and reconstruction of real-valued FRI signals.*

In this talk, we consider the stable reconstruction of real-valued signals with finite rate of innovations (FRI), up to a sign, from their magnitude measurements on the whole domain or their phaseless samples on a discrete subset. FRI signals appear in many engineering applications such as magnetic resonance spectrum, ultra wide-band communication and electrocardiogram. For an FRI signal, we introduce an undirected graph to describe its topological structure. We establish the equivalence between the graph connectivity and phase retrievability of FRI signals, and we apply the graph connected component decomposition to find all FRI signals that have the same magnitude measurements as the original FRI signal has. We also propose a stable algorithm with linear complexity to reconstruct FRI signals from their phaseless samples on the above phaseless sampling set. (Received September 07, 2018)

1145-00-787 **Alberto Ravagnani***, alberto.ravagnani@ucd.ie, and **Eimear Byrne**. *Asymptotic Enumeration and Coding Theory.*

We introduce the concept of a partition-balanced family of codes, and show how these families can be used to obtain precise asymptotic estimates for the number of codes that have a prescribed property (in various metrics).

As an application of our results, we prove the sparsity or density of codes that are extremal with respect to minimum distance, covering radius, and the related notion of maximality. In particular, we show that matrix MRD codes are not dense in the family of codes of a given dimension over GF(q). This is in sharp contrast with the behaviour of MDS codes endowed with the Hamming metric and vector rank-metric codes. (Received September 14, 2018)

1145-00-1167 **Negar Orangi-Fard*** (negar@math.ksu.edu). *Connections between multicommodity maximum flow and modulus.* Preliminary report.

Maximum flow problems involve finding a feasible flow through a single-source, single-sink flow network that has maximum value. Multicommodity maximum flow problems are a generalization of this that involve finding an optimal flow between multiple sink and source pairs. In the case of a single source and sink, the dual optimization problem can be rewritten as a more general type of problem, called a p-modulus problem.

Utilizing this connection, we will show that the maximum multicommodity flow problem also has a p-modulus interpretation, which gives insight into its solution. Moreover, by modifying this modulus problem, we introduce a family of generalizations to the multicommodity maximum flow problem, including one that is closely related to electrical current flow. (Received September 24, 2018)

1145-00-1262 **Jared E Hoppis*** (jehoppis@gmail.com), 1420 Beechwood Terrace, 19, Manhattan, KS 66502. *Modulus on Networks and Metric Spaces, and the Essential Metric.*

The study of Modulus originated in the plane, but there has been much recent work in the setting of networks. We will introduce the theory in this setting with some results on how Modulus relates to classical quantities. We will then introduce the theory in the context of general metric spaces and show how one of the relationships from the network setting holds in the metric space setting. We will also show how Modulus can be used to define a new metric that recovers a metric due to De Cecco and Palmieri. (Received September 20, 2018)

1145-00-1287 **Kapila G Kottegoda*** (kotteg1@ksu.edu). *Spanning tree modulus for secure broadcast games.*

The *p-modulus* is a general framework for quantifying the richness of a family of objects on a graph. When applied to the family of spanning trees, *p-modulus* has an interesting probabilistic interpretation. In particular, the 2-*modulus* problem in this case has been shown to be equivalent to the problem of finding a probability distribution on spanning trees that utilizes the edges of the graph as evenly as possible. For this reason, there is a strong connection between 2-*modulus* of the family of spanning trees and the edge-disjointness of this family. We use this fact to produce a game-theoretic interpretation of modulus and apply modulus to the problem of minimizing the number of broadcast messages intercepted by an eavesdropper listening on an unknown link. (Received September 20, 2018)

1145-00-1291 **Sean Lawton*** (slawton3@gmu.edu) and **Anton Lukyanenko** (alukyane@gmu.edu). *Geometry Labs United: Welcome and Overview.*

The purpose of a Geometry Lab is to foster a community of mathematics researchers involving undergraduate students, graduate students, and faculty—and to recruit future researchers through public engagement. Geometry Labs United brings together individual labs from universities around the United States to share institutional experience and resources, and to encourage the development of new labs at other universities.

At this special session, we will begin by giving an overview of the Geometry Labs United network and the general structure of a geometry lab. The rest of the day includes expository talks by representatives for each of the ten labs. The day culminates in a panel session on starting and running a geometry lab.

We welcome everyone interested in undergraduate research and outreach to join our session, and encourage them to take a look at the October 2018 AMS Notices article "Geometry Labs United: An Invitation". (Received September 20, 2018)

1145-00-1292 **Sean Lawton** (slawton3@gmu.edu) and **Anton Lukyanenko*** (alukyane@gmu.edu). *Panel on starting and running a Geometry Lab.*

The purpose of a Geometry Lab is to foster a community of mathematics researchers involving undergraduate students, graduate students, and faculty—and to recruit future researchers through public engagement. Geometry Labs United brings together individual labs from universities around the United States to share institutional experience and resources, and to encourage the development of new labs at other universities.

This panel will be the culmination of a day of talks by representatives for each of the ten labs. Panelists, to be announced, will discuss their experience starting and running a Geometry Lab.

We welcome everyone interested in undergraduate research and outreach to join our session, and encourage them to take a look at the October 2018 AMS Notices article "Geometry Labs United: An Invitation". (Received September 20, 2018)

1145-00-1296 **Sean Lawton** (slawton3@gmu.edu), **Jack Love*** (jlove6@gmu.edu) and **Anton Lukyanenko** (alukyane@gmu.edu). *Mason Experimental Geometry Lab: Overview and Community Engagement.*

In this talk, we will provide a brief overview of the structure of the Mason Experimental Geometry Lab, including research, visualization, and community engagement.

We will focus the talk on our outreach program, which has grown in the past 4 years to engage over 1,000 students per year in small-group activities at Northern Virginia schools, public libraries, and beyond. We will discuss how we develop the network that brings us to these venues, as well as how we develop age-specific activities that foster excitement in mathematics.

We will conclude with future directions for the growth of the lab and its outreach program. (Received September 20, 2018)

1145-00-1335 **Lesley M McGee*** (lmcgee@wpi.edu). *Recognizing and Responding to STEM Students in Distress.*

This session will characterize certain mental health reactions to stress that can be problematic for students and teachers in the STEM field. The talk will outline this issue, what to do when concerned about mental health distress, review resources available, and begin the conversation about the human aspect of mathematics education. (Received September 21, 2018)

1145-00-1359 **Edgar A. Bering IV*** (edgar.bering@temple.edu), 1805 N Broad Street, Department of Mathematics, Wachman Hall, Philadelphia, PA 19122. *3D Printing for outreach at the UIC Mathematical Computing Laboratory.* Preliminary report.

The Mathematical Computing Laboratory (MCL) at the University of Illinois at Chicago is an undergraduate research lab that hosts semester-long credit-bearing projects for teams of 2-4 students. These projects often focus on computational experiments and mathematical visualization related to the research of faculty members in the Department of Mathematics, Statistics, and Computer Science. I will briefly summarize the history and organization of the lab (since its founding in summer 2015). Then I will focus the role of 3D printing in recruiting workshops and research projects hosted by MCL over the last few years. The talk will conclude by discussing the long term impact of the lab's 3D printing activity. (Received September 21, 2018)

1145-00-1360 **Abdul-Aziz Yakubu*** (ayakubu@howard.edu), Howard University, Department of Mathematics, 2441 6th Street NW, Washington, DC. *Mathematics Research at Howard University: Pure and Applied Mathematics.* Preliminary report.

Howard University's Department of Mathematics was established in 1867. Currently, the department's approximately 26 tenured and tenure-track faculty members represent a broad spectrum of current mathematical research in both pure and applied mathematics. In this talk, I will highlight some of these research areas. The department is a top producer of African-Americans who earn Bachelor of Science, Master of Science, and Doctor of Philosophy degrees in Mathematics. (Received September 21, 2018)

1145-00-1577 **Ben Riley*** (bkri223@g.uky.edu) and **Christopher Manon** (christopher.manon@uky.edu). *An Overview of the University of Kentucky Math Lab.*

The University of Kentucky Math Lab is relatively new, having been active for the last year. In that time, we have established four research projects under faculty guidance. These projects include topics in tropical geometry, combinatorics, formal group laws, and persistent homology. In addition to these research projects, we also have groups working on mathematical visualization, including 3D printing and more tactile projects such as quilting and crochet. I will present an short overview of each of these projects with an emphasis on our visualization groups (Received September 23, 2018)

1145-00-1726 **Caleb J Ashley*** (cjashley@umich.edu), Department of Mathematics, 2074 East Hall, 530 Church Street, Ann Arbor, MI 48109. *A Capstone Companion to Mathematics.*

A Capstone Companion to Mathematics describes the theme of our talk; we share, via personal testimony, anecdotes and perspectives which span three generations of mathematics at Howard University. Special emphasis will be given to mentoring, mathematical community, developing as a young researcher, and current mathematical research. (Received September 24, 2018)

1145-00-1797 **Lillian B. Pierce***, Duke University, Department of Mathematics, Durham, NC 27708. *On torsion subgroups in class groups of number fields.*

Imagine an hourglass: within one bulb, we picture analytic number theory; within the other, algebraic number theory. Pincered in between is the class number. As we imagine this hourglass, we visualize information trickling back and forth between the two fields, passing via the class number. And yet the constriction of the pinched neck suggests a certain inaccessibility...

Each number field has an associated class number, which measures the cardinality of the field's class group—a finite abelian group that encodes information about how arithmetic behaves within the field. It is natural to think of number fields in families—for example, all number fields of a fixed degree. Correspondingly, we can ask about the distribution of the class number, or of the class group, as the field varies over a family. Tantalizingly precise conjectures have been formulated, but remain out of reach.

We will describe a diverse array of recent work, with a particular focus on counting elements of a fixed order within the class group, that is, bounding the size of torsion subgroups. True to the hourglass shape we first envisioned, it turns out that this question is closely connected to deep open questions on both sides, including counting number fields, and the Generalized Riemann Hypothesis. (Received September 24, 2018)

1145-00-1912 **David Damiano**, **Sarah McGuire*** (slmcgu19@g.holycross.edu) and **Richard Schmidt**. *Behavioral Synchrony and Functional EEG Networks.* Preliminary report.

People engaged in social interactions exhibit natural, unintentional coordination of their body movements. Although intense efforts have been made to localize behaviors in human brain activity, little is known about the functional networks that underlie human social interaction. We are interested in how social behavioral synchronization corresponds to functional networks in the brain. To this end, we analyzed electroencephalograph (EEG) activity from an experiment involving participant pairs swinging pendulums in different interpersonal coordination conditions. Using methods of computational topology and network theory, we are able to identify functional networks based on pair-wise coordination between electrodes. Initial results indicate the existence of dynamic network features across different coordination conditions and frequency bands. In future work, we will apply these novel network analysis techniques to evaluate the social brain networks in adolescents with Autism Spectrum Disorder (ASD), as one of the suggested tendencies of people with ASD is social disconnection. (Received September 24, 2018)

1145-00-1949 **Rachel V Barber*** (rvb41@msstate.edu) and **Edward Dobson** (ted.dobson@upr.si). *When Graphs are Wreath Products.* Preliminary report.

We provide necessary and sufficient conditions needed to determine when a Cayley Graph of a group G is isomorphic to a nontrivial wreath product of two vertex-transitive digraphs of smaller order. We consider the G-invariant partition formed by the left cosets of a subgroup $H < G$, and conditions on the connection set, S. $\mathrm{Cay}(G, S)$ is isomorphic to the wreath product of a coset digraph and a Cayley digraph. We provide preliminary results of our research into the conditions needed to determine when a coset digraph is isomorphic to a nontrivial wreath product. (Received September 24, 2018)

1145-00-2019 **Min Wu**, **Huaming Yan**, **Daniel Ramirez-Guerrero*** (ramired3@uci.edu) and **John Lowengrub**. *Mechanical feedback and stress relaxation in tumor spheroid growth.* Preliminary report.

In this work, the dynamics of tumor growth is simulated using a continuum model of tissue elasticity in an Eulerian frame. The model incorporates nonlinear elastic stresses and cell substrates to regulate cell proliferation and death. We also consider tissue remodeling, a result of structural and adhesive molecules, and recover linear elastic models when the relaxation rate is large. The model investigates the relation between stress and growth in tumor spheroids. Parameters are extrapolated from tumor growth experiments. Results from this model are in close agreement with experiment in simulating mechanotransduction and feedback regulation. Stress relaxation is quantified to predict spatial distributions of stress and net proliferation. We find that mechanotransduction and feedback regulation result in more stable proliferation states than those without feedback. We also extend the model by formulating tissue elasticity without assuming incompressibility. (Received September 24, 2018)

1145-00-2035 **Marcia F Wiedefeld*** (mwiedefeld@loyola.edu), Disability Support Services, Loyola University Maryland, 4501 N. Charles Street, Baltimore, MD 21210. *Teaching students with ADHD, learning disabilities and autism: Commonly recommended accommodations and why they are recommended.*

Professionals in a college's Disability Support Services office often notify professors about students' accommodations without an explanation other than it is a legal requirement. DSS professionals cannot release confidential information to faculty, so instructors are usually unaware about the reason a particular accommodations is recommended. This brief presentation will highlight some common accommodations provided for students with disabilities and explain some rationales for the accommodations. Additionally, the speaker will provide information about supports and teaching strategies for students with these disabilities. (Received September 25, 2018)

1145-00-2064 **Arindam Roy*** (arindam.roy@uncc.edu). *Rice Geometry Lab.*

Rice Geometry Lab (RGL) was founded in the spring of 2017. In this talk, I will share some of my experience on RGL. I will discuss the process of recruiting and motivating, both undergraduate and graduate, students. Some projects and their outcomes will be discussed as well. (Received September 24, 2018)

1145-00-2091 **Sarah Elizabeth Lubow*** (selubow@my.loyno.edu), 7214 St. Charles Ave., Box 521, New Orleans, LA 70118, and **Carlie J. Triplitt**, ctri8247@usao.edu. *Vertex-Minimal Planar Graphs with Prescribed Automorphism Groups.* Preliminary report.

In 1939, Frucht proved that for any finite group G, there exists a graph Γ such that the automorphism group of Γ is isomorphic to G. Naturally, this result gave rise to numerous extremal problems in graph theory. For instance, vertex-minimal graphs with a prescribed automorphism group are the subject of prior research by numerous authors. In this talk, we will discuss our proof of a conjecture made in 1980 by Marušič on the order of vertex-minimal planar graphs with cyclic symmetry of even order. Our proof completes a theorem giving the order of all vertex-minimal planar graphs with cyclic automorphism groups. We will also discuss further our proof regarding the order of vertex-minimal planar graphs with dihedral symmetry. (Received September 24, 2018)

1145-00-2242 **Mariano Tepper*** (marianotepper@gmail.com), **Victor Minden** and **Anirvan M Sengupta**. *From clusters to manifolds with semidefinite and completely-positive approximations.* Preliminary report.

In solving hard computational problems, convex relaxations often play an important role as they come with a guarantee of optimality. Here, we focus on a popular semidefinite relaxation of K-means clustering. In previous work, we reported an unexpected finding: when data contains (multiple) manifolds, the solution captures such geometrical structures.

Ideally, completely positive (CP) formulations provide a tighter relaxation to the original problem than semidefinite programs (SDP). Whereas SDPs are relatively easy to solve, CP programs are very hard, hindering their applicability. An important empirical question then becomes: are these semidefinite output matrices close to be CP? We answer this question in the positive, showing that they are indeed closely approximated by a subfamily of CP matrices, the RBF kernel matrix, which can be easily obtained with a convex program. Remarkably, these special CP matrices give rise to the natural low-dimensional embeddings of the input manifolds.

For each sub-problem, we present new, convex and efficient, algorithms based on the conditional gradient method. Our results render this SDP-CP hybrid algorithm a versatile, understandable, and powerful tool for manifold learning. (Received September 25, 2018)

1145-00-2303 **Hideo Nagahashi*** (hnagahashi@triton.uog.edu), Division of Mathematics and Computer Sciences, College of Natural and Applied Sciences, University of Guam, Mangilao, GU 96923. *Magic Card Tricks on Hamming Codes over Finite Fields.*

Magic tricks based on binary Hamming codes are well known. We generalize binary tricks to present magic card tricks based on Hamming codes over finite fields of 3, 4 and 5 elements. (Received September 25, 2018)

1145-00-2341 **Alan S Perelson*** (asp@lanl.gov), Theoretical Division, MS-K710, Los Alamos National Laboratory, Los Alamos, NM 87545. *Immunology for Mathematicians.*

The immune system is a complex distributed system of interacting cells and molecules that learns, exhibits memory and most importantly protects us from infectious disease. While we are still uncovering how the immune system works, I will show through a variety of examples that it provides a fertile ground for interesting mathematical problems, from the understanding of how the immune system can recognize an almost limitless number of pathogens including some never seen before in all of evolutionary history, to the design of computer immune systems to protect against computer viruses, to the choice of next season's flu vaccine. (Received September 25, 2018)

1145-00-2481 **Ruth Luo*** (ruthluo2@illinois.edu), 273 Altgeld Hall, 1409 W Green St, Urbana, IL 61801, and **Zoltan Furedi** and **Alexandr Kostochka**. *Generalized Turán problems for graphs and hypergraphs.*

We will talk about a generalization of the Turán problem for hypergraphs: given a graph F, what is the maximum number of hyperedges an r-uniform n-vertex Berge F-free hypergraph can have? In particular, we will discuss tools used to reduce the hypergraph problem to problems for graphs. Finally, I will present some recent results for graphs without long Berge cycles. This is joint work with (different subsets of) Zoltan Furedi and Alexandr Kostochka. (Received September 25, 2018)

1145-00-2483 **Xiaochuan Tian*** (xtian@math.utexas.edu). *Numerical mathematics for peridynamics and nonlocal models.*

Nonlocal continuum models are in general integral-differential equations in place of the conventional partial differential equations. While nonlocal models show their effectiveness in modeling a number of anomalous and singular processes in physics and material sciences, for example, the peridynamics model of fracture mechanics, they also come with increased difficulty in numerical analysis with nonlocality involved. We present in this talk numerical analysis for nonlocal models characterized by a horizon parameter which measures the range of nonlocal interactions. Considering their close connections to classical local PDE models in the limit when the horizon parameter shrinks to zero and to global fractional PDEs in the limit when the horizon parameter tends to infinity, we present numerical schemes that are robust under the changes of the horizon parameter. Those schemes are effective to deal with multiscale models where different scales of nonlocality are presented. (Received September 25, 2018)

1145-00-2547 **Daniel A Spielman*** (daniel.spielman@yale.edu), 17 Hillhouse Ave., room 340, Yale University, New Haven, CT 06520. *Miracles of Algebraic Graph Theory.*

I will never forget the feeling of awe I experienced as a student when I first learned that important properties of graphs are revealed by the eigenvalues and eigenvectors of their associated matrices. This talk should convey some of that feeling, but also provide some understanding and intuition.

We begin by thinking of graphs as networks of springs and by using Laplacians matrices to model them. Hall (1970) and Tutte (1963) showed that eigenvectors of and linear equations in the Laplacian can be used to obtain nice pictures of many graphs. A nice picture must encode important properties.

More intuition comes from considering the matrices that model random walks on graphs. Cheeger's inequality (1970) for graphs relates eigenvalues of the walk matrix to the conductance of a graph. The conductance of a graph measures how easily it can be partitioned, and is the foundation of some of the most important ways of discovering graph structure.

Babai, Grigoryev, and Mount (1982) showed how to efficiently use a graph's eigenvectors to determine whether or not it is isomorphic to another graph, provided that no eigenspace has large dimension.

We will survey these results, explain some fascinating proof techniques used to prove them, and describe some advances in this area. (Received September 25, 2018)

1145-00-2550 **Sarah Koch***, Department of Mathematics, University of Michigan, 530 Church Street, East Hall, Ann Arbor, MI 48109. *What is the shape of a rational map?*

One aspect of complex dynamical systems concerns the study of iterating rational maps on the Riemann sphere. A wealth of complicated and deep behavior can emerge when a rational map is iterated; this behavior is governed by the orbits of the critical points of the map under iteration. A rational map is said to be *postcritically finite* if every critical point eventually maps into a periodic cycle. Postcritically finite maps are particularly nice to study and are of central importance in complex dynamics. Loosely speaking, in the space of all rational maps, those that are postcritically finite play a role akin to the rational numbers in the reals. In this talk, we explore potential answers to the question in the title that come from complex dynamics, focusing on postcritically finite rational maps.

Material in this talk is based on joint work with: X. Buff and A. Epstein, and with L. DeMarco and C. McMullen. (Received September 25, 2018)

1145-00-2569 **Jordan Marie Spencer***, Department of Mathematics, Brigham Young University, Provo, UT 84602, and **Konnor J Petersen**, **Jane Cox** and **Tyler Jarvis**. *Using Survey Data and Mathematical Modeling to Prioritize Water Interventions in Developing Countries.*

We describe a method for combining the World Health Organization's cost-effectiveness analysis with country wide survey data in order to construct an ordered ranking of the areas within a given country which have the highest need for a more reliable water source, it also includes the optimal method of water intervention. We also address a key problem in the charitable water sector: while survey data is available, due to privacy issues, much of the geographical and spatial data is lost or confounded. This disconnects the information from the locations in which they were found, making the data largely unusable. To overcome this, we propose using a combination of Voronoi modelling and gamma distributions to estimate an accurate representation of the data, allowing charities to overcome the lost information and increase their ability to use the available data. This method has been tested on the countries of Namibia and Madagascar and should be applicable to many more. (Received September 25, 2018)

1145-00-2757 **Edgar E. Robles** (edgar.roblesarias@ucr.ac.cr), **Ching Pui Wan**, **Fatima Zaidouni*** (fzaidoun@u.rochester.edu), **Joanne Beckford** and **Aliki Mavromoustaki**. *Threshold optimization in multiple binary classifiers for extreme rare events using predicted positive data.*

Classification on imbalanced datasets is a challenging problem where a high rate of correct detection is required in the minority class. We analyze the output of binary classification models used by Google, where the inputs are documents categorized as either predicted positive or negative against a certain threshold. In rare-event problems, positives have a prevalence of around 0.1% and it is expensive to estimate all documents. Therefore, the problem is reformulated using the correct labels [true positive (TP) or false positive (FP)] on a sample of the predicted positives, as determined by human raters. It is important to pick an operating point (OP) on the TP/FP fitted curve whose position is adjusted to return the cost for one additional TP document in terms of the number of FP. We propose two solutions to select an optimal OP by maximizing the area under the curve (AUC): a graph-based and an analytic approach. The graph-based approach constructs a graph to select an optimal path in the threshold space that is then converted to a curve in the TP/FP space. The analytic approach estimates the AUC by minimizing a cost function. Our approaches improve over existing solutions by relating the TP/FP space to the threshold space and offer a business interpretation to the OP. (Received September 25, 2018)

1145-00-2826 **Catherine Ross*** (ross321@live.missouristate.edu). *Twisted Knots of Color.* Preliminary report.

The colorfulness of Knot Theory is, in fact, literal. Inspired by Perko's Theorm, which infers that a knot is $S_3 - colorable \iff S_4 - colorable$, more relationships of coloring knots with groups arise. When G is a group, it turns out $G - colorability$ in the class of Twist Knots has some desirable properties. These properties may also be generalizable within additional classes of alternating knots. (Received September 25, 2018)

1145-00-2946 **Amrita Acharyya** (amrita.acharyya@utoledo.edu), Toledo, OH, **Jon M Corson** (jcorson@ua.edu), Tuscaloosa, AL , and **Bikash C Das*** (bikash.das@ung.edu), Oakwood, GA. *Varieties of profinite graphs.*

We consider pro-C graphs for certain categories of finite graphs which we call pseudovarieties. After exploring some of the general theory, we specialize to a particular pseudovariety, denoted by E, that arises naturally in constructing end point compactifications of connected abstract graphs. Pro-E graphs and their fundamental profinite groups are shown to have structure analogous to abstract graphs in some ways. (Received September 25, 2018)

1145-00-3001 **Suzanne L Weekes*** (sweekes@wpi.edu), **Ron Buckmire** (ron@oxy.edu) and **Rachel Levy** (rlevy@maa.org). *Discussion.*

In this period, the audience is invited to engage in a discussion with the speakers and organizers on the topics presented, or on other issues in the minisymposium theme of human factors in mathematics education. (Received September 26, 2018)

1145-00-3002 **Renee Brady*** (renee.brady@moffitt.org), **Tian Zhang**, **Andrew Z Wang**, **John D. Nagy** and **Heiko Enderling**. *Optimizing docetaxel scheduling to delay progression in metastatic prostate cancer patients receiving hormone therapy.*

Continuous androgen deprivation therapy (ADT) has been the standard of care for patients with advanced prostate cancer since the 1940s. Treating concurrently with docetaxel chemotherapy has shown to significantly improve median overall survival from 71 months with ADT alone to 81 months with concurrent treatment ($p=0.006$) (PMID: 26719232). We developed a mathematical model of prostate cancer stem and non-stem cell dynamics, serum prostate specific antigen levels and docetaxel during concurrent treatment. We generate highly accurate fits to the longitudinal data of 100 patients receiving ADT treatment with docetaxel either given at the initiation of ADT treatment (50 patients, 6 cycles) or after the development of castration resistant prostate cancer (50 patients, 10 cycles) ($R2 = 0.79$). As androgen-independent prostate cancer stem cells are sensitive to docetaxel, simulations show that early administration of chemotherapy results in sufficient reduction of the prostate cancer stem cell population. In contrast, late administration is unable to efficiently combat the large stem cell population that has developed during androgen deprivation, thereby resulting in resistance earlier. Thus, it is optimal to administer docetaxel at the onset of androgen deprivation therapy. (Received September 26, 2018)

01 ► History and biography

1145-01-36 **Karen Hunger Parshall***, Department of Mathematics, P.O. Box 400137, University of Virginia, Charlottesville, VA 22904-4137. *The roaring twenties in American mathematics.* Preliminary report.

World War I served as a break in business as usual within the American mathematical research community. In its aftermath, American mathematicians had the sense, in Oswald Veblen's words, of entering into "a new era in the development of our science." To that end, "[e]very nerve," according to Roland Richardson, "should be strained to get our research back on its feet." These and others poured themselves into their work in the 1920s, but what did that mean? What were their main research interests? Where were those interests fostered? What, in short, was the lay of the American mathematical research landscape in the 1920s? This talk with explore the answers to these questions. (Received June 28, 2018)

1145-01-110 **William Dunham*** (bdunham@brynmawr.edu). *A Morsel from Euler.*

Consider the infinite series:

$$\tan(\pi/4) + \frac{1}{2}\tan(\pi/8) + \frac{1}{4}\tan(\pi/16) + \frac{1}{8}\tan(\pi/32) + \frac{1}{16}\tan(\pi/64) + \cdots .$$

A comparison test easily establishes convergence, but determining the *exact* sum is not for the faint of heart. Who could possibly do such a thing?

The answer is Leonhard Euler. To find the exact value, he developed a peculiar trig identity and then employed logarithms, derivatives, and something he called "infinite numbers." The sum of this series, which is simple in form but far from obvious, provides striking evidence of Euler's mathematical agility.

This talk is for those who want to match wits with one of history's great mathematicians. (Received July 31, 2018)

1145-01-142 **Nicholas Scoville*** (nscoville@ursinus.edu), 601 E Main Street, Math and CS, Collegeville, PA 19465. *Build your own topology: A history of some of the axioms of a topology with applications to the classroom.* Preliminary report.

Day 1 of a course in point-set topology usually begins with the open set axioms of a topology. During the course, one might show that the open set axioms are equivalent to the closed set axioms, but that tends to be the only equivalent system investigated. Yet there are other, less obvious equivalent sets of axioms for a topology. In this talk, we will look at two other sets of axioms for a topology, due to Hausdorff and Kuratowski. Hausdorff gives axioms in terms of neighborhoods while Kuratowski uses the closure operation. In both cases, different terms act as the "undefined terms" of the axiomatic system. This leads us to the idea of having students come up with their own set of undefined terms and axioms to create their own "topology," much like students in a college course in geometry can create their own geometry through undefined terms and axioms. (Received August 08, 2018)

1145-01-281 **Marjorie Senechal*** (senechal@smith.edu). *Max Dehn in America.* Preliminary report.
Max Dehn (1878 - 1952), the first to solve a problem (#3) on Hilbert's famous list, is remembered for Dehn invariants, Dehn surgery, Dehn twist, etc., and for his long-running, influential mathematics history seminar at the University of Frankfurt. His dramatic escape from Nazi Germany across Siberia and, eventually, into the mountains of North Carolina, is the stuff of published legend and, in some quarters, pity. But papers in the Dehn collection at the Briscoe Center for American History at the University of Texas, Austin, and the archives of the five very different American colleges and universities in which he taught give a fuller and more nuanced picture of that journey – and of Dehn himself. (Received August 28, 2018)

1145-01-582 **Stephan Ramon Garcia*** (stephan.garcia@pomona.edu), 610 N College Ave, Claremont, CA 91711. *The Bateman–Horn conjecture.*
The Bateman–Horn conjecture is one of the most significant and far-reaching conjectures in the theory of numbers. We discuss the conjecture and its origins, paying particular attention to original sources and first-hand accounts. (Received September 10, 2018)

1145-01-595 **Annette Imhausen*** (warner@em.uni-frankfurt.de), Cluster "Normative Orders", Max-Horkheimer-Straße 2, 60323 Frankfurt, Germany. *Mathematics and Justice in Ancient Egypt.*
Mesopotamia and Egypt were the earliest cultures that developed writing systems and notations for numbers. Both were used by their rulers (kings) to administer the country and to govern available resources. In addition, they were also employed to structure and justify formal collections of knowledge. These early formal systems include explicit and implicit elements of the normative orders that structured their respective societies, e.g. by prescribing the work-load (measured in quantities of produce) that had to be delivered in set time periods. Furthermore, at least for Mesopotamia, a relation between mathematical and legal procedure texts has been established by Jim Ritter based on the verbal structures in each of these texts. A similar case can be made for Greco-Roman Egypt based on the Demotic mathematical problem texts and the Demotic Legal Code of Hermopolis West. The case for Egypt before Greco-Roman times, however, is not as straightforward. The talk will explore additional sources for his earlier part of Egyptian history to indicate the role that mathematics may have had in establishing normative orders and justice in ancient Egypt. (Received September 11, 2018)

1145-01-689 **Amy Ackerberg-Hastings*** (aackerbe@verizon.net). *Analysis and Synthesis in A.-M. Legendre's Éléments de géométrie.* Preliminary report.
My 2000 dissertation and subsequent work explored how three different understandings of the terms "analysis" and "synthesis"—as mathematical styles, as directions of proof, and as educational approaches—influenced Americans' choices of geometry textbooks for colleges in the early 19th century. Although it provided the basis for two of these books, the 1819 translation attributed to Harvard's John Farrar and David Brewster's 1822 translation that was co-opted by Charles Davies of the US Military Academy, I have never examined Legendre's 1794 geometry textbook with respect to how these three dichotomies operated in his 18th-century French context. This talk reports on my effort to conduct such an inquiry. (Received September 12, 2018)

1145-01-723 **Christopher J. Phillips*** (cjp1@cmu.edu), Carnegie Mellon University, Dept. of History, Baker Hall 240, 5000 Forbes Ave., Pittsburgh, PA 15213. *Measuring Scouts and Trained Noses: Subjectivity, Objectivity, and the History of Mathematics.*
There's a well-worn claim that gets made about the rise of mathematics in domains ranging from archaeology to medicine, policing to education: mathematics enables forms of trust in people to be replaced with trust in numbers. Put differently, numbers displace subjective knowledge with objective knowledge. While there are certainly historical exemplars of this transition, many skillfully documented by Theodore Porter and others, this talk focuses on another way mathematics has been used historically: to make the subjective objective. Focusing on baseball, enology, and medicine, I will show the ways mathematics did not replace human knowledge but rather enabled its marshaling into new forms of reliable knowledge. The history of mathematics' spread is not one of opposition to or displacement of human expertise; the concepts are in dialog with each other. The tools and technologies crucial to my examples are deceptively simple—scouting reports, rating cards, and medical records—and the mathematics hardly advanced—basic probability, sequential analysis, 2x2 tables—but the result has been a profound and often under-appreciated contribution to the ubiquity of mathematics in the modern world. (Received September 13, 2018)

1145-01-844 **J J Tattersall*** (tat@providence.edu), Department of Mathematics, Providence College, Providence, RI 02918. *A Cambridge correspondence class in arithmetic for women.* Preliminary report.

In the late nineteenth century the Association for Promoting the Higher Education of Women in Cambridge began sponsoring a series of correspondence classes for women vying for certificates on the Cambridge Higher Local Examinations. These courses were designed for women who lived in remote areas devoid of suitable teachers and for governesses who did not have sufficient control over their time to permit them to attend classes or receiving oral instruction. In October that year, eighteen women enrolled in the arithmetic class organized by W.H.H. Hudson of St. John's College, Cambridge. The topics covered included measurement, vulgar fractions, ratio, proportions, decimal fractions, and interest. We discuss the contents of his correspondence to students that illustrate his educational philosophy, include tips on what books to consult, and his lessons on how to prepare for the examination. (Received September 16, 2018)

1145-01-1017 **Brigitte Stenhouse*** (brigitte.stenhouse@open.ac.uk). *Understanding the differential in the unpublished work of Mary Somerville (1780-1872).*

In the early 19th century, the need to increase the acceptance and utilization of the differential calculus in Great Britain was keenly felt by a significant group of British mathematicians, who saw their contemporaries' reliance on the Newtonian fluxional calculus as a hindrance to research. Mary Somerville (1780-1872) was an active member of both the London- and Edinburgh-based communities of scholars who publicly advocated for the adoption of 'French analysis' (in a variety of its manifestations). In 1834, she completed a treatise on the differential calculus and its applications to geometry; with nomenclature borrowed from Lacroix, notation similar to that of Lagrange, and a conspicuous absence of Cauchian limits, the manuscript of this unpublished work provides a new and detailed insight into her conceptual understanding of a differential. Considering her central place in the British mathematical community, my talk will focus on the new perspective to be gained from this treatise, especially on the accessibility of, and contemporary attitudes towards, French ideas on the foundations of the differential calculus in 1830s Great Britain. (Received September 18, 2018)

1145-01-1128 **Robert E. Bradley*** (bradley@adelphi.edu), Department of Mathematics & Computer Science, Adelphi University, Garden City, NY 11530, and **Salvatore J. Petrilli** (petrilli@adelphi.edu), Department of Mathematics & Computer Science, Adelphi University, Garden City, NY 11530. *Servois on Numerical Integration.*

In mid-1810s, the topic of numerical integration was hotly debated in the pages of the *Annales de Gergonne.* Christian Kramp (1760-1826) had published a paper in 1815 describing a novel method for estimating definite integrals, based on the Trapezoid Rule and an *ad hoc* extrapolation technique. This sparked a debate among Kramp, the editor Joseph Gergonne (1771-1859) and Joseph Bérard (1763-1844?). François Joseph Servois (1767-1847) entered the fray in 1817 with his *Mémoire sur les quadratures*, in which he resolved most of the issues under dispute by the other authors. In this talk, we will examine Servois' memoir, which is at turns a showpiece of the calculus of operations, a feat of numerical prowess, and a collection of philosophical observations and opinions, including his forward-looking attitude towards the utility of divergent series. (Received September 19, 2018)

1145-01-1367 **Michael J. Barany*** (michael@mbarany.com). *Internationalize first, ask questions later: Headlong diplomacy and American mathematical hegemony, 1920-1950.*

In 1920, American mathematicians first successfully bid to host an International Congress of Mathematicians in the United States, planned for 1924. They ultimately succeeded in hosting such a meeting on their third attempt, in 1950 in Cambridge, MA. Historians of American and international mathematics, most notably Karen Parshall, have given considerable recent attention to this period as a turning point for the international mathematical community and Americans' place within it. While it is tempting to emphasize Americans' noble ambitions and organizational triumphs in this period, their ignorance and blunders could be just as decisive for the particular kind of internationalism that emerged. Looking to international archives beyond the core institutional and personal sources typically used to understand these developments offers a striking view of these latter aspects of American internationalism. My presentation will explore Americans' headlong diplomacy, represented especially by the dramatic miscalculations of Marshall Stone, and its contexts and consequences for a globalizing discipline. (Received September 21, 2018)

1145-01-1429 **Elizabeth Cornwall*** (ecornwall@dixie.edu). *Cracking Al-Kāshī's Tables.*

During the 14^{th} century, the Persian astronomer and mathematician al-Kāshī wrote his influential *Khāqānī Zīj*, an astronomical work consisting of tables and accompanying text. Among the many astronomical tables contained in this work, al-Kāshī presented several tabulating trigonometric quantities including some devoted to the "shadow", numerical data mathematically equivalent in many respects to the modern day tangent function. This presentation investigates these 'tangent' tables, detailing how they were laid out and to be used, the broader context in which they were understood, as well as the more complex question of how the numerical data they contain was computed. (Received September 21, 2018)

1145-01-1495 **Tony Royle*** (tony.royle@open.ac.uk). *Magnificent Mathematicians in their Flying Machines.*

The turn of the twentieth century heralded a revolution in humankind's attempts to master powered flight. Mathematics lay at the heart of a new genre of engineering that would be created by a cohort of exceptionally talented academics to underpin the venture. A number would take to the air, whilst others toiled on the ground in support. I will attempt a brief overview of the salient characters, institutions and mathematics intimately connected with this narrative in Britain during WW1. (Received September 22, 2018)

1145-01-1503 **Duncan J. Melville*** (dmelville@stlawu.edu), Dept of Mathematics, St. Lawrence University, Canton, NY 13617. *Edward Hatton's Mercantile Mathematics.*

The expansion of trade and industry in late 17th-and early 18th-century England required increased numbers of clerks schooled in basic arithmetic and the arts of double-entry bookkeeping. Among those serving the new educational market was Edward Hatton (1664–1737), prolific author of some dozen works, many of which went through multiple editions, in some cases for a good sixty years after his death. In this talk I give a survey of his work illustrated with examples of his style and content. (Received September 22, 2018)

1145-01-1505 **Lawrence Arthur D'Antonio*** (ldant@ramapo.edu). *Newton Has a Headache but Clairaut Makes it Go Away.*

Newton's headache was his failure to compute the motion of the moon using his universal theory of gravitation. In particular Newton was not able to account for the rotation of the lunar apsides. In this talk we will see how Alexis Clairaut, after trials and tribulations, was able to solve this problem. We will discuss Clairaut's initial failure, his proposal to modify the inverse-square law of attraction, the subsequent dispute with Buffon, and the final success in 1749 using a clever iterative calculation. Newton's headache would surely have cleared up, if Newton were still alive. (Received September 22, 2018)

1145-01-1562 **Asamoah Nkwanta*** (asamoah.nkwanta@morgan.edu), Morgan State University, Department of Mathematics, 1700 E. Cold Spring Lane, Baltimore, MD 21251, and **Janet E. Barber** (jbarber774@gmail.com), Stratford University, The School of Arts & Sciences, 2900 Eisenhower Avenue, Alexandria, VA 22314. *Episodes in the Life of a Genius: J. Ernest Wilkins Jr.*

J. Ernest Wilkins Jr. had an IQ of 163 by age nine, earned a college degree at age 16, and received his doctorate in mathematics at age 19 from the University of Chicago. This paper highlights his noteworthy contributions as a mathematician, physicist, engineer, and educator. (Received September 23, 2018)

1145-01-1623 **Peggy Aldrich Kidwell*** (kidwellp@si.edu). *My Computing Device – A Mathematical Perspective.*

Mathematically minded people in the United States have long invented, used in their work, and personally owned computing devices. Those most common in the early nineteenth century were educational aids such as the blackboard, the teaching abacus or numeral frame, and simple geometrical solids. At mid-century, some proposed and a few purchased machines that carried out arithmetic mechanically. These would be quite common by 1900, used to produce mathematical tables and to solve routine arithmetic problems. The handheld slide rule also became popular among mathematicians, engineers, and scientists. A few early twentieth century statisticians embraced tabulating equipment, while some number theorists devised their own machines and, at midcentury, embraced the newly invented mainframe computer. However, it would only be with the advent of microcomputers, often linked to linked to one another, that computers came to play a general role in mathematical research, communication, publication, graphics, and modelling. (Received September 23, 2018)

1145-01-1666 **Leona A. Harris*** (leona.harris@udc.edu). *My Choice to Change the World: An Exploration of My Journey from the Spelman College Mathematics Department to an Urban Public HBCU in the Nation's Capital.*

As a student in the Spelman College Mathematics Department, I learned about the power of mathematics and the endless possibilities a degree in mathematics would afford me. I also learned about the vast underrepresentation of minorities and women in the mathematical sciences, and of my two-fold responsibility to help diversify the field, by becoming a mathematician and helping other minorities and women achieve the same goal. This presentation explores my HBCU journey from Spelman College to the University of the District of Columbia, and the various experiences that have shaped my path from student to administrator. In addition to the impact that Spelman College's Mathematics Department has had on my professional trajectory, we explore Spelman's impact on the mathematics community through its programs and graduates, and a myriad of attempts by its graduates to live by the College's motto to make "A Choice to Change the World." (Received September 23, 2018)

1145-01-1729 **Anna-Sophie Heinemann*** (annasoph@mail.uni-paderborn.de), Universitaet Paderborn, Inst. fuer Humanwissenschaften: Philosophie, Warburger Str. 100, 33098 Paderborn, Germany. *De Morgan on Barrett and Tetens: a British-Continental analogy in the history of statistic thinking?* Preliminary report.

Past decades have seen substantive research on the emergence of statistics as related to the development of insurances and actuarial mathematics. Some decisive approaches can be marked out in the second half of the 18th century, when actuaries' need for standardization of vital rates seems to have generated equivalents of methods in British and Continental authors alike while perhaps unconnectedly. one case of the 1780s is that of tables calculated by the practitioner George Barrett and the methods put forward by Johannes Nikolaus Tetens. In 1854, Augustus De Morgan published in the Assurance Magazine to valuate Barrett's merits and to vindicate his originality. De Morgan's inquiries are documented by manuscript material held by the London Senate House Library. the file contains one letter from De Morgan to Charles Babbage in which the former confesses that the similarities between Barrett's and Tetens's accounts are striking and can hardly be accounted except on the assumption that Barrett was somehow informed of Tetens's approach. Departing from this account, the presently proposed paper aims at a reconstruction of De Morgan's arguments and takes as its goal to test whether there is a possibility of indirect influences between British and Continental actuarial mathematics. (Received September 24, 2018)

1145-01-1821 **Dawn A Lott*** (dlott@desu.edu), Computational and Physical Sciences Division, 1200 N. DuPont Highway, Dover, DE 19904. *A Lott of History.*

The National Association of Mathematicians has been devoted to promoting excellence in the mathematical sciences and promoting the mathematical development of all underrepresented minorities. This organization has fostered the growth of and nurtured many prominent mathematicians, particularly mathematicians of color. Topics to be addressed include (i) the personal journey of an African-American , female, applied mathematician, Dr. Dawn A. Lott, who attributes her success to the support of NAM and its members and (ii) Dr. Lott's tenure as the Vice President of NAM. (Received September 24, 2018)

1145-01-1898 **Della Dumbaugh*** (ddumbaugh@richmond.edu), Department of Mathematics & Computer Science, University of Richmond, Richmond, VA 23173. *Aiming for High Standards: Solomon Lefschetz as Editor of the Annals of Mathematics.* Preliminary report.

Solomon Lefschetz played a critical role in the American mathematical community in the early twentieth century. He contributed significantly to algebraic topology, its applications to algebraic geometry, and the theory of non-linear ordinary differential equations. He not only exhibited academic excellence in mathematics, but he also demonstrated leadership as a faculty member at the University of Princeton and as President of the American Mathematical Society. Lefschetz served as the main editor for the Annals of Mathematics from 1928 to 1958, an important period for the journal. During this time, it became an increasingly well-known and respected journal. Its rise, in turn, stimulated American mathematics. This work specifically looks at Lefschetz'a role as editor of the Annals, the papers that were published in the journal, the editorial boards, and the authors of the more than 1800 articles that appeared during his editorship. (Received September 24, 2018)

1145-01-1965 **Deborah Kent***, Collier-Scripps Hall, 2702 Forest Avenue, Des Moines, IA 50311. *The Nautical Almanac Office harbors mathematical editors, 1849-1866.* Preliminary report.

An 1849 Naval Appropriations Act authorized an official United States national almanac so American scientists and navigators would no longer need to depend on foreign sources for astronomical data. The U.S. Nautical Almanac Office was established not at the Naval Observatory in Washington, D.C, but in Cambridge, MA, specifically to have access to Benjamin Peirce's expertise and oversight for the calculating staff. The Nautical Almanac Office functioned as a crucial source of income and training for individuals who became centrally involved as editors and contributors to American mathematical periodicals. (Received September 24, 2018)

1145-01-1976 **Dominic Klyve*** (klyved@cwu.edu). *Moral Arithmetic: Decisions, values, and the likelihood of death from the Count de Buffon.* Preliminary report.

Buffon's work in mathematics has long been overlooked. His famous "needle problem", of course, is often mentioned, but this is presented more as a parlor trick than as a serious bit of mathematics. Buffon is best remembered today for monumental *Histoire naturelle, générale et particulière*, a 36-volume work in which he considered an astonishing range of subjects, from the behavior of animals to the weather. However, Buffon was also the author of a fascinating text on mathematics – his *Essai d'Arithmetique Morale* (Essay on Moral Arithmetic). In it, Buffon treated a range of topics, including an experimental study of the St. Petersburg game, an early treatment of utility theory, and range of problems in geometric probability. This talk will survey Buffon's work and attempt to put his many ideas in their historical context. (Received September 24, 2018)

1145-01-2126 **Colin B. P. McKinney*** (mckinnec@wabash.edu). *Serenus' Sections of a Cylinder and Sections of a Cone.* Preliminary report.

Serenus (4th century CE) wrote a now-lost commentary on the *Conics* of Apollonius, along with two works on sections of a cone and of a cylinder. In this talk, I will detail my preliminary work translating and analyzing the texts, and discuss their relationship with Apollonius' text and the broader ancient Greek mathematical corpus. (Received September 24, 2018)

1145-01-2129 **Laura E Turner*** (lturner@monmouth.edu), Department of Mathematics, Monmouth University, 400 Cedar Avenue, West Long Branch, NJ 07764. *Notions of continua in E.V. Huntington's work.* Preliminary report.

In the early years of the 20th century, Harvard mathematician E.V. Huntington (1874–1952) published a number of different sets of postulates defining the algebra of real quantities and the underlying linear continuum. In this talk, we explore his treatment of continua. In particular, we consider his discussions of Cantor's and Dedekind's definitions, and his mathematical and pedagogical motivations. (Received September 24, 2018)

1145-01-2148 **John M Neuberger**, **Nandor Sieben*** (nandor.sieben@nau.edu) and **James W Swift**. *Synchrony And Anti-Synchrony For Difference-Coupled Vector Fields On Graph Network Systems.*

We define a graph network to be a coupled cell network where there are only one type of cell and one type of symmetric coupling between the cells. For a difference-coupled vector field on a graph network system, all the cells have the same internal dynamics, and the coupling between cells is identical, symmetric, and depends only on the difference of the states of the interacting cells. We define four nested sets of difference-coupled vector fields by adding further restrictions on the internal dynamics and the coupling functions. These restrictions require that these functions preserve zero or are odd or linear. We characterize the synchrony and anti-synchrony subspaces with respect to these four subsets of admissible vector fields. Synchrony and anti-synchrony subspaces are determined by partitions and matched partitions of the cells that satisfy certain balance conditions. We compute the lattice of synchrony and anti-synchrony subspaces for several graph networks. (Received September 24, 2018)

1145-01-2173 **Brenda Davison*** (bdavison@sfu.ca), 8888 University Dr., Burnaby, B.C. V5A 1S6, Canada. *Divergent Series near the turn of the* 20^{th} *century.* Preliminary report.

While Euler and others of the mid-18^{th} century had methods for assigning a value to some divergent series, the broad adoption of the Cauchy definition for the sum of a series made such objects problematic. However, by the mid-19^{th} century, renewed interest in these series, as a result of their usefulness in physics, appeared at the hands of Stokes and Poincaré. This talk will examine the reasons for renewed interest in divergent series and the mathematics of summability and asymptotic series that developed in the period from 1880 through 1920, at the hands of Borel and Cesàro, among others, as a result. (Received September 24, 2018)

1145-01-2204 **Kim Plofker*** (kim_plofker@alumni.brown.edu). *The mathematics of eclipse diagrams in Sanskrit astronomy.*

One of the few details we know about the professional incentives of medieval Indian mathematician-astronomers is that it was important to them to predict eclipses. The *parilekha* or eclipse diagram was a crucial part of this particular form of "public engagement with science", and depended on several ingenious mathematical techniques in areas ranging from simple trigonometry to numerical approximation. This talk discusses how such diagrams were devised and used to showcase the professional achievements of mathematicians. (Received September 25, 2018)

1145-01-2395 **Brit Shields*** (bshields@seas.upenn.edu). *Solving the "Shortage of Trained Brains": The Engineering, Science and Management War Training Program During the Second World War.*

With the outbreak of the Second World War, many US mathematicians, scientists and engineers began research work for the war effort. Those at universities also participated in one of the largest government-subsidized educational programs in US history. The Engineering, Science and Management War Training Program, funded by the US Office of Education, operated on over 200 campuses nationwide. The program included opportunities for students to train in engineering or for current engineers to gain new skills. This talk will discuss the role of the mathematical sciences within this program, focusing on how the courses developed at New York University. (Received September 25, 2018)

1145-01-2580 **Johnny L. Houston*** (jlhouston602@gmail.com). *The National Association of Mathematicians (NAM), The First Fifty Years (1969-2019): Contributions and Influences as an Advocate and a Catalyst for Improvement.*

The establishment of NAM was not the product of an abstract idea, but rather A Mission to bring about constructive improvements in the Mathematical Community that would impact positively how underrepresented American minorities would have fair and greater access to opportunities to participate and contribute to the mathematical excellence being demanded by the profession. From the past half century, there is substantial evident to be reviewed by objective observers to arrive at a clear decision as to whether or not this Mission is being accomplished. During the period of time allowed, the presenter will exhibit the evident and discuss the influences that appear to have occurred. At the end of the presentation, a discussion will be entertained, if time permits, as to what should be NAM's goals for the next thirty years. What does NAM wish to achieve by the year 2050 when White American males will not likely constitute the majority of the persons in the mathematical sciences community in America? (Received September 25, 2018)

1145-01-2941 **Shelly M. Jones*** (jonessem@ccsu.edu), 1615 Stanley Street, P.O. Box 4010, New Britain, CT 06050. *Motivating Students in Mathematics: Women Who Count.*

As an African American woman and a Mathematics Educator, I was inspired by the book and movie, Hidden Figures, to write a book entitled, Women Who Count: Honoring African American Women Mathematicians. The book aims to continue to bring attention to the positive narratives of African American women in Mathematics including their contributions to Mathematics and a glimpse into their personal lives as well. I will share several biographies of 29 African American Women Mathematicians featured in Women Who Count, that can be used to support students' mathematics identity development. A strong mathematics identity is critical to success in mathematics and is formed by one's belief about one's "(a) ability to do mathematics, (b) the significance of mathematical knowledge, (c) the opportunities and barriers to enter mathematics fields, and (d) the motivation and persistence needed to obtain mathematics knowledge" (Martin, 2000, p. 19). (Received September 25, 2018)

03 ► Mathematical logic and foundations

1145-03-59 **Luke S Serafin*** (lserafin@alumni.cmu.edu), 33838 N 83rd St., Scottsdale, AZ 85266. *A Formally Verified Proof of the Central Limit Theorem.*

We describe the results of a collaborative effort to formalize the proof of the central limit theorem of probability theory. This project was carried out in the Isabelle proof assistant, and builds upon and extends the libraries for mathematical analysis, in particular measure-theoretic probability theory. The formalization introduces the notion of weak convergence (also known as convergence in distribution) required to state the central limit theorem, and uses characteristic functions (Fourier transforms) to demonstrate convergence to the standard normal distribution under the hypotheses of the central limit theorem. Supporting such reasoning motivated significant changes to the measure-theoretic integration libraries of Isabelle. (Received July 15, 2018)

1145-03-460 **Sergey S. Goncharov**, **Julia F. Knight** and **Ioannis Souldatos*** (souldaio@udmercy.edu), 4001 W. McNichols Road, Department of Mathematics, Detroit, MI 48221. *The Hanf Number for Scott Sentences of Computable Structures.*

The *Hanf number* for a set S of sentences in $\mathcal{L}_{\omega_1,\omega}$ (or some other logic) is the least infinite cardinal κ such that for all $\varphi \in S$, if φ has models in all infinite cardinalities less than κ, then it has models of all infinite cardinalities. S-D. Friedman asked what is the Hanf number for Scott sentences of computable structures. We show that the value is $\beth_{\omega_1^{CK}}$. The same argument proves that $\beth_{\omega_1^{CK}}$ is the Hanf number for Scott sentences of hyperarithmetical structures. (Received September 06, 2018)

1145-03-484 **Douglas Cenzer*** (cenzer@ufl.edu), Department of Mathematics, University of Florida, Gainesville, FL 32611-8105. *Computability and complexity in structure theory: the work of Jeffrey B. Remmel.*

Jeff Remmel played a leading role in the application of computability and complexity to structure theory as well as other areas such as algebra and combinatorics. Here one major theme is to compare and contrast computable structures with structures which are computable at some subrecursive complexity, often polynomial time. The existence question is to classify the computable structures which are isomorphic to polynomial time structures. The uniqueness question is to determine the complexity-theoretic categoricity of a structure, that is, to see whether two isomorphic polynomial time structures of a certain type have, say, an exponential time isomorphism. Another theme is to explore the properties of polynomial time structures, for example, to look at the complexity of a vector space versus the complexity of a basis for the space. This talk will review some of the highlights of Remmel's work, including some recent work on automatic structures. (Received September 07, 2018)

1145-03-586 **Martin D Davis*** (martin@eipye.com), 3360 Dwight Way, Berkeley, CA 94704. *Undecidable Propositions in Number Theory: Are All of Them Monsters?*

Foundational work in the 1930s yielded two different kinds of impossibility: algorithmic unsolvability (the non-existence of a uniform algorithms for determining the truth or falsity of each of an infinite class of assertions) and undecidable propositions (individual assertions that could neither be proved nor disproved in a particular given logical formalism). Whereas examples of the former kind are to be found in almost every branch of mathematics, results of the latter kind have so far had virtually no impact on mathematical practice. This is particularly striking in the case of number theory where Gödel and others have made much of the fact that such propositions can be found of a simple Diophantine form. However, when these are written explicitly, a monster results. Given that we know that new Π_1^0 propositions become provable as ever stronger set-theoretic axioms are provided, it may well be the case that even such classic open problems as the Goldbach Conjecture and the Riemann Hypothesis may require set-theoretic methods. In his Gibbs address Gödel conjectured that this is indeed the case for RH. Fermat's Last Theorem has been proved, but it may not be provable in PA. Experts in weak arithmetics could seek models that falsify certain of these propositions. (Received September 10, 2018)

1145-03-658 **David Marker*** (marker@uic.edu), Dept. Mathematics UIC, 322 Science and Engineering Offices (M/C 249), 851 S. Morgan St., Chicago, IL 606077045. *Fifty years in the model theory of theory of differential fields.*

Blum's 1968 thesis introduced the use of stability theoretic methods to study differential fields. Many interesting model theoretic phenomena are illustrated in differentially closed fields and model theory methods have been surprising effective in obtaining differential algebraic results. The model theory of differential fields has also had important applications to differential Galois theory, Diophantine geometry and transcendence theory. I will survey some of these interactions. (Received September 12, 2018)

1145-03-661 **John Krueger*** (jkrueger@unt.edu), Department of Mathematics, University of North Texas, 1155 Union Circle #311430, Denton, TX 76210. *A forcing axiom for a non-special Aronszajn tree.*

Suppose that T^* is an Aronszajn tree with no stationary antichain. We introduce a forcing axiom $\mathsf{PFA}(T^*)$ for proper forcings which preserve these properties of T^*. $\mathsf{PFA}(T^*)$ implies many of the strong consequences of PFA, such as the failure of very weak club guessing, that all of the cardinal characteristics of the continuum are greater than ω_1, and the P-ideal dichotomy. On the other hand, $\mathsf{PFA}(T^*)$ implies some of the consequences of diamond principles, such as the existence of Knaster forcings which are not stationarily Knaster. (Received September 12, 2018)

1145-03-662 **Jeffry L. Hirst*** (hirstjl@appstate.edu), Department of Mathematical Sciences, ASUBox 32092, Appalachian State University, Boone, NC 28608. *Reverse mathematics and colorings of hypergraphs.*

Given a sequence of hypergraphs, how hard is it to select those with a two coloring? We answer this question using the framework of reverse mathematics. In the worst case, when the hypergraphs may contain infinite edges, the existence of the selection function is equivalent to $\Pi_1^1\text{-}\mathsf{CA}_0$ over the base system RCA_0. This is joint work with Caleb Davis and Jake Pardo. (Received September 12, 2018)

1145-03-664 **Michael Chris Laskowski*** (mcl@math.umd.edu), Department of Mathematics, University of Maryland, College Park, MD 20742. *35 years later: A fresh perspective on classifiable theories.* Preliminary report.

Several years after their identification, we give a friendly presentation of the model theory of classifiable theories, i.e., those theories T for which isomorphism types in $Mod(T)$ can be described by trees of invariants. We give more agreeable (but equivalent) definitions of classifiability in terms of how independent triples of models of T can be completed to a model. Also, we describe and investigate many species of regular types $\text{tp}(a/M)$ and explain when a prime model exists over $M \cup \{a\}$, thereby clarifying which T have which uncountable spectra.

This is an ongoing project with Elisabeth Bouscaren, Bradd Hart, and Ehud Hrushovski. (Received September 12, 2018)

1145-03-681 **Francis Adams*** (fadams@gsu.edu), Department of Mathematics and Statistics, Georgia State University, 25 Park Place 14th Floor, Atlanta, GA 30303. *Injection structures and the Ershov hierarchy.*

We investigate properties of injections structures related to the Ershov hierarchy. In particular, we provide a finer analysis of the effective categoricity of Δ^0_2-categorical injection structures. A substantial amount of machinery and background results are provided by work of Remmel and others on computability and categoricity of injections structures [1], and on equivalence structures in the Ershov hierarchy [2].

[1] Cenzer, Douglas, Valentina Harizanov, and Jeffrey B. Remmel. "Computability-theoretic properties of injection structures." Algebra and Logic 53.1 (2014): 39-69.

[2] Cenzer, Douglas, Geoffrey Laforte, and Jeffrey Remmel. "Equivalence structures and isomorphisms in the difference hierarchy." The Journal of Symbolic Logic 74.2 (2009): 535-556. (Received September 12, 2018)

1145-03-726 **Will Boney** and **Ioannis Souldatos***, souldaio@udmercy.edu. *The First Measurable is a Lower Bound for the Hanf Number for Joint Embedding.*

From [1], if μ is a strongly compact cardinal, K is an Abstract Elementary Class (AEC) with $\text{LS}(K) < \mu$, and K satisfies joint embedding cofinally below μ, then K satisfies joint embedding $\geq \mu$. The question was raised if the strongly compact upper bound was optimal.

The following theorem provides a lower bound.

Theorem [2] There exists an AEC K axiomatized by an $L_{\omega_1,\omega}$-sentence, so that if μ is the first measurable cardinal, then joint embedding holds/fails cofinally below μ , and everywhere above μ.

This proves that the Hanf number for joint embedding is contained between the first measurable and the first strongly compact. Since these two cardinals can consistently coincide, the upper bound from [1] is consistently optimal.

Moreover, it is consistent that for any club C on the first measurable μ, JEP holds exactly on $\lim C$ and everywhere above μ.

References

[1] John Baldwin, Will Boney.

Hanf numbers and presentation theorems in aecs.

In Jose Iovino, editor, Beyond First Order Model Theory, pages 81–106. Chapman Hall, 2017.

[2] Will Boney, Ioannis Souldatos

A Lower Bound for the Hanf Number for Joint Embedding

pre-print: https://arxiv.org/abs/1808.03017 (Received September 13, 2018)

1145-03-869 **Henry P Towsner*** (htowsner@math.upenn.edu). *Regularity Lemmas in the Limit.*

In a precise way, Szemeredi's regularity lemma is a quantitative version of the existence of the conditional expectation. Similarly, hypergraph regularity corresponds to the existence of a sequence of conditional expectations on a sequence of nested sigma algebras.

We will discuss the nature of the correspondence between finitary, quantitative statements like regularity and infinitary statements like the existence of conditional expectation. (Received September 16, 2018)

1145-03-914 **Nigel Pynn-Coates*** (pynncoa2@illinois.edu), Department of Mathematics, University of Illinois at Urbana–Champaign, 1409 W Green St, Urbana, IL 61801. *Model companions of theories of valued differential fields.* Preliminary report.

The model companion of the theory of monotone valued differential fields is already well understood. I will discuss ongoing work towards obtaining a similar model companion result in the setting of H-asymptotic valued differential fields, including positive results at the level of asymptotic couples and algebraic results, such as the existence of differential-henselizations, that may be useful. (Received September 17, 2018)

1145-03-953 **Kenneth Kramer** and **Russell Miller*** (russell.miller@qc.cuny.edu), Mathematics Dept., Queens College, 65-30 Kissena Blvd., Queens, NY 11367. *Hilbert's Tenth Problem as a Pseudojump Operator.*

For a ring R, Hilbert's Tenth Problem is the set $HTP(R)$ of polynomial equations in several variables over R which have solutions in R. When we restrict our view to subrings R of $\mathbb{Q}$, we can therefore view HTP as an operator, mapping each subring (viewed as a subset of $\mathbb{Q}$) to a subset of $\mathbb{Z}[X_1, X_2, \ldots]$. As such, HTP satisfies Jockusch and Shore's definition of a *pseudojump operator*: by appropriate coding, we can consider it to map each subset of $\mathbb{N}$ to another subset of $\mathbb{N}$, and the resulting set $HTP(R)$ is uniformly computably enumerable in R, lying somewhere between R and its jump R' under Turing reducibility.

It is natural to ask whether this operator preserves Turing reducibility. We show that, unlike the true jump operator, it fails to do so: indeed, it can actually reverse Turing reductions. We also introduce a notion of completeness for sets under the HTP-operator, and show that, although very few sets are HTP-complete in this sense, every Turing degree contains an HTP-complete set. (Received September 17, 2018)

1145-03-976 **Daniel Turetsky*** (dan.turetsky@msor.vuw.ac.nz). *Constructing a fixed point of the structural jump.*

The structural jump is a sort of reverse Marker-extension, where the complexity of all formulae is reduced by one quantifier. Montalbán constructed a fixed-point for the structural jump, meaning a structure for which the degree spectrum is the same for it and its structural jump. His construction requires a large cardinal axiom; S. Friedman & Welch, and independently Puzarenko, produced constructions inside ZFC. We present a simplified construction, also in ZFC. (Received September 17, 2018)

1145-03-998 **Rachael Alvir** and **Julia F. Knight*** (knight.1@nd.edu), 255 Hurley Hall, Mathematics Department, University of Notre Dame, Notre Dame, IN 46556, and **Charles McCoy**. *Complexity of Scott sentences.*

By an old result of A. Miller, if a countable structure $\mathcal{A}$ has a $\Pi_{\alpha+1}$ Scott sentence and one that is $\Sigma_{\alpha+1}$ Scott sentence, then it has a d-Σ_α Scott sentence. The result of A. Miller is based on a result of D. Miller on separators for disjoint $\mathbf{\Pi}_{\alpha+1}$ classes of structures. Montalbán showed that $\mathcal{A}$ has a $\Pi_{\alpha+1}$ Scott sentence iff the orbits of all tuples are defined by Σ_α formulas. We consider effective versions of these results. In particular, we show that if a countable structure $\mathcal{A}$ has a computable $\Sigma_{\alpha+1}$ Scott sentence and one that is computable $\Pi_{\alpha+1}$, then it has a computable d-Σ_α Scott sentence. We also show that if $\mathcal{A}$ has a computable $\Pi_{\alpha+1}$ Scott sentence, then the orbits of all tuples are defined by computable Σ_α formulas—the converse fails. (Received September 18, 2018)

1145-03-1011 **Dan E. Willard*** (dwillard@albany.edu). *On the Utility of Partial Evasions of the Second Incompleteness Theorem in the Modern Digital Era.*

We have published several articles about generalizations of the Second Incompleteness Theorem and partial evasions of it under formalisms that own a partial knowledge about their own self-consistency (These papers are cited and summarized in http://arXiv.org/abs/1807.04717 of the Cornell archives). The late physicist Stephen Hawking has predicted that global warming will likely be so severe that civilization emanating from Earth will find it difficult to continue without employing Artificially Intelligent computers and probably space travel within the Solar System. Our research into Self-Justifying logic systems should be germane to at least one facet of Hawking's aspirations for AI. This is because for any r.e. axiom system A, our formalism can devise a system "IS(A)" that can prove analogs of all A's Π_1 theorems (under a revised language that treats multiplication as a 3-way relation), as well as to recognize the validity of at least a fragmentary definition of its own consistency, and to support an AI system that can survive even if the potential extinction of mankind on Earth does occur. Much added engineering will need be done, but IS(A)'s formalism should be a helpful start to what will be a much larger, more ambitious project. (Received September 18, 2018)

1145-03-1014 **Mirna Džamonja*** (m.dzamonja@uea.ac.uk) and **Ivan Tomašić**. *Using combinatorial limits to obtain regularity lemmas.*

We show how to obtain some old and some new regularity lemmas using combinatorial limits. (Received September 18, 2018)

1145-03-1046 **Julia F. Knight*** (knight.1@nd.edu), **Karen Lange** and **Reed Solomon**. *Roots of polynomials in fields of generalized power series.*

Let K be an algebraically closed field of characteristic 0. Newton and Puiseux showed that the field $K\{\{t\}\}$ of *Puiseux series* is algebraically closed. Maclane showed that for a divisible Abelian group G, the field $K((G))$ of *Hahn series* is algebraically closed. Puiseux series have length at most ω. For a given polynomial $p(x)$, Newton's method for finding roots does not look computable. However, guessing at the non-computable bits, we get a uniform effective procedure that, when applied to any K and a non-constant polynomial $p(x)$ over $K\{\{t\}\}$, yields a root. Hahn series have ordinal length. We can show that if $p(x)$ is a polynomial and γ is a limit ordinal greater than the lengths of all coefficients in $p(x)$, then the roots all have length less than ω^{ω^γ}. At least for countable ordinals γ, this is sharp. We would like to measure, in terms of the usual hierarchies from computability, the complexity of the process that, for a computable ordinal α, given K, G, and a polynomial $p(x)$ over $K((G))$, either produces r_α of length α that is an initial segment of a root, or else determines a root r of length less than α. (Received September 18, 2018)

1145-03-1092 **Reed Solomon*** (david.solomon@uconn.edu). *Revisiting Remmel's analysis of computably categoricity for linear orders.* Preliminary report.

One of Jeff Remmel's most quoted theorems is that a computable linear order L with infinitely many successor pairs has infinite computable dimension. In the main step of this theorem, he proved there is a computable linear order R which is $0'$-isomorphic to L but not computably isomorphic to L. Marie Nicholson considered which computable linear orders L and Δ^0_2 degrees have a similar property. In this talk, I will survey some of the results from Marie's dissertation as well as some more recent examples. (Received September 18, 2018)

1145-03-1150 **Nate Ackerman*** (nate@math.harvard.edu). *Irregular Pairs in Structures with Bounded VC Dimension.*

In Szemerédi's regularity lemma for graphs there are three parameters which measure the complexity of a regularity partition: the amount of regularity, the size of the partition, and the number of irregular pairs of parts in the partition. Suppose we fix an amount of regularity ϵ and a class of finite graphs C. Let $f_{\epsilon,C}$ be the function whose input is a partition size k and whose output is the least value ℓ such that every element of C has an ϵ-regular partition of size k with at most ℓ irregular pairs.

In this talk we will review what is known about $f_{\epsilon,C}$ for various classes C. In the case where C is a collection of graphs of VC dimension at most d, we will provide an upper bound on $f_{\epsilon,C}$ that depends on d and is strictly better than the general case. These results generalize to finite structures in arbitrary finite relational languages.

This is joint work with Cameron Freer and Rehana Patel (Received September 24, 2018)

1145-03-1180 **Antonio Montalban***, montalban@berkeley.edu. *A new metatheorem.*

We present a new metatheorem based on Ash's original α-priority argument and subsequent formulations by the speaker. The previous modification of Ash's metatheorem by the author were more hands-on and slightly more general than the original. This new version is more abstract, less hands-on, less general, but much easier to apply. (Received September 19, 2018)

1145-03-1209 **Andrey Morozov*** (morozov@math.nsc.ru), Sobolev Institute of Mathematics SB RAS, Novosibirsk, 630090, Russia. *On Σ–definable preorderings over the reals.*

We prove that any preorder Σ–definable with parameters over the hereditarily finite superstructure over the reals (HF(R)) does not contain a chain of type ω_1. Using this result, we obtain complete descriptions of ordinals and Gödel constructive sets of kind L_α Σ–presentable over HF(R) and prove that there is no such presentations for the structures of T–, m–, 1–, and tt–degrees. (Received September 20, 2018)

1145-03-1231 **Yimin Zhong*** (yiminz@uci.edu) and **Kui Ren** (kr2002@columbia.edu). *Reconstruction of acoustic and optical properties in PAT from multispectral data.*

This work is concerned with the simultaneous reconstruction of acoustic and optical properties in photoacoustic (PAT). We consider the inverse problem linearized at constant backgrounds and prove that it is possible to uniquely reconstruct the perturbations of the acoustic sound speed, acoustic attenuation and optical absorption coefficient with data collected from optical illuminations at multiple wavelengths. We derive some stability estimates associated to the simultaneous reconstruction process under some additional assumptions. Numerical simulations based on synthetic data are presented to support the theoretical derivation. (Received September 20, 2018)

1145-03-1238 **Ethan Brauer*** (eebrauer@gmail.com), 350 University Hall, 230 N. Oval Mall, Columbus, OH 43210. *Relevance and the perfect sequents of classical logic.*

Relevance logics are typically offered as alternatives to classical logic on the assumption that there is no place for studying relevance in classical logic. I argue that this assumption is mistaken. There is a coherent and robust notion of relevance that has a place in the study of classical logic: the ideal of relevance is best embodied by the so-called *perfect sequents*—sequents that are valid but have no valid proper subsequents. In this talk I address two questions: What syntactic properties do perfect sequents have? Are there fragments of classical logic that prove only perfect sequents?

In response to the first question I establish a strong variable-sharing property for the perfect sequents. Concerning the second question, I consider a modification of LK that restricts initial sequents to be of the form $P \Rightarrow P$, for P atomic, and has no rules of cut or weakening. This system is shown to be sound, complete, and cut-admissible with respect to the class of perfect sequents whose logical vocabulary is among $\forall, \exists$ and at most one of $\neg, \vee, \wedge$ (in the fragment based on $\wedge$, the completeness result only holds in the restricted form: if $\Delta \vdash \phi$ is perfect, then $\bigwedge \Delta \Rightarrow \phi$ is provable). (Received September 20, 2018)

1145-03-1244 **Jennifer Chubb**, **Russell Miller*** (russell.miller@qc.cuny.edu) and **Reed Solomon**. *Model completeness and relative decidability of countable structures.*

The definition of a model-complete theory T is standard in model theory. It is equivalent for T to have quantifier elimination down to existential formulas. From the quantifier elimination, one quickly sees that every computable model of a computably enumerable, model-complete theory T must be decidable. We call a structure *relatively decidable* if this holds more broadly: if for all its copies $\mathcal{A}$ with domain ω, the elementary diagram of $\mathcal{A}$ is Turing-reducible to the atomic diagram of $\mathcal{A}$. In some cases, this reduction can be done uniformly by a single Turing functional for all copies of $\mathcal{A}$, or even for all models of a theory T.

We discuss connections between these notions. For a c.e. theory, model completeness is equivalent to uniform relative decidability of all countable models of the theory, but this fails if the condition of uniformity is excluded. On the other hand, for relatively decidable structures where the reduction is not uniform, it can be made uniform by expanding the language by finitely many constants to name certain specific elements. This is shown by forcing, and we conjecture that a similar result may hold for theories T such that every model of T is relatively decidable. (Received September 21, 2018)

1145-03-1248 **Douglas Cenzer*** (cenzer@ufl.edu), Department of Mathematics, University of Florida, Gainesville, FL 32611-8105. *Computable aspects of homogeneous structures.*

The effective categoricity of homogeneous structures is investigated. Any computable homogeneous structure is Δ^0_2 categorical. A structure $\mathcal{A}$ is said to be *weakly homogeneous* if there is a finite (*exceptional*) set of elements $a_1, \ldots, a_n$ such that $\mathcal{A}$ becomes homogeneous when constants representing these elements are added to the language. Characterizations of the weakly homogeneous structures are presented for families of structures, including: linear orderings, Boolean algebras, Abelian p-groups, equivalence structures, injection structures and trees. These are compared with characterizations of the computably categorical and Δ^0_2 categorical structures. Index sets are used to determine the complexity of the notions of homogenous and weakly ultrahomogeneous for various structures. (Received September 20, 2018)

1145-03-1371 **Athar Abdul-Quader*** (athar.abdulquader@purchase.edu) and **Roman Kossak**. *Neutrally expandable models of arithmetic.*

A subset of a model of PA is called *neutral* if it does not change the definable closure relation. A model of PA with undefinable neutral classes is called *neutrally expandable*. Clearly, every 0-definable set is neutral in any model. We give examples of neutrally expandable models and prove that recursively saturated models are not neutrally expandable. We also show that neutrality is not a first-order property: in particular, there is no theory T extending PA such that, for any recursively saturated model M and any set X, X is neutral iff $(M, X) \models T$. This work is inspired by work by Chatzidakis and Pillay, *Generic structures and simple theories*, ***Annals of Pure and Applied Logic***, vol. 95 (1998), no. 1-3, pp. 71–92 and Dolich, Miller, and Steinhorn, *Extensions of ordered theories by generic predicates*, ***The Journal of Symbolic Logic***, vol. 78 (2013), no. 2, pp. 369–387 and *Expansions of o-minimal structures by dense independent sets*, ***Annals of Pure and Applied Logic***, vol. 167 (2016), no. 8, pp. 684–706, who studied generic expansions of ordered structures. (Received September 21, 2018)

1145-03-1394 **Karen M. Lange*** (karen.lange@wellesley.edu), Wellesley College, 106 Central St., Wellesley, MA 02481. *Classifications of definable subsets of equivalence and injection structures.*

For a fixed syntactic-complexity class $\mathcal{C}$, a subset of a structure is *$\mathcal{C}$-definable* if the subset is defined by some $\mathcal{C}$-formula. Generalizing an idea of Friedberg, Goncharov and Kogabaev introduced the notion of a *$\mathcal{C}$-classification* of a structure; this is a computable list of $\mathcal{C}$-formulas such that every $\mathcal{C}$-definable subset of the structure is defined by a unique formula in the list. We study the connections among Σ_1^0-, $d-\Sigma_1^0$-, and Σ_2^0-classifications in the context of two families of structures: unbounded computable equivalence structures and unbounded computable injection structures. This is joint work with Simona Boyadzhiyska, Abigail Raz, Rebecca Scanlon, John Wallbaum, and Xueyin Zhang. (Received September 21, 2018)

1145-03-1399 **Tyler A. Brown*** (tab5357@iastate.edu), Department of Mathematics, Iowa State University, Ames, IA 50011-2104, and **Timothy H. McNicholl** (mcnichol@iastate.edu). *On the Degrees of Categoricity of Semi-Atomic L^p Spaces.*

In 2015, T. McNicholl proved that the purely atomic L^p spaces with finitely many atoms are computably categorical when $p \geq 1$ is computable and that the degree of categoricity of purely atomic L^p spaces with infinitely many atoms is **0'** whenever $p \geq 1$, $p \neq 2$ is a computable real. Thereafter, it was shown by Clanin, McNicholl, and Stull that the purely non-atomic L^p spaces are computably categorical when $p \geq 1$ is a computable real. In this talk we will investigate the semi-atomic L^p spaces. For computable $p \geq 1$, $p \neq 2$ we then illustrate how the interplay between atomic and non-atomic parts of these spaces increases the degree of categoricity by one jump when a semi-atomic L^p space has finitely and infinitely many atoms. (Received September 21, 2018)

1145-03-1420 **Wesley Calvert*** (wcalvert@siu.edu), Department of Mathematics, Mail Code 4408, 1245 Lincoln Drive, Southern Illinois University, Carbondale, IL 62901. *Random Structures.* Preliminary report.

At least since the use of random graphs by Erdös and Renyi, random structures have been objects of ongoing interest in mathematics and logic. Zero-one laws and the structure of Fraïssé limits are certainly of classical interest. However, related considerations have given rise to such concerns as pseudofinite structures, the Lovasz Local Lemma, graphons, Keisler randomizations, algorithmically random structures, and more.

In the present talk we will survey these areas of work and their relations to one another and to other areas of mathematical logic. (Received September 21, 2018)

1145-03-1431 **Victor W. Marek***, marek@cs.uky.edu. *Investigating relationship between Logic Programming and Recursion Theory - Jeffrey B. Remmel contributions.*

We discuss contributions of J.B. Remmel and his collaborators to the investigations of relationship between Logic Programming and Recursion Theory. Specifically, we will discuss the basic complexity result for so-called stable models of (predicate) logic programs, complexity results for the index sets of various classes of predicate logic programs, properties of so-called Gelfond-Lifschitz operator, and the algorithm for computation of the stable models of propositional logic programs. (Received September 21, 2018)

1145-03-1434 **Mojtaba Moniri*** (mojtaba.moniri@normandale.edu). *Addition with or without multiplication: algorithms, maximality, and near-linearity.*

We first mention two algorithms for a certain sequence of nonnegative integers, one which calculates in $(\mathbb{Z}, +)$ in conjunction with the counting operator # and the exponential substitution, and applies to any positive integer input. The other algorithm calculates in $(\mathbb{Z}, +, \cdot)$, and is more efficient when the input is a power of 2.
Next, let F be an ordered field, D a maximal discrete subring of F, and G a maximal discrete additive subgroup of F. We point out that although there are examples where F has elements of infinite distance to D, it can never realize any gaps of G. For countable F, the subgroup G can be constructed Δ_2^0 relative to F.
Finally we consider some nonstandard models M of weak arithmetic which have $\mathbb{Z}$ as an additive direct summand. We present functions $f, g: M \to M$ whose value at a sum minus sum of values is always 0 or 1 yet for some $x, y, u, v \in M^{\geq 1}$, $f(xy) < xf(y)$ and $g(uv) > ug(v) + u - 1$. (Received September 21, 2018)

1145-03-1452 **Artem Chernikov*** (chernikov@math.ucla.edu). *Model theory and hypergraph regularity.*
I will give a survey of some recent interactions between model theory and the study of various pseudo-randomness phenomena for restricted families of hypergraphs. (Received September 22, 2018)

1145-03-1474 **Caroline Terry***, Department of Mathematics, The University of Chicago, 5734 S. University Avenue, Chicago, IL 60637, and **Julia Wolf**, Department of Pure Mathematics, Centre for Mathematics Sciences, Wilberforce Road, Cambridge, CB3 0WB, United Kingdom. *A stable arithmetic regularity lemma in finite abelian groups.*

The arithmetic regularity lemma for $\mathbb{F}_p^n$ (first proved by Green in 2005) states that given $A \subseteq \mathbb{F}_p^n$, there exists $H \leq \mathbb{F}_p^n$ of bounded index such that A is Fourier-uniform with respect to almost all cosets of H. In general, the growth of the index of H is required to be of tower type depending on the degree of uniformity, and must also allow for a small number of non-uniform elements. Previously, in joint work with Wolf, we showed that under a natural stability theoretic assumption, the bad bounds and non-uniform elements are not necessary. In this talk, we present results extending these results to stable subsets of arbitrary finite abelian groups. This is joint work with Julia Wolf. (Received September 22, 2018)

1145-03-1492 **Philipp C K Hieronymi*** (phierony@illinois.edu), 1409 W Green Street, Urbana, IL 61821. *Decidability, Diophantine Approximation and Ostrowski numeration systems.*

It has long been known that the theory of the expansion $(\mathbb{R}, <, +, \mathbb{Z})$ of the ordered additive group of real numbers by the set of integers is decidable. Arguably due to Skolem, the result can be deduced easily from Buechi's theorem on the decidability of monadic second order theory of one successor, and was later rediscovered independently by Weispfenning and Miller. However, a consequence of Goedel's incompleteness theorem states that when expanding this structure by a symbol for multiplication, the theory of the resulting structure $(\mathbb{R}, <, +, \cdot, \mathbb{Z})$ becomes undecidable. This observation gives rise to the following question: How many traces of multiplication can be added to $(\mathbb{R}, <, +, \mathbb{Z})$ without making the theory undecidable? For $b \in \mathbb{R}$, let $f_b : \mathbb{R} \to \mathbb{R}$ be the function that takes x to bx. Then the theory of $(\mathbb{R}, <, +, \mathbb{Z}, f_b)$ is decidable if and only if b is quadratic. The proof rests on the observation that many of the Diophantine properties (in the sense of Diophantine approximation) of b can be coded in these structures. In particular, the Ostrowski numeration system based on b is definable in this structure. (Received September 22, 2018)

1145-03-1528 **Jana Marikova*** (j-marikova@wiu.edu). *Valuations and o-minimality.*

O-minimality provides a common framework for many topologically well-behaved structures, the prototypical example being the semialgebraic sets. Valuations have been quite useful in establishing the o-minimality of certain structures (such as the real exponential field) as well as in determining properties of definable sets within the framework of o-minimality (measures, preparation theorems). On the other hand, an o-minimal structure together with a convex subring (and hence a valuation) yields a generalization of o-minimality which is interesting in its own right.

We shall discuss the relationship between valuations and o-minimal structures as well as more recent results and open questions about valuational weakly o-minimal structures. (Received September 22, 2018)

1145-03-1575 **Julia Knight**, **Dan Turetsky** and **Rose Weisshaar*** (rweisshaar11@gmail.com). *Countable ω-models of KP and paths through computable ω-branching trees.* Preliminary report.

It is well known that the Π_1^0 class $\mathcal{C}_{PA} \subseteq 2^\omega$ of completions of Peano arithmetic is universal among nonempty Π_1^0 subsets of Cantor space. When we consider Π_1^0 subsets of Baire space, however, there is no such universal example. In this talk, we consider a Π_1^0 class $\mathcal{C}_{KP} \subseteq \omega^\omega$ whose elements compute the complete diagrams of countable ω-models of Kripke-Platek set theory (KP). We develop an analogy between how elements of $\mathcal{C}_{PA}$ and $\mathcal{C}_{KP}$ try to compute members of nonempty Π_1^0 subsets of Cantor space and Baire space, respectively, and we examine how this analogy breaks down. This is joint work with Julia Knight and Dan Turetsky. (Received September 23, 2018)

1145-03-1607 **Valentina Harizanov***, Department of Mathematics, Washington, DC 20052. *Effectively categorical structures.*

Since we are interested in transferring computability-theoretic properties of structures, we investigate computable isomorphisms. A computable structure is computably categorical if for every computable isomorphic copy of the structure there is a computable isomorphism. Remmel characterized computably categorical linear orderings and Boolean algebras. The same characterization was obtained independently by Dzgoev and Goncharov. For these structures, computable categoricity corresponds to the existence of computably enumerable Scott family of existential formulas. Surprisingly, this is not always the case. Goncharov provided the first example where this correspondence of computability and definability does not exist. We will present some new examples of such structures. We will also discuss structures categorical at higher levels of arithmetical hierarchy and their degrees of categoricity. (Received September 23, 2018)

1145-03-1661 **Florian Pop*** (pop@math.upenn.edu). *On the strong elementary equivalence vs Isomorphism problem.*

The problem under discussion here is arguably the main open problem in the first-order theory of finitely generated fields, and asks whether every such field K can be characterized by a single sentence (i.e., axiom) in the language of fields in the class of all finitely generated fields. The answer is obviously "yes" for finite fields, true but not obvious for global fields (proved by Rumely, building on results by Julia Robinson), true but even more difficult for function fields of curves over global fields... The aim of the talk is to comment on the higher dimensional cases, in particular to present a solution to the general problem in characteristic zero. (Received September 23, 2018)

1145-03-1663 **Daniel M Roy*** (droy@utstat.toronto.edu), **Cameron E. Freer**, **Jeremy Avigad**, **Nathanael L. Ackerman** and **Jason M. Rute**. *Algorithmic barriers to representing conditional independence in sequences and arrays.*

We begin by formalizing a computational representation of conditional independence. In this terms, Freer and Roy (2012) shows that the conditional independence underlying exchangeable sequences is computable. Where it is efficiently computable is an open problem. We study exchangeable arrays, investigating the relative computability of exchangeable binary relational data when presented in terms of the distribution of an invariant measure on graphs, or as a graphon in either L1 or the cut distance. We establish basic computable equivalences, and show that L1 representations contain fundamentally more computable information than the other representations, but that 0' suffices to move between computable such representations. We show that 0' is necessary in general, but that in the case of random-free graphons, no oracle is necessary. We also provide an example of an L1-computable random-free graphon that is not weakly isomorphic to any graphon with an a.e. continuous version. (Received September 23, 2018)

1145-03-1671 **Barbara F Csima***, Department of Pure Mathematics, Waterloo, Ontario N2L 3G1, Canada, and **Nancy A Day** and **Matthew Harrison-Trainor**. *Which Classes of Structures Are Both Pseudo-elementary and Definable by an Infinitary Sentence?*

When classes of structures are not first-order definable, we might still try to find a nice description. There are two common ways for doing this. One is to expand the language, leading to notions of pseudo-elementary classes, and the other is to allow infinite conjuncts and disjuncts. We examine the intersection. Namely, we address the question: Which classes of structures are both pseudo-elementary and $\mathcal{L}_{\omega_1\omega}$-elementary? We find that these are exactly the classes that can be defined by an infinitary formula that has no infinitary disjunctions. (Received September 23, 2018)

1145-03-1676 **Laurent Bienvenu** and **Barbara F Csima***, Department of Pure Mathematics, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada, and **Matthew Harrison-Trainor**. *Optimal bounds for single-source Kolmogorov extractors.*

The rate of randomness (or dimension) of a string σ is the ratio $C(\sigma)/|\sigma|$ where $C(\sigma)$ is the Kolmogorov complexity of σ. While it is known that a single computable transformation cannot increase the rate of randomness of all sequences, Fortnow, Hitchcock, Pavan, Vinodchandran, and Wang showed that for any $0 < \alpha < \beta < 1$, there are a finite number of computable transformations such that any string of rate at least α is turned into a string of rate at least β by one of these transformations. However, their proof only gives very loose bounds on the correspondence between the number of transformations and the increase of rate of randomness one can achieve. By translating this problem to combinatorics on (hyper)graphs, we provide a tight bound, namely: Using k transformations, one can get an increase from rate α to any rate $\beta < k\alpha/(1 + (k-1)\alpha)$, and this is optimal. (Received September 23, 2018)

1145-03-1680 **Valentina Harizanov***, Department of Mathematics, Washington, DC 20052. *Effective ultraproducts and applications.*

We use an effective analogue of the ultraproduct construction. We start with the product of a uniformly computable sequence of computable structures indexed by the set of natural numbers. The equality of elements, which are partial computable functions, and satisfaction of formulas are defined modulo an infinite set, which is cohesive, that is, indecomposable with respect to computably enumerable sets. We investigate which definable properties transfer from structures to their cohesive products. We are especially interested in the case when the cohesive set is the complement of a computably enumerable set. Such computably enumerable sets are called maximal sets in computability theory. We then study the isomorphism types of cohesive powers of the field of rational numbers and other structures. These cohesive powers of fields have been used in the characterization of certain filters in a vector space lattice of importance in computable model theory. Cohesive powers were introduced in modern computable model theory by Rumen Dimitrov. Previously, a number of authors considered related constructions in the context of nonstandard models of fragments of arithmetic. (Received September 23, 2018)

1145-03-1700 **Xizhong Zheng*** (zhengx@arcadia.edu), Department of Computer Science and Mathematic, Arcadia University, 450 S. Easton Road, Glenside, PA 19038. *Weak Computabilities of Real Numbers and Relative Randomness.*

A real x is *computable* if it is the limit of an effectively convergent computable sequence of rationals. If the effective convergence is replaced by weaker conditions, various weak computabilities can be introduced. For example, if the convergence is *weakly effectively*, then the limit is *d.c.e.*; if the convergence is *divergence bounded*, then the limit is *d.b.c.* The weak computabilities are closely related to relative randomnesses described by the Solovay reduction. The Solovay reduction originally defined only for the c.e. reals can be extended as follows. (A). $x \leq_S^1 y$ if there are two computable sequences (x_s) and (y_s) of rational numbers which converge to x and y, respectively, such that $|x - x_s| \leq c(|y - y_s| + 2^{-s})$ for some constant c and for all s. (B). $x \leq_S^2 y$ if there are two computable sequences (x_s) and (y_s) of rational numbers which converge to x and y, respectively, and there is a computable function h such that $|y - y_s| \leq 2^{-h(n)} \implies |x - x_s| \leq 2^{-n}$ for all s and n. We will show that, the c.e. random reals are $\leq_S^1$-complete and $\leq_S^2$-complete for the classes of d.c.e. reals and d.b.c. reals, respectively. (Received September 24, 2018)

1145-03-1703 **Jan Reimann*** (jan.reimann@psu.edu), Department of Mathematics, Pennsylvania State University, University Park, PA 16802. *Hausdorff dimension and randomness for continuous measures.*

The connection between supporting a non-atomic probability measure and the Hausdorff dimension of a set is a fundamental tool in geometric measure theory. It is also helpful in the study of algorithmic randomness. An effective version of Frostman's Lemma states that if a real has positive effective Hausdorff dimension, it is Martin-Löf random with respect to a continuous probability measure. In this talk, we present some new results on the connection between Hausdorff measures and randomness for continuous measures. In particular, we will use iterates of the dissipation function of a continuous measure on Cantor space to define a family of generalized Hausdorff measures. These measures can in turn be used to construct examples of NCR reals (i.e., reals not random with respect to any continuous probability measure) in a wide array of hyperarithmetic Turing degrees. This is joint work with Mingyang Li (Penn State). (Received September 24, 2018)

1145-03-1712 **David J. Webb***, dwebb@math.hawaii.edu. *On Several New Notions of Algorithmic Dimension.* Preliminary report.

Following the work of Freer and Kjos-Hanssen on complex packing dimension, we investigate a new notion of *inescapable* dimension, obtained by modifying effective packing dimension to consider all infinite computable sets in place of all intervals $[n, \infty)$. It is shown that while the inescapable and complex packing dimensions are both bounded above and below by the effective packing and Hausdorff dimensions, respectively, these two newer notions are incomparable. We also examine two families of dimension obtained from all infinite sets (co-)enumerable in an oracle, and demonstrate that in both cases an oracle A is Turing reducible to another oracle B if and only if the dimension induced by A is dominated by the dimension induced by B for all strings $X \in 2^\omega$. (Received September 24, 2018)

1145-03-1818 **Natasha Dobrinen*** (natasha.dobrinen@du.edu), University of Denver, Department of Mathematics, C.M. Knudson Hall 300, Denver, CO 80208. *Ramsey theory of the Henson graphs.*

A central question in the theory of homogeneous relational structures asks which structures have finite big Ramsey degrees. An infinite structure $\mathbf{S}$ is *homogeneous* if any isomorphism between two finitely generated substructures of $\mathbf{S}$ can be extended to an automorphism of $\mathbf{S}$. $\mathbf{S}$ has *finite big Ramsey degrees* if for each finite substructure A of $\mathbf{S}$, there is a number $n(\mathrm{A})$ such that any coloring of the copies of A in $\mathbf{S}$, can be reduced down to no more than n colors on some substructure $\mathbf{S}'$ isomorphic to $\mathbf{S}$. A main obstacle to a fuller development of this research area has been the lack of techniques and methods. In this talk, we present new work proving that all Henson graphs $\mathcal{H}_k$, the k-clique-free universal homogeneous graphs for $k \geq 3$, have finite big Ramsey degrees. Our proof provides a streamlined and unified approach to the Ramsey theory of Henson graphs, likely to extend to a large class of homogeneous structures with forbidden configurations. Central to the proof is the method of forcing, used to obtain a Ramsey theorem in ZFC for trees coding copies of $\mathcal{H}_k$, building on ideas of Harrington. (Received September 24, 2018)

1145-03-1879 **Danul K Gunatilleka*** (danulg@math.umd.edu). *Baldwin-Shi hypergraphs in infinite languages.*

We extend the study of theories of Baldwin-Shi hypergraphs to the case where we have a countably infinite language L. We begin by establishing a link between the Baldwin-Shi hypergraph for L and its L_0 reduct where $L_0 \subseteq L$ is finite. We use this link to obtain stability and and certain amalgamation properties satisfied by the Baldwin-Shi hypergraphs. We further explore their atomic models, countable models and regular types. (Received September 24, 2018)

1145-03-2017 **Takayuki Kihara** and **Arno Pauly*** (a.m.pauly@swansea.ac.uk). *A Turing ideal with positive outer measure.* Preliminary report.

We present a construction of a non-trivial Turing ideal $\mathcal{I}$ such that for every oracle p, there exists some $q \in \mathcal{I}$ which is random relative to p; equivalently, such that $\mathcal{I}$ has positive outer Lebesgue measure. That $\mathcal{I}$ is non-trivial is witnessed by $\emptyset' \notin \mathcal{I}$. Our construction makes some mild assumptions about cardinal invariants of the continuum, which are independent of ZFC but follow from CH or MA.

A non-trivial Turing ideal with positive outer measure is the ultimate object that is not small in the sense of measure or dimension, that is closed under nice operations, and yet is not the whole. For example, we immediately obtain a proper subfield of the reals of positive outer measure, which is nonetheless algebraically closed, closed under the exponential function, every other computable operation, and even more so, closed under a set of operations with positive outer Wiener measure. (Received September 24, 2018)

1145-03-2198 **Linda Brown Westrick*** (lzw299@psu.edu). *Sofic subshifts and completely positive topological entropy.* Preliminary report.

A Turing-complete computation framework arises naturally in the setting of multidimensional shifts of finite type (SFTs). Recently Barbieri and García-Ramos have described an ω_1-length hierarchy structure among the dynamical systems of completely positive topological entropy (CPTE). They constructed a three-dimensional SFT with rank 3 in that hierarchy, and asked whether there was a two-dimensional rank 3 SFT. We construct, for each computable ordinal α, a two-dimensional sofic shift of CPTE rank α, and show the property of CPTE is Π^1_1-complete in the class of two-dimensional sofic shifts. We also discuss the question of improving "sofic" to "SFT". All the terms from symbolic dynamics will be explained in the talk. (Received September 25, 2018)

1145-03-2206 **Barbara Csima**, **Damir Dzhafarov**, **Denis Hirschfeldt**, **Carl G. Jockusch**, **Reed Solomon** and **Linda Brown Westrick*** (lzw299@psu.edu). *Computability and Hindman's Theorem for bounded sums.*

Hindman's Theorem states that for every coloring of $\mathbb{N}$ by finitely many colors, there is an infinite subset $H \subseteq \mathbb{N}$ such that all non-empty finite sums of distinct elements of H have the same color. One can weaken the conclusion of the theorem by requiring only that all non-empty sums of up to k distinct elements of H have the same color, but all known proofs of this weaker fact are also proofs of Hindman's Theorem. We analyze the computability-theoretic aspects of bounded versions of Hindman's Theorem. (Received September 25, 2018)

1145-03-2389 **C Chang***, 555 Broadway, Dobbs Ferry, NY 10522, and **S Gao**. *Relative complexities of various homeomorphic equivalent relations on closed subsets of* $[0,1]^n$. Preliminary report.

We show that the homeomorphic equivalent relation on the closed subsets of $[0,1]^n$, for $n \geq 2$, does not admit classification by countable structures. In particular, we show by construction that a turbulence action is Borel reducible to the homeomorphic relation on the closed subsets of $[0,1]^2$. (Received September 25, 2018)

1145-03-2420 **Nguyet N Nguyen***, Department of Mathematics and Statistics, Youngstown State University, 1 University Plaza, Youngstown, OH 44555, and **Isaac Adjetey**. *Modeling and Pricing Weather Derivatives.* Preliminary report.

Weather derivatives are financial instruments that corporations, especially energy and utility companies, use to hedge against risks due to adverse and unpredictable weather. In this talk, we will introduce the financial tools and some models for pricing the weather derivatives whose underlying asset depends on the heading or cooling temperatures. We then implement a model to predict the average temperatures and use the predicted underlying asset to estimate the prices of a corresponding weather option. (Received September 25, 2018)

1145-03-2435 **Nguyet N Nguyen***, Department of Mathematics and Statistics, Youngstown State University, 1 University Plaza, Youngstown, OH 44555. *Machine-Learning Hidden Markov Model for Global Stock Portfolio.* Preliminary report.

The Machine-learning hidden Markov model (HMM) is widely used to detect the hidden regimes of observation data, especially time series. The application of HMM in stock selection and portfolio management is motivated by the similarity between the construction of this model and the interpretation of the stock market. In this paper, we introduce a multi-step procedure for using HMM to select stocks from the global stock market. We show that HMM outperforms the benchmark global index and the equal weight model, being an efficient approach for global stock portfolio selections. (Received September 25, 2018)

1145-03-2439 **Johanna N.Y. Franklin*** (johanna.n.franklin@hofstra.edu), Department of Mathematics, Room 306, Roosevelt Hall, Hofstra University, Hempstead, NY 11549, and **Timothy H. McNicholl**. *Lowness for isometric isomorphism.*

Lowness for isomorphism, first introduced by Franklin and Solomon in 2014, has recently been extended to the context of computable Banach spaces; here it is called lowness for isometric isomorphism. In this talk, we characterize the degrees that are low for $\ell^p_n \oplus L^p[0,1]$-isometric isomorphism for a computable real $p \geq 1$ not equal to 2. (Received September 25, 2018)

1145-03-2447 **Johanna N.Y. Franklin*** (johanna.n.franklin@hofstra.edu), Department of Mathematics, Room 306, Roosevelt Hall, Hofstra University, Hempstead, NY 11549, and **Russell Miller**. *Measure and randomness for algebraic structures.*

R. Miller has recently introduced a method for defining an effective measure on the spaces of the isomorphism types of computable algebraic structures such as algebraically closed fields and finitely branching trees. This gives us a new way to discuss the frequency of certain properties of computable structures, including computable categoricity.

In fact, we can ask whether there is a type of randomness that will guarantee $\mathcal{P}$ for any measure-one property $\mathcal{P}$. In the case of algebraically closed fields of characteristic 0, we have shown that Schnorr randomness is enough to guarantee uniform computable categoricity. I will present this result as well as some comments on finitely branching trees. (Received September 25, 2018)

1145-03-2599 **Neil Lutz***, Dept. of Computer and Information Science, University of Pennsylvania, 3330 Walnut Street, Philadelphia, PA 19104. *Algorithmic Dimensions of Projected Points.*

To what extent are fractal dimensions preserved by projection mappings? In this talk, we will consider an effective and pointwise version of this question in the Euclidean plane. I will describe recent progress on this question and show how it has yielded new results about the classical Hausdorff dimension of projected sets, including new extensions to Marstrand's projection theorem. (Received September 25, 2018)

1145-03-2704 **Anil Nerode*** (an17@cornell.edu), 545 Malott Hall, Cornell University, Ithaca, NY 14850. *Reminiscences of Jeff Remmel.*

I will summarize our long history of collaborations. They stretch from his days as my Ph. D. student in the early 1970's to his death in 2017. We collaborated first in the theory of Dekker's isols, then in determining the computable content of various algebraic constructions (now partially subsumed into Friedman's reverse mathematics), then with Victor Marek in the theory non-monotonic logics, finally with Wolf Kohn in hybrid systems and their potential commercial applications (an area now widely pursued in engineering and computer science under a variety of names.) (Received September 25, 2018)

1145-03-2823 **Joachim Mueller-Theys*** (mueller-theys@gmx.de). *On the Induction Problem.* Preliminary report.

Pure empiricism fails for $\sigma := \forall x\, \phi(x)$ (e. g. "all men are mortal") if parts of the structure $\mathcal{M}$ considered are inaccessible, whether by place, time, number, or in an other way. Then $\mathcal{M} \models \sigma$ simply has no such solution.

This calls for the other way of recognition: *deduction*: If evident, entailing axioms Σ can be detected, ideally $\mathcal{M} \models \Sigma$ and $\Sigma \vdash \sigma$, then $\mathcal{M} \models \sigma$, as desired. Though ostensibly mysterious, it can be that axioms are immediately discernible, whereas consequences are not.

However, the axiomatic method requires conceptual determination: If mortal is universal (to human), "Fosca" (or "MacLeod") was not human; if mortal is not universal, "Fosca" might be human.
(Received September 25, 2018)

1145-03-3011 **Ermek Nurkhaidarov*** (esn1@psu.edu). *On Generic Automorphisms.*

In this talk we discuss generic automorphisms of countable models. [?] introduces the notion of generic automorphism and it is used to show the small index property. Truss [?] defines another notion of generic automorphism. We study the relationship between these two types of generic automorphisms. [1] Hodges W., Hodkinson I., Lascar D., and Shelah, S., The small index property for !-stable !-categorical structures and for the random graph, Journal of the London Mathematical Society, vol. 48, no. 2 (1993), pp. 204-218. [2] Truss, J.K., Generic

automorphisms of homogeneous structures, Proceedings of the London Mathematical Society, vol. 64 (1992), pp. 121-141. (Received September 26, 2018)

05 ► Combinatorics

1145-05-62 **Stephen Melczer** (smelczer@gmail.com), 209 South 33rd Street, Philadelphia, PA 19104, **Greta Panova** (greta.panova@gmail.com), 209 South 33rd Street, Philadelphia, PA 19104, and **Robin Pemantle*** (pemantle@math.upenn.edu), 209 South 33rd Street, Philadelphia, PA 19104. *Counting partitions inside a rectangle.*

We find an asymptotic formula for the number of partitions of n whose Young diagrams fit inside an m by l rectangle, equivalently, the coefficients of the q-binomial coefficient m+l choose m. Our formula is valid throughout the regime where l, m and sqrtn are all comparable. Previously, sharp asymptotics were derived by Takacs (1986), only in the Central Limit regime, where n is within order m of l m / 2. Our approach is to solve a large deviation problem. We describe the tilted measure that produces configurations whose bounding rectangle has the given aspect ratio and is filled to the given proportion. Our results are sufficiently sharp also to yield the first asymptotic estimates on the consecutive differences of these numbers when n is increased by one and m and l remain the same, hence significantly refining Sylvester's unimodality theorem. (Received July 17, 2018)

1145-05-78 **Grant I. Fickes** and **Dylan P. Green***, TNU Department of Science and Mathematics, 333 Murfreesboro Pike, Nashville, TN 37210, and **Karen B. McCready**, **Kathleen M. Ryan**, **Nathaniel J. Sauerberg** and **Jill K. Stifano**. *Maximum proper diameter of 2-connected graphs.* Preliminary report.

A properly colored path is a path in which no two consecutive edges have the same color. A properly connected coloring of a graph is one in which there exists a properly colored path between every pair of vertices. Given a graph G with a properly connected coloring, the proper distance between any two vertices is the length of a shortest properly colored path between them. Furthermore, the proper diameter of G is the largest proper distance between any pair of vertices in G. Since the proper diameter of G is a function of its coloring, we can refer to the maximum proper diameter of G, that is, the maximum value of the proper diameter across all properly connected colorings of G.

If G has n vertices, a natural upper bound for its maximum proper diameter is $n-1$ but this value is not attainable for all graphs, such as graphs without a Hamiltonian path. We introduce a new family of graphs, $\mathcal{T}_n$ graphs, and we show that a 2-connected graph on n vertices with a properly connected 2-coloring has a maximum proper diameter of $n-1$ if and only if the graph is a $\mathcal{T}_n$ graph. (Received July 23, 2018)

1145-05-91 **Hayley Boynton**, **Ethan Burroughs*** (erb8134@g.rit.edu) and **Stephanie Gaston**. *On the Classification of Graphs Based on Their Rank Numbers.*

A k-ranking of a graph G is a function $f : V(G) \to \{1, 2, \dots, k\}$ such that if $f(u) = f(v)$ then every uv simple path contains a vertex w such that $f(w) > f(u)$. The rank number of G, denoted $\chi_r(G)$, is the minimum k such that a k-ranking exists for G. Rank number is a variant of graph colorings. It is known that given a graph G and a positive integer t the question of whether $\chi_r(G) \leq t$ is NP-complete. In this paper we completely characterize n-vertex graphs whose rank number is equal to $n-1$ or $n-2$. Also, we establish rank numbers of some dense subgraphs of complete graphs, some dense subgraphs of complete bipartite graphs, and complements of trees. In addition, we completely characterize the rank number of a subdivided star graphs and establish the rank number of all trees that contain a complete binary tree of the same height. (Received July 27, 2018)

1145-05-94 **Melanie Ferreri*** (fermj15@wfu.edu) and **Jacob Liddy** (liddyjacob@gmail.com). *Ramsey Problems for Cycles versus K_5.*

For graphs F, G, and H, if all red-blue edge colorings of F contain either red G or blue H as a subgraph, then we write $F \to (G, H)$. The Ramsey number for graphs G and H, denoted $R(G, H)$, is the smallest integer s such that $K_s \to (G, H)$. It is known that $R(C_n, K_5) = 4n - 3$ for $n \geq 5$. We prove that for all $n \geq 5$, any graph on $4n - 4$ vertices which does not contain C_n or an independent set of order 5 contains $4K_{n-1}$, and thus we characterize all Ramsey-critical graphs for C_n versus K_5. The graph $K_{s-1} \sqcup K_{1,t}$ is constructed by adding a vertex to K_{s-1} and joining it to t of its vertices. The star-critical Ramsey number $r_*(G, H)$ is defined as the minimum t such that $K_{s-1} \sqcup K_{1,t} \to (G, H)$, where $s = R(G, H)$. Values of $r_*(C_n, K_m)$ are known for $m \in \{3, 4\}$. In this work, we extend this to $m = 5$ and some cases for $m = 6$, and we present computational proofs of small cases and a computer-free proof of the general result for $n \geq 8$ and $m = 5$. We also compile a survey of known star-critical Ramsey numbers involving simple graphs such as cycles, paths, and fans. (Received July 28, 2018)

1145-05-103 **Amin Bahmanian*** (mbahman@ilstu.edu), Illinois State University, Campus Box 4520, Normal, IL 61790-4520. *Embedding Partial Latin Cubes.* Preliminary report.

A *latin square* of order n is an $n \times n$ array filled with n different symbols, each occurring exactly once in each row and exactly once in each column. There is celebrated result due to Ryser (1951) that a partial latin square A of order n in which cell (i, j) is filled if and only if $i \leq r$ and $j \leq s$ can be completed if and only if $N(i) \geq r + s - n$ for $i \in [n]$, where $N(i)$ denotes the number of elements of A that are equal to i. A *latin cube* of order n is a 3-dimensional array of n^3 cells so that each layer contains exactly one of $1, 2, \ldots, n^2$ (A layer is obtained by fixing one coordinate). In this talk, we provide a 3-dimensional analogue of Ryser's theorem, and we also obtain partial results for higher dimensions. Our results are closely related to completing partial factorizations of multipartite hypergraphs. (Received July 29, 2018)

1145-05-109 **Alejandra Brewer*** (breweralie@gmail.com), Florida Southern College, Mathematics, 111 Lake Hollingsworth Drive, Polk Science Building, Lakeland, FL 33801, **Adam Gregory** (adgregory1@catamount.wcu.edu), Western Carolina University, College of Arts & Sciences, Stillwell 426, Cullowhee, NC 28723, and **Quindel Jones** (quindel.d.jones@gmail.com), Department of Mathematics, Jackson State University, P. O. Box 17610, Jackson, MS, MS 39217. *The Asymmetric Index of a Graph and Families of Asymmetric Graphs.*

A graph is *asymmetric* if it has a trivial automorphism group. Asymmetric graphs were first studied by Erdős and Rényi in 1963. We define the *asymmetric index* of a graph, denoted $ai(G)$, to be the minimum of $r+s$ so that the resulting graph is asymmetric, where r is the number of edges removed from a graph and s is the number of edges added to a graph. We show that when $n \geq 8$, $ai(P_n) = 1$, $ai(C_n) = 2$, $ai(C_{n^2 \pm 1}(1, n)) = 2$, $ai(K_{1,n-1}) = 2n-9$, $ai(P_n + tP_1) = t$, $ai(C_n + tP_1) = t + 1$, $ai(C_{n^2 \pm 1}(1, n) + tP_1) = t + 1$, and $\lfloor \frac{6n}{7} \rfloor \leq ai(K_n) \leq n - 2$.

Erdős and Rényi also posed the question of finding the number of asymmetric trees. We give a partial result, showing that the number of asymmetric subdivided stars is approximately $q(n - 1) - \lfloor \frac{n-1}{2} \rfloor$ where $q(n)$ yields the number of ways to sum to n using distinct positive integers, found by Hardy and Ramanujan in 1918.

In addition, we investigate k-regular asymmetric Hamiltonian graphs and determine infinite families for $k = 3$ and $k = 4$. Furthermore, we show the existence of k-regular asymmetric Hamiltonian graphs for each $k > 6$. (Received September 26, 2018)

1145-05-127 **Jacob Liddy*** (liddyjacob@gmail.com), Department of Mathematics, Buchtel College of Arts and Sciences, The University of Akron, Akron, OH 44325-4002, and **Jeffrey M. Riedl** (riedl@uakron.edu), Department of Mathematics, Buchtel College of Arts and Sciences, The University of Akron, Akron, OH 44325-4002. *Generating All Odd Primitive Abundant Numbers with d Prime Divisors.*

For an integer n, if the sum of the proper divisors of n equals or exceeds n, then we say that n is an *abundant number*. An abundant number is said to be *primitive* if none of its proper divisors are abundant. An abundant number must have at least one primitive abundant divisor. In 1913, Dickson proved that for an arbitrary positive integer d there exists only finitely many odd primitive abundant numbers having exactly d distinct prime divisors. In 2017, all odd primitive abundant numbers with up to 5 distinct prime divisors have been found by Dičiūnas. In this paper, we describe a fast algorithm that finds all odd primitive abundant numbers with d distinct prime divisors. We use this algorithm to find all odd primitive abundant numbers with 6 distinct prime divisors. An abundant number n is said to be *weird* if no subset of the proper divisors of n sums to n. We use our algorithm to show that an odd weird number must have at least 6 prime divisors. (Received August 06, 2018)

1145-05-168 **Stephanie van Willigenburg*** (steph@math.ubc.ca), Department of Mathematics, University of British Columbia, 1984 Mathematics Road, Vancouver, BC V6T 1Z2, Canada. *The shuffle conjecture.*

This talk assumes no prior knowledge, and will be accessible to undergraduates.

Walks in the plane taking unit-length steps north and east from $(0, 0)$ to (n, n) never dropping below $x = y$, and parking cars subject to preferences, are two intriguing ingredients in a formula conjectured in 2005, now famously known as the shuffle conjecture.

Here we describe the combinatorial tools needed to state the conjecture. We also give key parts and people in its history, including its eventual algebraic solution by Carlsson and Mellit, which was published in the Journal of the American Mathematical Society in 2018. Finally, we conclude with some remaining open problems. (Received August 14, 2018)

1145-05-170 **Acadia Larsen*** (acadia.larsen01@utrgv.edu). *A Generalization of Partition Identities for First Differences of Partitions of n Into at most m Parts.*

We show for a prime power number of parts m that the first differences of partitions into at most m parts can be expressed as a non-negative linear combination of partitions into at most $m-1$ parts. To show this relationship, we combine a quasipolynomial construction of $p(n,m)$ with a new partition identity for a finite number of parts. We prove these results by providing combinatorial interpretations of the quasipolynomial of $p(n,m)$ and the new partition identity. We extend these results by establishing conditions for when partitions of n with parts coming from a finite set A can be expressed as a non-negative linear combination of partitions with parts coming from a finite set B. (Received September 04, 2018)

1145-05-188 **Stephen Melczer*** (smelczer@sas.upenn.edu). *Asymptotic regime change for multivariate generating functions.*

The study of multivariate generating functions comprises the domain of Analytic Combinatorics in Several Variables (ACSV). Analogously to the univariate case, the techniques of ACSV show how the singularities of a (typically rational) multivariate generating function dictate asymptotics of its coefficients. Unlike the univariate case, however, a multivariate generating function encodes a wealth of sequences. In particular, one can fix a direction vector $\mathbf{r} = (r_1, \ldots, r_d) \in \mathbb{R}^d_{>0}$ and examine asymptotics of the coefficient sequence $f_{nr_1,\ldots,nr_d}$ as n approaches infinity. Although this definition is a priori only non-trivial when $\mathbf{r}$ contains rational entries, the techniques of ACSV show asymptotics typically vary in a uniformly predictable way as $\mathbf{r}$ varies smoothly, meaning asymptotics can be defined in a limit sense for "generic" directions $\mathbf{r} \in \mathbb{R}^d_{>0}$. In this talk we discuss the first uniform study of non-generic directions, around which asymptotics sharply transition, and study how this transition between different regimes occurs.

Joint work with Yuliy Baryshnikov and Robin Pemantle. (Received August 17, 2018)

1145-05-218 **Justin Allman*** (allman@usna.edu). *Generalization of combinatorial partition identities via topology and geometry.*

The Durfee square identity (and generalizations) gives an effective way, going back to at least Cauchy, to count the number of partitions of an integer. When encoded in terms of generating functions, this identity has remarkable connections to the equivariant geometry of degeneracy loci by counting Betti numbers for group orbits in quiver representation spaces. We will describe this connection and further generalizations to the theory of Donaldson-Thomas invariants and quantum dilogarithm series. (Received August 20, 2018)

1145-05-226 **Nathan T. Moyer*** (nmoyer@whitworth.edu), Whitworth University, Math and Computer Science Dept., 300 W. Hawthorne Rd., Spokane, WA 99251. *A Walk Counting Combinatorial Identity for Recurrence Sequences.*

The beautiful and simple Fibonacci identity $f_n = \sum_{k\geq 0}\binom{n-k}{k}$ can be generalized to relate any recurrence relation of the form $a_n = pa_{n-1}+qa_{n-2}$ with arbitrary initial conditions to a sum involving binomial coefficients. This talk will introduce and prove this generalized identity by using a method that views the sequence's generating matrix as an adjacency matrix for a graph. By counting the number of closed walks of fixed length on this graph, one can demonstrate a correspondence that yields the generalized identity for the sequence a_n. (Received August 24, 2018)

1145-05-258 **Darren Narayan*** (dansma@rit.edu), School of Mathematical Sciences, Rochester Institute of Technnology, Rochester, NY 14623, **Alejandra Brewer** (breweralie@gmail.com), Mathematics Department, Florida Southern College, 111 Lake Hollingsworth Drive, Lakeland, FL 33801, **Adam Gregory** (agregory1@catamount.wcu.edu), Mathematics and Computer Science Department, Western Carolina University, Cullowhee, NC 28723, and **Quindel Jones** (quindel.d.jones@gmail.com), Dept. of Mathematics & Statistical Sciences, 1400 John R. Lynch Street, Jackson State University, Jackson, MS 39217. *The Asymmetric Index of a Graph.*

A graph G is asymmetric if its automorphism group of vertices is trivial. Asymmetric graphs were introduced by Erdős and Rényi in 1963 where they measured the degree of asymmetry of an asymmetric graph. They proved that any asymmetric graph can be made non-asymmetric by removing some number r of edges and/or adding adding some number s of edges, and defined the degree of asymmetry of a graph to be the minimum value of $r+s$. In this paper, we define another property that how close a given non-asymmetric graph is to being asymmetric. We define the asymmetric index of a graph G, denoted $ai(G)$, to be the minimum of $r+s$ in order to change G into an asymmetric graph.

We investigate the asymmetric index of both connected and disconnected graphs and present new results: $ai(P_n) = 1$; $ai(C_n) = 2$; $ai(W_n) = 2$; for $n \geq 6$, $\lfloor \frac{n-1}{2} \rfloor \leq ai\,(K_{1,n-1}) \leq n-3$; for $n \geq 8$, $\lfloor \frac{6n}{7} \rfloor \leq ai\,(K_n) \leq n-2$ for all $r, s \geq 2$; $ai\,(P_r \times P_s) = 1$; for $r \geq 2, s \geq 3$; $ai\,(P_r \times C_s) = 2$; and for $r, s \geq 10$, $ai\,(C_r \times C_s) = 3$. (Received August 26, 2018)

1145-05-270 **Kevin K Ferland*** (kferland@bloomu.edu), Mathematical and Digital Sciences, Bloomsburg University of PA, Bloomsburg, PA 17815. *Advancing Results in Maximum Toughness.*

Suppose a graph represents a computer network. The toughness of that graph is then a measure of how well the network can handle a computer-disabling attack seeking to maximize the ratio of resultant components left behind to disabled computers. Thus, given n computers and m cables with which to directly connect pairs of computers, it is preferable to build the toughest possible network. That is, we are interested in the maximum toughness among graphs with n vertices and m edges. After formally defining the graph vulnerability parameter toughness, we survey the known results on the maximum toughness among graphs. Along with some new results, several conjectures and open questions are expressed and meant to serve as a call to arms on this problem. (Received August 27, 2018)

1145-05-271 **Gary Gordon** and **Keith Vreeland*** (vreelank@lafayette.edu). *Leafiness of Trees.* Preliminary report.

For each subtree S of a given tree T, we compute the ratio of the number of leaves of S to the number of vertices of S. Using this statistic in a variety of ways, we give several definitions of global and local versions of the *leafiness* of a tree. For the global invariants, we are interested in families of trees that maximize or minimize the leafiness. For a fixed tree, we consider which vertices maximize and minimize the local versions of these invariants. In particular, we consider the leafiness for the *center, centroid,* and *core* of the tree. (Received August 27, 2018)

1145-05-279 **Mark E. Kidwell*** (mark_peggy@verizon.net), 368 Dewey Drive, Annapolis, MD 21401. *T.S.Michael's joint work on intrinsically knotted graphs.*

In a 2010 paper, T.S.Michael, Brenda Johnson and the speaker proved that any graph with 20 edges or fewer can be embedded in 3-space so that each cycle in the graph is unknotted. This bound is best possible, since Conway and Gordon had proved in 1983 that the complete graph K(7), with 21 edges, is unknotted. The proof makes heavy use of the delta-wye transformation. (Received August 28, 2018)

1145-05-297 **Curtis Bennett*** (curtis.bennett@csulb.edu), **Juan Carrillo**, **John Machecek** and **Bruce E. Sagan**. *Combinatorial Lattice Path Interpretations of Lucas Analogues.*

The Lucas sequence is a sequence of polynomials in s and t defined recursively by $\{0\} = 0$, $\{1\}$=1, and $\{n\} = s\{n-1\} + t\{n-2\}$ for $n \geq 2$. For $s = 1$ and $t = 1$, $\{n\}$ is the nth Fibonacci number. Given a quantity which is expressed in terms of products and quotients of nonnegative integers, we obtain Lucas analogues by replacing each factor of n in the expression with $\{n\}$. Using lattice paths, we give combinatorial interpretations for the Lucas analogues of the binomial coefficients as well as the Catalan numbers and their relatives, such as those for finite Coxeter groups. We also give combinatorial proofs of certain Lucas analogue identities. (Received August 29, 2018)

1145-05-304 **Robert Davis*** (rdavis@hmc.edu), 320 E. Foothill Blvd., Claremont, CA 91711. *Using Lattice Polytopes to Study Combinatorial Neural Codes.*

Combinatorial neural codes are 0/1 vectors that are used to model the co-firing patterns of a set of place cells in the brain. One wide-open problem in this area is to determine when a given code can be algorithmically drawn in the plane as a Venn diagram-like figure. A sufficient condition to do so is for the code to have a property called k-inductively pierced. Gross, Obatake, and Youngs recently used toric algebra to show that a code on three neurons is 1-inductively pierced if and only if the toric ideal is trivial or generated by quadratics. No result is known for additional neurons in the same generality.

In this talk, we study two infinite classes of combinatorial neural codes in detail. For each code, we explicitly compute its universal Gröbner basis. This is done for the first class by recognizing that the codewords form a Lawrence-type matrix. With the second class, this is done by showing that the matrix is totally unimodular. These computations allow one to compute the state polytopes of the corresponding toric ideals, from which all distinct initial ideals may be computed efficiently. Moreover, we show that the state polytopes are combinatorially equivalent to well-known polytopes: the permutohedron and the stellohedron. (Received August 29, 2018)

1145-05-325 **Sally Cockburn*** (scockbur@hamilton.edu), 198 College Hill Road, Clinton, NY 13323.
Homomorphic Preimages of Graphs.

A graph G is a homomorphic preimage of another graph H, or equivalently G is H-colorable, if there exists a graph homomorphism $f : G \to H$. A geometric graph $\overline{G}$ is a simple graph G together with a straight line drawing of G in the plane with the vertices in general position. A geometric homomorphism (resp. isomorphism) $\overline{G} \to \overline{H}$ is a graph homomorphism (resp. isomorphism) that preserves edge crossings (resp. and non-crossings). The homomorphism poset $\mathcal{G}$ of a graph G is the set of isomorphism classes of geometric realizations of G partially ordered by the existence of injective geometric homomorphisms. A geometric graph $\overline{G}$ is $\mathcal{H}$-colorable if $\overline{G} \to \overline{H}$ for some $\overline{H} \in \mathcal{H}$. In this talk, I will provide necessary and sufficient conditions for $\overline{G}$ to be $\mathcal{P}_n$-colorable for $n \geq 2$. (Received August 31, 2018)

1145-05-327 **Steven Schluchter*** (steven.schluchter@gmail.com), 4400 University Drive, MS 3F2, Fairfax, VA 22030, and **Tyrus Berry** (tberry@gmu.edu), 4400 University Drive, MS 3F2, Fairfax, VA 22030. *Applications of topological graph theory to 2-manifold learning.*

We show how, given a sufficiently large point cloud sampled from an embedded 2-manifold in $\mathbb{R}^n$, we may obtain a global representation as a cell complex with vertices given by a representative subset of the point cloud. The vertex spacing is based on obtaining an approximation of the tangent plane which insures that the vertex accurately summarizes the local data. Using results from topological graph theory, we couple our cell complex representation with the known Classification of Surfaces in order to classify the manifold. The algorithm developed gives a meaningful description of the embedding as a piecewise linear structure, which is obtained from combinatorial data by projecting points in the point cloud into estimates of tangent planes. (Received September 01, 2018)

1145-05-358 **Colin Defant*** (cdefant@princeton.edu), **Michael Engen** and **Jordan A Miller**.
Lassalle's Sequence Counts Uniquely Sorted Permutations.

Consider the sequence $(A_m)_{m\geq 1}$ satisfying $A_1 = 1$ and

$$A_m = (-1)^{m-1}C_m + \sum_{j=1}^{m-1} (-1)^{j-1}\binom{2m-1}{2m-2j-1} A_{m-j}C_j$$

for $m \geq 2$, where C_n is the n^{th} Catalan number. Lassalle gave an algebraic proof that the terms in this sequence are positive and increasing, settling a conjecture of Zeilberger. We show that A_{k+1} is the number of permutations $\pi \in S_{2k+1}$ satisfying $|s^{-1}(\pi)| = 1$, where s is West's stack-sorting map. This result follows from a more general bijection between certain weighted set partitions and relatively new combinatorial objects called *valid hook configurations*. These objects were introduced in order to provide a method, which we will describe, for computing $|s^{-1}(\pi)|$ for any permutation π. We discuss connections between valid hook configurations and cumulants arising in free probability theory. Finally, let $A_{k+1}(\ell)$ denote the number of permutations $\pi = \pi_1\pi_2\cdots\pi_{2k+1} \in S_{2k+1}$ satisfying $|s^{-1}(\pi)| = 1$ and $\pi_1 = \ell$. We show that the sequence $A_{k+1}(1), A_{k+1}(2), \ldots, A_{k+1}(2k+1)$ is symmetric, and we conjecture that it is log-concave. (Received September 03, 2018)

1145-05-359 **Joshua Fallon**, **Kirsten Hogenson*** (khogenson@coloradocollege.edu), **Lauren Keough**, **Mario Lomelí**, **Marcus Schaefer** and **Pablo Soberón**. *On the maximum rectilinear crossing number of spiders.*

The maximum rectilinear crossing number of a graph G is the maximum number of crossings in a good straight-line drawing of G in the plane. In a good drawing any two edges intersect in at most one point (counting endpoints), no three edges have an interior point in common, and edges do not contain vertices in their interior. A spider is a subdivision of $K_{1,k}$. In this talk, I will present both upper and lower bounds for the maximum rectilinear crossing number of spiders. While there are not many results on the maximum rectilinear crossing numbers of infinite families of graphs, our methods can be used to find the exact maximum rectilinear crossing number of $K_{1,k}$ where each edge is subdivided exactly once. This is a first step toward calculating the maximum rectilinear crossing number of arbitrary trees. (Received September 03, 2018)

1145-05-387 **Jenny Kaufmann*** (jennak@princeton.edu) and **Maria Chudnovsky**. *The Structure of Fork-Free C_4-Free Graphs.* Preliminary report.

A *claw* is the star graph $K_{1,3}$. A *fork* is the five-vertex tree with exactly three leaves; i.e. the graph obtained by adding a pendant edge to a claw. A graph is *H-free* if it contains no induced subgraphs isomorphic to H. A *hole* is a cycle C_n with $n > 3$. A graph is called *chordal* if it is hole-free. This talk will present a set of four simple operations that can be used to construct fork-free C_4-free graphs out of claw-free C_4-free subgraphs. In particular, we show that a graph G is fork-free and C_4-free if and only if it can be constructed by starting with a claw-free C_4-free subgraph $G_0 \subseteq G$ and applying a sequence of these operations. Furthermore, the operations preserve the number of holes in the graph, and hence G is chordal if and only if G_0 is chordal. (Received September 15, 2018)

1145-05-390 **Mojtaba Moniri*** (mojtaba.moniri@normandale.edu). *Binary subtrees with fewest labeled paths; simulations and illustrations.*

Complete ternary trees T of depth $n \geq 1$ with $\{0,1\}$-labeled edges, and their complete binary subtrees of that depth which have as few path labels as possible were considered by Downey-Greenberg-Jockusch-Milans in their 2011 paper. For such an edge-labeled tree T, its weight $f(T)$ was defined as the minimum number of path labels possible for such a binary subtree. For a fixed depth n, the maximum of the weight of T over all its 0-1 edge-labelings was denoted $f(n)$. Their main results were bounds on f and certain consequences in computability theory. In the introductory parts they showed that for $n \leq 4$, $f(n) = n$. They also announced $f(5) = 8$; their proof is presented here and a similar method is used to show $f(6) \geq 10$. Milans asked what the expected value of $f(T)$ (with T of a fixed depth n) is. We deal with cases of the first few n. E.g., among the 2^{39} trees of depth 3 it is $\frac{31033}{16384}$. For such small depths, we run simulations on random samples and observe close means. For depth 4, our simulations indicate weight 1-4 trees to constitute $\approx 0.4^{-}\%, 36\%, 56^{+}\%$, and 7%, respectively, of the 2^{120} depth-4 trees. We present examples and provide analysis for each of the possible values of $f(T)$ for such small n. (Received September 05, 2018)

1145-05-407 **Anant Godbole*** (godbolea@etsu.edu). *Universal cycles, pattern avoiding permutations, and generalized arc sine distributions.* Preliminary report.

In this talk, we give three contexts in which lattice path combinatorics is encountered. The contexts are contained in the title of the talk, and Catalan numbers as well as Catalan convolutions play an important role. (Received September 05, 2018)

1145-05-433 **Ryan R Martin**, **Abhishek Methuku**, **Andrew Uzzell** and **Shanise Walker*** (walkersg@uwec.edu). *The size of a family forbidding the $Y_{k,2}$ poset and its dual.*

The poset $Y_{k,2}$ consists of $k+2$ distinct elements $x_1, x_2, \ldots, x_k, y_1, y_2$, such that $x_1 \leq x_2 \leq \cdots \leq x_k \leq y_1, y_2$. The poset $Y'_{k,2}$ is the dual poset of $Y_{k,2}$. The sum of the k largest binomial coefficients of order n is denoted by $\Sigma(n,k)$. Let $\mathrm{La}^\sharp(n, \{Y_{k,2}, Y'_{k,2}\})$ be the size of the largest family $\mathcal{F} \subset 2^{[n]}$ that contains neither $Y_{k,2}$ nor $Y'_{k,2}$ as an induced subposet. Methuku and Tompkins proved that $\mathrm{La}^\sharp(n, \{Y_{2,2}, Y'_{2,2}\}) = \Sigma(n,2)$ for $n \geq 3$ and conjectured the generalization that if $k \geq 2$ is an integer and $n \geq k+1$, then $\mathrm{La}^\sharp(n, \{Y_{k,2}, Y'_{k,2}\}) = \Sigma(n,k)$. On the other hand, it is known that $\mathrm{La}^\sharp(n, Y_{k,2})$ and $\mathrm{La}^\sharp(n, Y'_{k,2})$ are both strictly greater than $\Sigma(n,k)$. In this talk, we introduce a simple approach, motivated by discharging, to prove this conjecture. (Received September 06, 2018)

1145-05-474 **Lindsey-Kay Lauderdale*** (llauderdale@towson.edu), **Christina Graves** and **Stephen Graves**. *Edge-minimal Graphs with Given Generalized Quaternion Automorphism Group.* Preliminary report.

For a finite group G, let $e(G,m)$ denote the minimum number of edges among all graphs with m vertices and automorphism group isomorphic to G; if no such graphs exists, then consider $e(G,m)$ to be undefined. This invariant is the subject of prior research by several authors, but its value is known only for two finite groups and a few other infinite families of finite groups. In this talk, we will consider the value of $e(Q_{2^n}, m)$ for the generalized quaternion group, Q_{2^n}, where $n \geq 3$. Specifically, if $m \geq 2^{n+1}$, we determine the value of $e(Q_{2^n}, m)$; the value of $e(Q_{2^n}, m)$ is undefined provided $m < 2^{n+1}$. Additionally, we will discuss the sizes of connected edge-minimal graphs with quaternion symmetry and conclude with some open questions on the value of $e(G,m)$ in general. (Received September 07, 2018)

1145-05-535 **Pamela E. Harris*** (peh2@williams.edu), 33 Stetson Court, Williamstown, MA 01267, and **Dalia K. Luque**, **Claudia Reyes Flores** and **Nohemi Sepulveda**. *Broadcast Domination of Triangular Matchstick Graphs and the Triangular Lattice.*

Blessing, Insko, Johnson and Mauretour gave a generalization of the domination number of a graph G called the (t,r) *broadcast domination number* which depends on the positive integer parameters t and r. In this setting, a $v \in V$ is a *broadcast vertex of transmission strength* t if it transmits a *signal* of strength $t - d(u,v)$ to every vertex $u \in V$ with $d(u,v) < t$. Given a set of broadcast vertices $S \subseteq V$, the *reception* at vertex u is the sum of the transmissions from the broadcast vertices in S. The set $S \subseteq V$ is called a (t,r) *broadcast dominating set* if every vertex $u \in V$ has a reception strength $r(u) \geq r$ and for a finite graph G the cardinality of a smallest broadcast dominating set is called the (t,r) broadcast domination number of G. In this talk, we consider the infinite triangular grid graph and define *efficient* (t, r) broadcast dominating sets as those broadcasts that minimize signal waste. Our main result constructs efficient (t, r) broadcasts on the infinite triangular grid graph for all $t \geq r \geq 1$ and provides upper bounds for the (t, r) broadcast domination numbers for triangular matchstick graphs when $(t, r) \in \{(2, 1), (3, 1), (3, 2), (4, 1), (4, 2), (4, 3), (t, t)\}$. (Received September 11, 2018)

1145-05-544 **Walter Morris*** (wmorris@gmu.edu) and **Mac Gallagher** (jmgallagher36@gmail.com). *A Proof of the Strict Monotone 5-step Conjecture.*

A computer search through the oriented matroid programs with dimension 5 and 10 facets shows that the maximum strictly monotone diameter is 5. Thus $\Delta_{sm}(5, 10) = 5$. This enumeration is analogous to that of Bremner and Schewe for the non-monotone diameter of 6-polytopes with 12 facets. Similar enumerations show that $\Delta_{sm}(4, 9) = 5$ and $\Delta_m(4, 9) = \Delta_m(5, 10) = 6$. We shorten the known non-computer proof of the strict monotone 4-step conjecture. (Received September 09, 2018)

1145-05-600 **Yuliy Baryshnikov**, **Stephen Melczer** and **Robin Pemantle*** (pemantle@math.upenn.edu), 209 South 33rd Street, Philadelphia, PA 19104, and **Armin Straub**. *Extracting coefficients of symmetric rational functions.*

ACSV finds asymptotics for coefficients of multivariate rational generating functions. The procedure is usually automatic once the geometry can be established that locates the dominant singularity. We show how the difficulty of locating this singularity can be greatly reduced in the case where the generating function is symmetric. (Received September 11, 2018)

1145-05-602 **Federico Castillo** and **Jose Alejandro Samper***, 1365 Memorial Drive, Ungar 505, Coral Gables, FL 33146. *Finiteness theorems for matroid complexes with prescribed homotopy type.*

It is well known that the independence complex of any matroid without coloops is homotopy equivalent to a wedge of k > 0 equidimensional spheres. We prove that if the dimension and the number of spheres is fixed, then only finitely many such independence complexes exist. This counterintuitive property leads to new structural questions such as upper and lower bound theorems/conjectures for matroids based on the two parameters mentioned. (Received September 11, 2018)

1145-05-607 **William J. Keith*** (wjkeith@mtu.edu), 1400 Townsend Dr, Fisher 316, Houghton, MI 49931. *Iterated differences in Gaussian coefficients.*

In the Gaussian coefficients $\begin{bmatrix} j+k \\ k \end{bmatrix}_q = \sum_{n=0}^{jk} p(n; j, k)q^n$, the second differences $p(n + 2; j, k) - 2p(n + 1; j, k) + p(n; j, k)$ exhibit, for some indexes k, a striking separation between their values at even and odd n. We prove that this property holds for small k and consider possible underlying combinatorial explanations. Confirmation of the full phenomenon is still open. (Received September 11, 2018)

1145-05-609 **Nicholas A. Loehr***, 225 Stanger Street, 460 McBryde Hall, Blacksburg, VA 24060-0123, and **Kyungyong Lee** and **Li Li**. *Chain decompositions for q, t-Catalan numbers.*

The *q, t-Catalan numbers* $C_n(q, t)$ are polynomials in q and t that reduce to the ordinary Catalan numbers when $q = t = 1$. These polynomials have important connections to representation theory, algebraic geometry, and symmetric functions. Work of Garsia, Haglund, and Haiman has given us combinatorial formulas for $C_n(q, t)$ as sums of Dyck lattice paths weighted by area and dinv. This talk continues an ongoing quest for a bijective proof of the symmetry property $C_n(q, t) = C_n(t, q)$.

We conjecture some structural decompositions of Dyck objects into infinite chains that can be paired up to prove the symmetry of some coefficients in $C_n(q, t)$. The chains are built from certain initial objects by applying an operator that increases dinv by 1 and reduces area by 1. A remarkable feature of these chains is that they do not depend on n but explain the joint symmetry for all n simultaneously. The chain construction leads to a combinatorial proof that for $0 \leq k \leq 9$ and all n, the terms in $C_n(q, t)$ of total degree $\binom{n}{2} - k$ obey the required symmetry property. (Received September 11, 2018)

1145-05-612 **Nicholas A. Loehr***, 225 Stanger Street, 460 McBryde Hall, Blacksburg, VA 24060, and **T. S. Michael**. *The combinatorics of evenly spaced binomial coefficients.* Preliminary report.

A curious identity for binomial coefficients states that $\sum_k \binom{n}{km} = \frac{1}{m} \sum_{j=0}^{m-1} (1 + e^{2\pi ij/m})^n$. There are similar formulas for the sum of $\binom{n}{a}$ over all a's with a given remainder mod m. This talk undertakes a combinatorial exploration of these formulas emphasizing bijective proofs. Our goal is to find a combinatorial explanation of why these sums are "almost" $2^n/m$. We give a bijective proof that the minimum of the sums $\sum_k \binom{n}{km+r}$ equals $(2^n - \ell(n, m))/m$, where the "error term" $\ell(n, m)$ has an explicit combinatorial interpretation involving words satisfying certain parenthesis-matching conditions. Among other consequences, this leads to a novel combinatorial model for alternate Lucas numbers. (Received September 11, 2018)

1145-05-619 **Satyan Devadoss*** (devadoss@sandiego.edu). *An Introduction to the Combinatorics of Shape: Polygons, Polytopes, and Configurations.*

We present an overview of the rich and vast world of geometric and topological combinatorics through the particular lens of polygons, polytopes, and configurations. In particular, the interplay between these three ideas will showcase the beauty and elegance of this field. The talk will be accessible to a curious audience, and heavily infused with visual imagery. (Received September 24, 2018)

1145-05-678 **Marie Meyer** and **Tefjol Pllaha*** (tefjol.pllaha@gmail.com). *Additive codes associated to Laplacian simplices.*

We start with necessary background from lattice polytope theory, and show that the lattice points of the fundamental parallelepiped of a simplex form an abelian group. We focus on a class of simplices introduced by Braun and Meyer, called Laplacian simplices. To a reflexive Laplacian simplex we associate an additive code, which we study in detail. We end with some interesting open problems. This is joint work with Marie Meyer. (Received September 12, 2018)

1145-05-683 **Larry J. Gerstein*** (gerstein@cox.net). *A new approach to the graph isomorphism problem.* Preliminary report.

Graphs G and H with adjacency matrices A and B are isomorphic if and only if there is a permutation matrix P such that $B = P^{-1}AP$. Thus, similarity of A and B is a necessary condition for isomorphism of G and H. On the other hand, the inverse of a permutation matrix is its transpose, and therefore *congruence* of A and B via a unimodular matrix P is also a necessary condition for isomorphism of G and H. We will see that matrix non-congruence can demonstrate non-isomorphism even in situations where the associated adjacency matrices are similar. This approach can succeed even if A and B have the same invariant factors. (Received September 12, 2018)

1145-05-685 **Rebecca Lynn Jackson*** (rljackson@csustudent.net), 423 Lazy Hill Rd, Moncks Corner, SC 29461. *Introducing 3-path Domination.* Preliminary report.

A dominating set of a graph G is a set of vertices S such that for every $v \in V(G)$ either $v \in S$ or v is adjacent to a $v_1 \in S$. The domination number, $\gamma(G)$, is the minimum number of vertices needed to create a dominating set. Haynes and Slater introduced paired-domination in 1998. A paired-dominating set is a dominating set whose induced subgraph contains a perfect matching. The paired-domination number, $\gamma_p(G)$, is the minimum number of vertices needed to create a paired-dominating set. Building on paired-domination, we introduce 3-path domination. We define a 3-path dominating set of G to be $S = \{P_1, P_2, \ldots, P_k | P_i \text{ is a 3-path}\}$ such that the vertex set $V(S) = V(P_1) \cup V(P_2) \cup \cdots \cup V(P_k)$ is a dominating set and the 3-path domination number, $\gamma_{P_3}(G)$, to be the minimum number of 3-paths needed to dominate G. We have shown that the 3-path domination problem is NP-complete, so it is of interest to find bounds on $\gamma_{P_3}(G)$ and closed formulas for particular families of graphs such as Harary graphs, Hamiltonian graphs, and subclasses of trees. We will share these results along with generalizations of 3-path domination. Part of this material is based upon work supported by the NSF under grant no. DMS 1757616. (Received September 12, 2018)

1145-05-688 **Geir Agnarsson*** (math.geir@gmail.com), Dept. of Math. Sciences, 4400 University Drive, MS: 3F2, Exploratory Hall, room 4400, Fairfax, VA 22030. *How to vertex color acyclic digraphs and what is it good for?*

Graph coloring was certainly a topic close to T. S. Michael's heart as is evident in his keen interest in a variety of art gallery problems and the elegant proof of Steve Fisk of the original Art Gallery Problem of a simple polygon. One of the earliest topics I had the pleasure to discuss at length with T. S. Michael about was that of coloring vertices of an acyclic digraph in such a way that two vertices with a common ancestor receives distinct colors. Optimal such colorings by the smallest number of colors have connections to problems for hypergraphs, BIBDs and finite geometries. In this talk we describe some problems, results and connections that tickled T. S. Michael's fancy. (Received September 12, 2018)

1145-05-695 **Ashwin Sah*** (asah@mit.edu). *Improving the $\frac{1}{3}-\frac{2}{3}$ Conjecture for Width Two Posets.*

Extending results of Linial (1984) and Aigner (1985), we prove a uniform lower bound on the balance constant of a poset P of width 2. This constant is defined as $\delta(P) = \max_{(x,y)\in P^2} \min\{\mathbb{P}(x \prec y), \mathbb{P}(y \prec x)\}$, where $\mathbb{P}(x \prec y)$ is the probability x is less than y in a uniformly random linear extension of P. In particular, we show that if P

is a width 2 poset that cannot be formed from the singleton poset and the three element poset with one relation using the operation of direct sum, then

$$\delta(P) \geq \frac{-3 + 5\sqrt{17}}{52} \approx 0.33876\ldots.$$

This partially answers a question of Brightwell (1999); a full resolution would require a proof of the $\frac{1}{3} - \frac{2}{3}$ Conjecture that if P is not totally ordered then $\delta(P) \geq \frac{1}{3}$.

Furthermore, we construct a sequence of posets T_n of width 2 with $\delta(T_n) \to \beta \approx 0.348843\ldots$, giving an improvement over a construction of Chen (2017) and over the finite posets found by Peczarski (2017). Numerical work on small posets by Peczarski suggests the constant β may be optimal. (Received September 13, 2018)

1145-05-733 **Jonathan L Gross*** (gross@cs.columbia.edu), 86 Rittenhouse Circle, Newtown, PA 18940, **Toufik Mansour** (tmansour@univ.haifa.ac.il), 3498838 Haifa, PA, Israel, and **Thomas W Tucker** (ttucker@colgate.edu), Hamilton, NY 13346. *Partial Duals of Oriented Embeddings.*

We explore Chmutov's construction of *partial duality* as a topic of independent interest. Our perspective is largely that of rotation systems and permutations. As our main result, we derive a formula for the genus of a partial dual of an embedding, which is related to a problem posed by Moffatt. We use the main formula to calculate the *partial-dual genus polynomials* for a couple of infinite sequences of embedded graphs. (Received September 13, 2018)

1145-05-741 **Kim A.S. Factor** and **Larry J Langley***, Department of Mathematics, 3601 Pacific Ave, Stockton, CA 95211, and **Sarah K Merz**. *A Tight Lower Bound for the Split Domination Number of a Regular Tournament.*

A set of vertices, S, in a strongly connected digraph D, is split dominating provided it is: 1) dominating and 2) $D - S$ is trivial or not strongly connected. The split domination number of a strongly connected digraph is the minimum cardinality of a split dominating set for that digraph. We show that for any k-regular tournament, the split domination number is at least $\lceil \frac{2k+3}{3} \rceil$ and this bound is tight. (Received September 13, 2018)

1145-05-747 **Noah Kravitz*** (noah.kravitz@yale.edu). *Counting Simultaneous Core Partitions with d-Distinct Parts.*

An integer partition is called s-core if its associated Young diagram has no hook of length s, and we say that an integer partition has d-distinct parts if its consecutive parts differ by at least d. In this talk, we investigate the number $N_{d,r}(s)$ of integer partitions with d-distinct parts that are simultaneously s-core and $s + r$-core. After reducing this problem to the enumeration of certain finite subsets of the natural numbers, we prove several results for the regime $r \leq d$, including a recurrence relation that was conjectured by Sahin in 2018. We also derive generating functions, asymptotics, and exact formulas for $N_{d,r}(s)$ when r is within d of a multiple of s. Finally, we exhibit a surprising connection to A-restricted compositions. (Received September 13, 2018)

1145-05-748 **Jack E. Graver** and **Mark E. Watkins*** (mewatkin@syr.edu), Mathematics Department, Syracuse University, Syracuse, NY 13244-1150. *Lobe- and Edge-Transitivity of Countable Graphs of Connectivity 1.* Preliminary report.

Let $\mathbb{G}$ be the class of countably infinite graphs of connectivity 1. We give necessary and sufficient conditions for a graph in $\mathbb{G}$ to be lobe-transitive. We further show that given any biconnected graph L, any subgroup H of $\mathrm{Aut}(L)$, and a prescribed list of multiplicities of H-orbits, there exists a unique lobe-transitive graph $G \in \mathbb{G}$ whose lobes are isomorphic to L and such that the multiset of H-orbits of copies of L to which each vertex of G belongs is determined by the given list. These results are then applied to give necessary and sufficient conditions for a graph in $\mathbb{G}$ to be edge-transitive. (Received September 13, 2018)

1145-05-749 **Daniel Bienstock*** (dano@columbia.edu), Dept of IEOR, 500 W 120th St, New York, NY 10027. *Optimization problems with bounded width.* Preliminary report.

In recent work we have presented results on polynomial optimization problems whose intersection graph has fixed treewidth. Treewidth, via approximate discretization, yields linear programming formulations that provide provably good approximation and polynomial size. In this talk we will describe applications of these ideas to machine learning. A basic result is that given a fixed network, one can provide a uniform (i.e. universal) linear program such that any realization of training data gives rise to a face of the associated polyhedron; solving the optimization problem over that face yields a provably good approximation to training error. Joint work with G. Munoz (Montreal) and S. Pokutta (Georgia Tech). (Received September 13, 2018)

1145-05-771 **Thomas W. Tucker*** (ttucker@colgate.edu), 406 Williston Rd, PO Box 163, Sagamore Beach, MA 02562, and **Jonathan L. Gross** and **Toufik Mansour**. *Log-Concavity for Graph Imbedding Polynomials.* Preliminary report.

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 oriented surface of genus i. It has been conjectured that this polynomial is log-concave. If we begin instead with a specific imbedding (or ribbon graph), of G in a closed surface, orientable or not, there are other polynomials we can study. If the imbedding is orientable, there is the partial duality polynomial discussed in the previous talk. There is also the partial Petrie duality polynomial, where instead of looking at the partial dual over all choices of edge-induced subgraphs A, we instead give each of the edges of A an extra twist. Of course, now the imbedding may be non-orientable, so we count partial Petrie duals with given Euler genus, possibly partitioning by orientability and non-orientability. A natural question for all of these polynomials is whether they are log-concave. (Received September 14, 2018)

1145-05-790 **Bryan L Shader*** (bshader@uwyo.edu). *A matrix rank identity with applications to combinatorial matices.*

A T.S. Michael-esque proof a matrix rank identity will be given, and the identity will be utilized to give various combinatorial results about tournaments, biclique partitions, and Laplacians. (Received September 14, 2018)

1145-05-792 **Joanna A. Ellis-Monaghan*** (jellis-monaghan@smcvt.edu). *Origami Knotting in Graphs.* Preliminary report.

We present a knotting problem in spatial graphs arising from DNA self-assembly that involves Euler circuits as opposed to the cycles of intrinsically linked and knotted graphs. Design strategies for the origami method of self-assembly use a single circular (unknotted) strand of DNA called the *scaffolding strand* which must traverse all the edges of the target graph, subject to constraints on how it may pass through the vertices and how/if any edges are repeated. If the target structure is modeled as a graph embedded on an oriented surface in 3-space, then these routes correspond to *A-trails*, which are Eulerian circuits that turn either left or right at each vertex. If the surface is a sphere, then all A-trails in the target structure are necessarily unknotted and so provide possible scaffolding strand routes. On higher-genus surfaces however there are settings in which every A-trail is knotted. For geometrically embedded graphs that are not necessarily surface meshes, the initial challenge is formalizing the constraints on how the scaffolding strand may pass through vertices. These are captured *O-trails*, which generalize A-trails and provide a general framework in which to study origami knotted graphs, that is, graphs with knotted O-trails. (Received September 14, 2018)

1145-05-794 **Joshua Carlson*** (jmsdg7@iastate.edu). *Throttling for Zero Forcing and its Minor Monotone Floor.*

Zero forcing is a process on a graph in which the goal is to force all vertices to become blue by applying a color change rule. Throttling minimizes the sum of the number of vertices that are initially blue and the number of time steps needed to color every vertex in the graph. The minor monotone floor of zero forcing uses a variation of the standard color change rule. This talk will introduce the concept of using a zero forcing process to extend a given graph. These extensions will be used to give characterizations for throttling zero forcing and its minor monotone floor. (Received September 14, 2018)

1145-05-802 **Axel Brandt**, **Nathan Tenpas** and **Carl Yerger*** (cayerger@davidson.edu). *Planar Graphs with Girth 20 are Additively 3-choosable.*

The *additive choice number* of a graph G, denoted $ch_{\Sigma}(G)$, is the minimum positive integer k such that whenever each vertex is given a list of at least k positive integers, vertex labels can be chosen from respective lists in such a way that adjacent vertices have distinct sums of labels on their neighbors. Recently, bounds on the additive choice number have been obtained for planar graphs under certain girth assumptions. In this talk, we give a brief history of these bounds and present a proof that for a planar graph G with girth at least 20, $ch_{\Sigma}(G) \leq 3$. Our approach applies the Combinatorial Nullstellensatz to streamline arguments within a proof that uses the discharging method. (Received September 15, 2018)

1145-05-805 **Grant Fickes*** (gfick710@live.kutztown.edu) and **Wing Hong Tony Wong**. *Edge-Distinguishing Chromatic Number for Three-Legged Spiders.*

Let G denote a simple graph consisting of vertices and edges, where each edge connects two distinct vertices. When we color the vertices of G, each edge will then be labeled by the colors of the two vertices it connects. For example, if an edge connects a red vertex and a blue vertex, then this edge is labeled by $
$red, blue$
$. We call the coloring of G "edge-distinguishing" if all the edge labels are distinct, and the minimum number

of colors that we need to create an edge-distinguishing coloring is called the "edge-distinguishing chromatic number" (EDCN) of G. In previous literature by Al-Wahabi et al., the EDCN was found when G was a path and a cycle. In this presentation, I will expand their ideas to find the EDCN when G is a three-legged spider graph. (Received September 15, 2018)

1145-05-814 **Seyyedeh Tahereh Jalali*** (staherehjalali1358@gmail.com), 20 Elm-Sanat Blvd, 13548 Semnan, Semnan, Iran, and **Masoud Ghods** (mghods@semnan.ac.ir), 20 Elm-Sanat Blvd, 13548 Semnan, Semnan, Iran. *On K Banhatti indices.*

In this project, we introduce some connectivity indices of a graph. A topological index is a numeric quantity from the structural graph of a molecule. Let G = (V, E) be a connected graph. The K Banhatti indices were introduced by Kulli in 2016. They are defined as B1 (G) =Σ ue [dG (u) + dG (e)] and B2 (G) = Σ ue dG (u) dG (e), where ue means that the vertex u and edge e are incident and dG (e) denotes the degree of the edge e in G. In this work, formulas for the K Banhatti index of several derived graphs are obtained. Analogous to other topological polynomials, the K Banhatti-polynomial of graph G is also defined. We also determine K Banhatti and K Banhatti-polynomial for certain important chemical structures like nanotubes covered by C5 and C7. (Received September 15, 2018)

1145-05-818 **Beifang Chen**, **Mark Ellingham*** (mark.ellingham@vanderbilt.edu), **Nora Hartsfield**, **Serge Lawrencenko**, **Wenzhong Liu**, **Hui Yang**, **Dong Ye** and **Xiaoya Zha**. *The even-faced genus of complete graphs and the Even Map Color Theorem.*

The well-known Map Color Theorem extends the Four Color Theorem by providing a sharp bound for the chromatic number of a graph embeddable in a given surface. The bound was found by Heawood in 1890, but it took another 78 years to find all of the sharpness examples, using minimum genus embeddings of complete graphs. In 1975 Joan Hutchinson showed that a graph with an embedding in a given surface with all faces of even degree satisfies a stronger bound on its chromatic number. We have recently determined the minimum genus, both orientable and nonorientable, of embeddings of complete graphs in which all faces have even degree. These embeddings, and embeddings derived from them, provide sharpness examples for Hutchinson's bound except for a couple of surfaces of small genus. Thus, we now have a sharp Even Map Color Theorem. (Received September 15, 2018)

1145-05-847 **Lowell Abrams*** (labrams@gwu.edu) and **Vance Faber**. *Quadrangulated Immersions of Cubic Graphs in the Sphere.*

A quadrangulated immersion of a graph G in a surface S is a drawing of G in S so that each crossing is transversal, each point of crossing is formed by exactly two edges, and each connected region of the complement of G in S is bounded by [portions of] four edges of G. We discuss basic constraints on quadrangulated immersions of cubic graphs in the sphere, and demonstrate various methods of constructing such immersions, including methods for constructing non-isomorphic immersions of the same graph. (Received September 17, 2018)

1145-05-867 **Yukun Yao** and **Doron Zeilberger*** (doronzeil@gmail.com), Department of Mathematics, Rutgers University, Piscataway, NJ 08544. *An experimental mathematics approach to Parking Functions.*

We illustrate the experimental, empirical, approach to mathematics (that contrary to popular belief, is often rigorous), by using parking functions and their "area" statistic, as a case study. Our methods are purely finitistic and elementary, taking full advantage, of course, of our beloved silicon servants. (Received September 16, 2018)

1145-05-871 **Atsuhiro Nakamoto*** (nakamoto@ynu.ac.jp), Yokohama National University, Yokohama, Kanagawa 240-8501, Japan, and **Yuta Omizo**. *A new $Y\Delta$ equivalence class of projective planar maps.*

A map G on a closed surface F^2 is *k-representative* if every noncontractible closed curve on F^2 hits G at least k times. Randby proved that for any $k \geq 1$, any two *minor-minimal* k-representative maps on the projective plane P^2 (i.e., w.r.t. minor operations) can be transformed by $Y\Delta$-exchanges. So the class of minor-minimal k-representative maps on P^2 forms a $Y\Delta$-equivalence class.

Recently, finding a relation between a certain quadrangulation on P^2 and a rhombus tiling of a regular $2k$-gon, we proved that if G is a minor-minimal k-representative map on P^2, then the "medial graph" $M(G)$ can be regarded as a system of "straight" noncontractible curves on P^2 (where $M(G)$ is the 4-regular map with vertex set $E(G)$ such that two vertices e and e' are adjacent in $M(G)$ if and only if e and e' are consecutive on some facial walk in G). This fact enables us to give a intuitive proof of Ranbdy's theorem.

In our talk, extending the above observation on geometry, we find a new $Y\Delta$ equivalence class of projective planar maps, including those classes of minor minimal k-representative maps on P^2. (Received September 16, 2018)

1145-05-876 **Brice Huang*** (bmhuang@mit.edu), 500 Memorial Drive #434, Cambridge, MA 02139.
Cyclic Descents for General Skew Tableaux.

A cyclic descent function on standard Young tableaux of size n is a function that restricts to the usual descent function when n is omitted, such that the number of standard Young tableaux of given shape with cyclic descent set $D \subset [n]$ is invariant under any modulo n shift of D. The notion of cyclic descent was first studied for rectangles by Rhoades, and then generalized to certain families of skew shapes by Adin, Elizalde, and Roichman. Adin, Reiner, and Roichman proved that a skew shape has a cyclic descent map if and only if it is not a connected ribbon. Unfortunately, their proof is nonconstructive; until now, explicit cyclic descent maps are known only for small families of shapes.

In this paper, we construct an explicit cyclic descent map for all shapes where this is possible. We thus provide a constructive proof of Adin, Reiner, and Roichman's result. Our construction of a cyclic descent map generalizes many of the constructions in the literature. (Received September 16, 2018)

1145-05-912 **Guy Moshkovitz***, guymoshkov@gmail.com, and **Asaf Shapira**. *A Tight Bound for Hypergraph Regularity.*

The hypergraph regularity lemma — the extension of Szemeredi's graph regularity lemma to the setting of k-graphs — is one of the most celebrated combinatorial results obtained in the past decade. By now there are various (very different) proofs of this lemma, obtained by Gowers, Rodl et al. and Tao. Unfortunately, what all these proofs have in common is that they yield partitions whose order is given by the k-th Ackermann function. We prove that such Ackermann-type bounds are unavoidable for every k>=2, thus confirming a prediction of Tao. Prior to our work, the only result of this kind was Gowers' famous lower bound for graph regularity. (Received September 17, 2018)

1145-05-913 **Joseph Doolittle*** (jdoolitt@ku.edu). *Constructing Counterexamples to a Conjecture of Perles.*

In 1970, Micha Perles conjectured that facets of simple d-polytopes were exactly the $d-1$-regular, $d-1$-connected, induced, separating subgraphs of the vertex-edge graph of the polytope. This was proved false in Haase and Ziegler's 2002 paper, where they construct a counterexample starting with Bing's House with two rooms. In this talk, I will discuss how this construction can be simplified and generalized, as well as give methods to generate more starting points that lead to counterexamples with additional desirable properties. (Received September 17, 2018)

1145-05-927 **Connor Thomas Ahlbach*** (ahlbach@uw.edu), 1901 NE 85th St., Apt. 311, Seattle, WA 98115, and **Joshua P Swanson**. *Cyclic Sieving, Necklaces, Branching Rules, and Thrall's problem.*

The cyclic sieving phenomenon relates a statistic generating function on a finite set to a cyclic action on the same set. On the other hand, the higher Lie modules, first constructed by Thrall, have been heavily studied, but a combinatorial description of their decomposition into irreducibles is still open. We show that the cyclic sieving phenomenon of Reiner–Stanton–White together with necklace generating functions arising from work of Klyachko offer a remarkably unified, direct, and largely bijective approach to a series of results due to Kraśkiewicz–Weyman, Stembridge, and Schocker related to the so-called higher Lie modules and branching rules for inclusions the wreath product of cyclic and symmetric group into a symmetric group. This provides a relatively rare instance of cyclic sieving being used to derive results in representation theory rather than the other way around. Extending the approach gives monomial expansions for certain graded Frobenius series arising from a generalization of Thrall's problem. (Received September 17, 2018)

1145-05-941 **Hunter Rehm** (hunter.rehm@uvm.edu), **Alex Schulte*** (aschulte@iastate.edu), **Nathan Warnberg** (nwarnberg@uwlax.edu) and **Michael Young** (myoung@iastate.edu).
The anti-van der Waerden number of graphs.

The anti-van der Waerden number is the smallest r such that every exact r-coloring of G contains a rainbow k-term arithmetic progression. In this presentation the anti-van der Waerden number of a graph is investigated. In particular, bounds are found for the anti-van der Waerden number of a graph using radius and diameter conditions. Moreover, it is shown that the cartesian product of two graphs has an anti-van der Waerden number of at most 4. (Received September 17, 2018)

1145-05-942 **Yezhou Wu** and **Dong Ye***, 1301 E. Main St., Murfreesboro, TN 37132. *Circuit Covers of Highly Connected Signed Graphs.* Preliminary report.

A signed graph (G, σ) is a graph associated with a mapping $\sigma : E(G) \to \{-1, +1\}$. A cycle is positive if it has an even number of negative edges and negative otherwise. A barbell is a subgraph consisting of two negative cycles intersecting exactly at one vertex or two disjoint negative cycles joined by a path internally disjoint from the two cycles. A circuit is either a positive cycle or a barbell. A circuit cover is a family of circuits which cover all edges of G. It is known that a signed graph has a nowhere-zero flow if and only if it has a circuit cover. However, it is also known that a 3-connected signed graph may not have a circuit 4-cover. In this talk, we talk about the circuit k-cover and shortest circuit cover of highly connected signed graphs. (Received September 17, 2018)

1145-05-949 **Michael Tait*** (mtait@cmu.edu). *Using random polynomials in extremal graph theory.*

For a fixed integer k we consider the problem of how many edges may be in an n-vertex graph where no pair of vertices have t internally disjoint paths of length k between them. When $t = 2$ this is the notorious even cycle problem. We show that such a graph has at most $c_k t^{1-1/k} n^{1+1/k}$ edges, and we use graphs constructed via random polynomials to show that the dependence on t is correct when k is odd.

This is joint work with Boris Bukh and Sunny He (Received September 17, 2018)

1145-05-950 **Emily Marshall*** (marshalle@arcadia.edu) and **Michael Santana**. *Finding disjoint theta graphs.* Preliminary report.

For a graph G on exactly $4k$ vertices, Kawarabayashi proved that if $\delta(G) \geq \frac{5}{2}k$, then G contains k vertex-disjoint theta graphs. We extend this result and show that every graph G on at least $4k$ vertices with $\delta(G) \geq \frac{5}{2}k$ contains k vertex-disjoint theta graphs; this result is best possible when $4k \leq n < 5k$. For graphs on a large number of vertices, however, Chiba et al. proved that if $\delta(G) \geq 2k$, then G contains k vertex-disjoint theta graphs. We discuss when this minimum degree threshold might transition from $\frac{5}{2}k$ to $2k$. This work is joint with Michael Santana. (Received September 17, 2018)

1145-05-971 **sarah-marie belcastro*** (smbelcas@toroidalsnark.net) and **Ruth Haas**. *Color-induced subgraphs of Grünbaum colorings of triangulations.*

We consider properly edge 3-colored cellularly embedded cubic graphs and their dual Grünbaum-colored triangulations. The collection of edges of a single color induces a matching in the cubic graph and, in the dual triangulation, a *color-induced subgraph (CISG).*

Previous study of CISGs has regarded the properties of an embedding corresponding to all CISGs being connected—this has been characterized for the sphere and projective plane. In the present work, we focus on Hamilton cycles in embedded cubic graphs and the structure of corresponding CISGs in the dual triangulations. Unsurprisingly, the CISG structure depends on the embedding surface. For all surfaces, we characterize CISG structure in triangulations when the dual cubic graph has a Hamilton cycle. We also indicate conditions under which particular CISG structures in a triangulation reveal the existence of a Hamilton cycle in the dual cubic graph. As time permits, we will comment on other aspects of CISG structure.

This is joint work with Ruth Haas, University of Hawaii. (Received September 17, 2018)

1145-05-977 **Shane Chern*** (shanechern@psu.edu), Department of Mathematics, The Pennsylvania State University, University Park, PA 16802, and **Zhitai Li**. *Kanade–Russell conjectures and linked partition ideals.*

The concept of linked partition ideals, introduced by George Andrews in the 1970s, may play an important role in finding generating functions for various partition sets.

In this talk, I will interpret partition sets with certain difference-at-a-distance themes under this setting. These partition sets are closely related to the Kanade–Russell conjectures. In particular, I will recover six generating function identities due to Kanade and Russell, and Kursungoz. I will also present more identities of the same flavor.

This is joint work with Zhitai Li from Penn State University. (Received September 17, 2018)

1145-05-983 **Lauren M. Nelsen*** (lauren.nelsen@du.edu) and **Paul Horn**. *Rainbow spanning trees in general graphs.*

A rainbow spanning tree in an edge-colored graph is a spanning tree in which each edge is a different color. Carraher, Hartke, and Horn showed that for n and C large enough, if G is an edge-colored copy of K_n in which each color class has size at most $n/2$, then G has at least $\lfloor n/(C \log n) \rfloor$ edge-disjoint rainbow spanning trees. Here we strengthen this result by showing that if G is *any* edge-colored graph with n vertices in which each color appears on at most $\delta \cdot \lambda_1/2$ edges, where $\delta \geq C \log n$ for n and C sufficiently large and λ_1 is the second-smallest eigenvalue of the normalized Laplacian matrix of G, then G contains at least $\left\lfloor \frac{\delta \cdot \lambda_1}{C \log n} \right\rfloor$ edge-disjoint rainbow spanning trees. (Received September 17, 2018)

1145-05-996 **Kenta Ozeki*** (ozeki-kenta-xr@ynu.ac.jp), 79-2 Tokiwadai, Hodogaya-ku, Yokohama, 240-8501, Japan. *Spanning trees with few leaves in graphs on surfaces.*

This work is a joint work with Atsuhiro Nakamoto (Yokohama National University).

In a graph G, a cycle or a path is **Hamiltonian** if it contains all vertices of G. In 1956, Tutte proved that every 4-connected planar graph is Hamiltonian. Since planar graphs can be regarded as graphs on the sphere, it is natural to think about graphs on higher genus surfaces. With this direction, the most attractive conjecture is due to Nash-Willams and Grüunbaum, which says that every 4-connected graph on the torus is Hamiltonian. This conjecture is still open. Note that for any such a surface F^2 with genus more than the torus, there exist infinitely many 4-connected non-Hamiltonian graphs on F^2. However, we can expect the existence of some structures which have weaker (but still interesting) property than the Hamiltonicity. For example, it is unknown that whether every 4-connected graph on the nonorientable surface of crosscap number 3 has a Hamiltonian path. Similarly, the speaker conjectured that for any surface of Euler characteristic χ, there exists a spanning tree with at most $O(-\chi)$ leaves. In this talk, we will give a recent result concerning the conjecture. (Received September 18, 2018)

1145-05-1016 **Richard A Brualdi*** (brualdi@math.wisc.edu). *T.S. Michael and his Mathematics.*

T.S. Michael was my 13th PhD student receiving his degree in 1988 with a thesis entitled “The structure matrix of the class of multigraphs with a prescribed degree sequence”. Primarily interested in graphs and matrices, T.S.’s research spanned a a number of topics: (0,1)-matrix classes, permanents, tournaments, Hadamard matrices and designs, sphere of influence graphs, graph decompositions, block designs, and, of course, guarding art galleries. His 2009 book “How to guard an art gallery and other discrete mathematical adventures” illustrates his wonderful expository skills. His 2011 paper “Guards, Galleries, Fortresses, and the Octoplex” was awarded a prize for exposition by the MAA in 2012. In this talk I will first give some personal reminiscences about T.S. and his career, and then discuss some of his mathematical research. (Received September 18, 2018)

1145-05-1019 **Elanor West*** (ewest13@jhu.edu) and **Xiao Xie**. *Rendezvous Search on the Edges of Vertex-Transitive Solids.* Preliminary report.

A classic “rendezvous search” problem is the “astronaut problem,” in which two agents are placed on a sphere and move around until they meet. Research focuses on finding an optimal strategy for both agents to use. We consider a model that utilizes discrete units of time, with movement along the edges of vertex-transitive solids. The search ends when the two agents can see each other. We first examine the five platonic solids, then look at several larger Archimedean solids for comparison. We compare the mean times to meet on the solids under an unbiased random walk strategy, and we alter assumptions and strategies in various versions of the search to see how certain changes affect the mean time to end. One version involves the possibility of waiting on any given turn under both biased and unbiased random strategies. We also examine multi-step strategies, which involve a random step and a predetermined sequence of directions. The calculations of expected meeting times all involve first-step Markov chain decompositions. (Received September 18, 2018)

1145-05-1028 **Caleb Ji*** (caleb.ji@wustl.edu). *Distinguishing numbers and generalizations.*

The distinguishing number of a graph was introduced by Albertson and Collins as a measure of the symmetry contained in its automorphism group. Tymoczko extended this definition to faithful group actions on sets. In this talk, we first show a solution to an open problem on distinguishing numbers. We then generalize this notion further to distinguishing partitions, which naturally leads to a new partially ordered set on partitions. We show that the dominance order is a refinement of this order and raise a few open questions regarding its properties. We then introduce the distinguishing symmetric function and raise a question regarding the Schur-positivity of this polynomial for automorphism groups of graphs. We prove some special cases and outline a possible approach which relates distinguishing labelings of graphs to partitions of Cartesian powers of the vertex set. (Received September 18, 2018)

1145-05-1037 **Michael D. Weiner*** (mdw8@psu.edu), 3000 Ivyside Park, Altoona, PA 16601, and **Daniel Birmajer** and **Juan B. Gil**. *On factor-free Dyck words with half-integer slope.*

We study a class of rational Dyck paths with half-integer slope corresponding to factor-free Dyck words, as introduced by P. Duchon. We show that, for the slopes considered in this paper, the language of factor-free Dyck words is generated by an auxiliary language that we examine from the algebraic and combinatorial points of view. We provide a lattice path description of this language, and give an explicit enumeration formula in terms of partial Bell polynomials. As a corollary, we obtain new formulas for the number of associated factor-free generalized Dyck words. (Received September 18, 2018)

1145-05-1040 **Katie Anders*** (kanders@uttyler.edu), **Alissa S. Crans**, **Briana Foster-Greenwood**, **Blake Mellor** and **Julianna Tymoczko**. *Characteristics of graphs admitting only constant splines.*

We study the generalized graph splines introduced by Gilbert, Tymoczko, and Viel. We consider graphs that admit only constant splines and provide a characterization for splines on such graphs over the ring $\mathbb{Z}_m$. (Received September 18, 2018)

1145-05-1042 **Juan B. Gil*** (jgil@psu.edu), 3000 Ivyside Park, Altoona, PA 16601, and **Daniel Birmajer** and **Michael D. Weiner**. *On rational Dyck paths and the enumeration of factor-free Dyck words.*

Motivated by independent results of Bizley and Duchon, we study rational Dyck paths and their subset of factor-free elements. On the one hand, we give a bijection between rational Dyck paths and regular Dyck paths with ascents colored by factor-free words. This bijection leads to a new statistic based on the reducibility level of the paths for which we provide a corresponding formula. On the other hand, we derive a formula for the enumeration of factor-free words and give alternative formulas for various enumerative sequences that appear in the context of rational Dyck paths. (Received September 18, 2018)

1145-05-1056 **Ryan W Solava*** (ryan.w.solava@vanderbilt.edu) and **Mark Ellingham**. *Fine structure of 3-connected $K_{2,t}$-minor-free graphs.*

In this talk, I will discuss two results that describe the structure of graphs that avoid certain minors. The first of these is a structural characterization of 3-connected $K_{2,5}$-minor-free graphs. The second describes the structure of 3 and 4-connected $K_{2,t}$-minor-free graphs for any given t. This result gives some asymptotic information about the number of graphs in these families. (Received September 18, 2018)

1145-05-1072 **Neil Hindman*** (nhindman@aol.com). *The research of 20 Ph.D. students at Howard University.*

I shall discuss, necessarily very briefly, the research of my twenty Ph.D. students at Howard University from 1987 through 2017. (Received September 18, 2018)

1145-05-1113 **Rosa C Orellana***, Department of Mathematics, 6188 Kemeny Hall, Hanover, NH 03755, and **Mike Zabrocki** (zabrocki@mathstat.yorku.ca), Department of Mathematics and Statistics, York University, Toronto, Ontario M3J 1P3, Canada. *Symmetric functions and the symmetric group.*

The representation theory of the symmetric group and the general group are deeply connected to symmetric functions. And it is well known that Schur functions evaluate to characters of the general linear group.

In this talk I will discuss basis of the ring of the symmetric functions. This basis evaluates to the characters of the symmetric group just as the Schur functions evaluate to the characters of the general linear group. The structure coefficients when we multiply our basis elements are the stable Kronecker coefficients. In this talk I will discuss the combinatorics related to this new basis and how it relates to the partition algebra. (Received September 19, 2018)

1145-05-1161 **Ji Young Choi*** (jychoi@ship.edu), 1871 Old Main Dr, Shippensburg, PA 17257. *Digit Sum of Integers Generalizing Binomial Coefficients.* Preliminary report.

For any positive integer $b > 1$, we use the digit sum of base-b representation of integers to define four different generalization of binomial coefficients. One generalization is identified as the extended binomial coefficients, and we express every other generalization in terms of the extended binomial coefficients. We also express every generalization in terms of binomial coefficients and find the explicit formula for each generalization. (Received September 19, 2018)

1145-05-1162 **T. S. Michael** and **Val Pinciu*** (pinciuv1@southernct.edu). *Guarding Art Galleries, Fortresses and Prison Yards.*

The original art gallery problem, posed by Klee, asks for the minimum number of guards that are always sufficient and sometimes necessary to protect the interior of a polygon with n sides. Over the years numerous variations of this problem have been proposed and studied with different restrictions placed on the shape of the galleries and the power of guards. We extend and unify most known results about guarding orthogonal polygons by introducing the same-sign diagonal graphs of a convex quadrangulation and applying results about vertex covers for graphs. Our approach also yields new theorems and often guarantees two disjoint vertex guard sets of relatively small cardinality. (Received September 19, 2018)

1145-05-1169 **Jared Marx-Kuo*** (jmarxkuo@uchicago.edu), **Jiyang Gao** and **Vaughan McDonald**. *The Sandpile Group of Cayley Graphs.*

The **Abelian Sandpile Model** and its recurrent configurations, known as the **Sandpile group**, are abundant in modern mathematics and have combinatoric, algebraic, and geometric descriptions. Past work has focused on the sandpile group of the n-dimensional hypercube. In this project, we perform a more general analysis on the Cayley graph of the group $\mathbb{F}_2^r$ and any of its generating sets. While the p-sylow component of the sandpile group has been classified for $p \neq 2$, significantly less is known about the 2-sylow component. In this paper, we use representation theory and ring theory to prove a sharp upper bound for the largest 2-sylow subgroup in the sandpile group of an arbitrary Cayley graph. We also partially classify the number of 2-sylow subgroups in the sandpile group and make further reductions into determining its structure. Using these reductions, we provide a full classification of the sandpile group for the $r = 2$ case and other enlightening results for small r cases. (Received September 26, 2018)

1145-05-1197 **Tad White***, 17100 Science Drive, Bowie, MD 20715. *Quota Trees.* Preliminary report.

Usually, a graph search ends when each vertex has been reached once. Quota trees arise when you need to arrive at each vertex a prescribed number of times. We use Lagrange inversion to count the resulting search trees (or forests) in a digraph in terms of a determinant which generalizes the graph Laplacian. We will discuss applications to finite automata and other areas, indicate a number of known enumeration problems which are really about quota trees, and state some open questions. (Received September 19, 2018)

1145-05-1198 **Marshall M. Cohen*** (marshall.cohen@morgan.edu). *Elements of finite order in the Riordan group.*

We consider elements $\big(g(x), F(x)\big)$ in the Riordan group $\mathcal{R}$ over a field $\mathbb{F}$ of characteristic 0, where $g(x) = g_0 + g_1x + g_2x^2 + \cdots$, $g_0 \neq 0$, and $F(x) = \omega x + f_2x^2 + \cdots$, $\omega \neq 0$. We answer some foundational questions about elements of finite order in $\mathcal{R}$.

Theorem 1 states that $\big(g(x), F(x)\big)$ has finite order n in $\mathcal{R}$ if and only if (a) $n = \ell.c.m\big(\mathrm{ord}(g_0), \mathrm{ord}(\omega)\big)$ in $\mathbb{F} \setminus \{0\}$ and (b) $F(x)$ has finite compositional order and (c) There exists $h(x) = h_0 + h_1x + \cdots$, $h_0 \neq 0$ such that $g(x) = g_0 \cdot \Big(h(x)/\,h\big(F(x)\big)\Big)$.

Theorem 2 classifies elements of finite order in $\mathcal{R}$ up to conjugation.

Theorem 3 determines the set of eigenvectors of a given element $\big(g(x), F(x)\big)$ of finite order in $\mathcal{R}$. Finally we note that knowledge of the eigenvectors leads to interesting combinatorial formulas. (Received September 19, 2018)

1145-05-1202 **Danielle Wang*** (diwang@mit.edu). *On roots of Wiener polynomials of trees.*

The *Wiener polynomial* of a connected graph G is the polynomial $W(G;x) = \sum_{i=1}^{D(G)} d_i(G)x^i$ where $D(G)$ is the diameter of G, and $d_i(G)$ is the number of pairs of vertices at distance i from each other. We examine the roots of Wiener polynomials of trees. We prove that the collection of real Wiener roots of trees is dense in $(-\infty, 0]$, and the collection of complex Wiener roots of trees is dense in $\mathbb{C}$. We also prove that the maximum modulus among all Wiener roots of trees of order $n \geq 31$ is between $2n - 15$ and $2n - 16$, and we determine the unique tree that achieves the maximum for $n \geq 31$. Finally, we find trees of arbitrarily large diameter whose Wiener roots are all real. (Received September 20, 2018)

1145-05-1205 **N. Jonoska*** (jonoska@mail.usf.edu), **J. Durand-Lose** and **H.J. Hoogeboom**. *The Computational Power of Deterministic Tile Self-assembly.*

Complex DNA molecules that can build large two-dimensional arrays are modeled by square Wang tiles with colored edges. The assembly process is simulated by placing Wang tiles, one after another on the integer lattice $\mathbb{Z}^2$, where at least one edge between neighboring tiles has a matching color. The systems where assemblies with mismatched colors are allowed are considered 'non-cooperative'. We consider non cooperative binding, in deterministic (called *confluent*) tile self-assembly systems (TAS) and prove the standing conjecture that such systems do not have universal computational power. We observe that a confluent TAS has at most one maximal producible assembly, (an assembly that cannot grow further) $\alpha_{\max}$ and provide a characterization for $\alpha_{\max}$. To a given $\alpha_{\max}$ we associate a finite labeled directed graph such that every path visits at most two cycles, called *quipu*. We show that the union of all labels of paths in a quipu equals $\alpha_{\max}$, therefore giving a finite description for $\alpha_{\max}$. This finite description implies that $\alpha_{\max}$ is a union of semi-linear subsets of $\mathbb{Z}^2$ and therefore such systems cannot have universal computational power. (Received September 20, 2018)

1145-05-1234 **Sam Armon*** (sarmon1@macalester.edu) and **Tom Halverson** (halverson@macalester.edu). *Transition Matrices for Young's Representations of* S_n. Preliminary report.

The irreducible representations of the symmetric group S_n are indexed by integer partitions $\lambda \vdash n$. The corresponding simple modules are denoted $\{\mathsf{S}_n^\lambda \mid \lambda \vdash n\}$, and the dimension of S_n^λ equals the number f_λ of standard Young tableaux of shape λ. In the 1920s, A. Young defined two bases of S_n^λ — the natural and seminormal bases — by describing the action of $\sigma \in \mathsf{S}_n$ on vectors indexed by standard Young tableaux of shape λ. We give a formula for the entries in the transition matrix between the seminormal and natural bases, answering an open question in the representation theory of the symmetric group. Our method is to use a graph Γ_λ, which has vertices labeled by the standard tableaux of shape λ and colored edges corresponding to adjacent transpositions in S_n. This graph is the Hasse diagram of weak Bruhat order on standard tableaux. The entries in the transition matrix are calculated using weights on walks on Γ_λ. We generalize our method to the wreath product group $\mathsf{S}_n \wr \mathbb{Z}_r$ and the Iwahori-Hecke algebra $\mathsf{H}_n(q)$ of S_n. (Received September 20, 2018)

1145-05-1241 **Ana Luzon*** (anamaria.luzon@upm.es), ETSI Montes, Forestales y Medio Natural, Ciudad Universitaria s/n, 28040 Madrid, Spain, 28040 Madrid, Madrid, Spain. *On some complementary Riordan arrays.*

I am going to deal with the m-complementary of a Riordan array. In particular, I will compute Catalan triangle's complementary. Using this, I will provide an answer to Shapiro's question 4 proposed in 4RART in Madrid. I will compute the complementary for another examples of Riordan arrays. Moreover, I will propose some related questions. I am going to look for some symmetries within bi-infinite Riordan matrices with extra properties. In particular, I will solve $D^{\{}\perp\} = -D$ for D in the Riordan group. (Received September 20, 2018)

1145-05-1270 **Mehtaab Sawhney*** (msawhney@mit.edu), 290 Massachusetts Avenue, Cambridge, MA 02139, and **Ashwin Sah**. *On the Discrepancy Between Two Zagreb Indices.*

We examine the quantity

$$S(G) = \sum_{uv \in E(G)} \min(\deg u, \deg v)$$

over sets of graphs with a fixed number of edges. The main result shows the maximum possible value of $S(G)$ is achieved by three different classes of constructions, depending on the distance between the number of edges and the nearest triangular number. Furthermore we determine the maximum possible value when the set of graphs is restricted to be bipartite, a forest, or to be planar given sufficiently many edges. The quantity $S(G)$ corresponds to the difference between two well studied indices, the irregularity of a graph and the sum of the squares of the degrees in a graph. These are known as the first and third Zagreb indices in the area of mathematical chemistry.
(Received September 20, 2018)

1145-05-1284 **Yue Cai*** (ycai@math.tamu.edu) and **Catherine H. Yan**. *Rational parking functions.* Preliminary report.

The classical parking functions, enumerated by $(n+1)^{n-1}$, is the set of all sequences $(a_1, \ldots, a_n) \in [n]^n$ whose increasing rearrangement $b_1 \leq b_2 \leq \cdots \leq b_n$ satisfies $b_i \leq i$. In this talk, we will introduce the notion of rational parking functions indexed by a pair of coprime integers (a, b). We will present some enumerative results on the rational parking functions and discuss the more general case where $\gcd(a, b) \neq 1$. (Received September 20, 2018)

1145-05-1321 **Zhexiu Tu*** (tuzhexiu@gmail.com). *Circuit axiomatizations of symplectic matroids.*

One generalization of ordinary matroids is symplectic matroids. While symplectic matroids were initially defined by their collections of bases, there has been no cryptomorphic definition of symplectic matroids in terms of circuits. We give a definition of symplectic matroids by collections of circuits. As an application, we construct a class of examples of symplectic matroids from graphs in terms of circuits. (Received September 24, 2018)

1145-05-1350 **Amanda Lohss***, alohss@messiah.edu. *Regular Permutation Graphs.*

This talk will introduce permutation graphs, graphs whose edges correspond to inversions in permutations. One question of interest is how many permutation graphs are r-regular? There are numerous examples of r-regular permutation graphs, but certainty not all permutation graphs are regular. This talk will present an answer to this question. In fact, our research has shown that there are infinitely many connected r-regular permutation graphs for r>4. (Received September 21, 2018)

1145-05-1354 **Peter Doyle**, **Jay Pantone*** (jay.pantone@gmail.com) and **Everett Sullivan**. *How many chord diagrams have no short chords?* Preliminary report.

A chord diagram with n chords is a set of $2n$ points in a line connected in n pairs. Chord diagrams, sometimes called matchings, play an important role in mathematical biology, knot theory, and combinatorics, and as a result they have been intensely studied by mathematicians, computer scientists, and biologists alike. We use a combination of symbolic, analytic, and experimental methods to examine the enumeration of chord diagrams without short chords. (Received September 21, 2018)

1145-05-1368 **Tara Abrishami*** (tabrish1@jhu.edu) and **Edward Scheinerman** (ers@jhu.edu), Office of Engineering Graduate Acad Affairs, Wyman Park Building, 3rd Floor, Johns Hopkins University, Baltimore, MD 212128. *Eigenvalues of Cographs.* Preliminary report.

Cographs are a recursively defined family of graphs built from a single vertex by the operations of disjoint union and complement. The eigenvalues of a cograph's Laplacian are nonnegative integers, and we explore their combinatorial significance, including the case of randomly generated cographs. We are particularly interested in understanding the second smallest eigenvalue of the Laplacian (known as the algebraic connectivity). (Received September 21, 2018)

1145-05-1391 **Lorinda Leshock*** (lleshock@udel.edu). *Pappus Configurations in Finite Projective Planes.* Preliminary report.

In the classical projective planes both Desargues' theorem and Pappus' theorem hold. According to a result of Ostrom, the Desargues configuration can also be found in every finite projective plane of order greater than 3, classical or not. The existence of a Pappus configuration in every non-classical finite affine or projective plane is unknown. We study whether the Pappus configuration is present in all such planes. In particular, we show that in finite Hall affine or projective planes the Pappus configuration exists. More precisely, we prove that in finite Hall affine planes, the following strong version for the existence of the Pappus configurations holds. For every pair of lines ℓ_1, ℓ_2, every triple of points on ℓ_1 and every point on ℓ_2, two more points can be found on line ℓ_2 that define a Pappus configuration. (This is a joint work with Felix Lazebnik.) (Received September 23, 2018)

1145-05-1395 **Lara Dolecek***, Eng IV 56-147B, Los Angeles, CA 90024, and **Homa Esfahanizadeh** and **Ahmed Hareedy**. *Recent advances in spatially coupled codes and applications in data storage systems.*

In this talk, we will review recent results on finite-length spatially coupled (SC) codes, wth the primary focus on code design for data storage applications. We will present a combinatorial framework for constructing binary and non-binary SC codes, multidimensional SC codes, and demonstrate the effectiveness of these codes for a variety of practical storage channels. We will also briefly discuss future directions. (Received September 21, 2018)

1145-05-1408 **Torin Greenwood*** (greenwo1@rose-hulman.edu) and **Christine E Heitsch**. *Using Experimental Data to Deconvolve Structural Signals.*

The combinatorial arrangement of RNA base pairings encodes functional information, and a sequence is typically predicted to fold to a single minimum free energy conformation. But, an increasing number of RNA molecules are now known to fold into multiple stable structures. Discrete optimization methods are commonly used to predict foldings, and adding experimental data as auxiliary information improves prediction accuracy when there is a single dominant conformation. In this talk, we describe the challenges of extending the thermodynamic prediction approaches with experimental data to multimodal structural distributions. Using a probabilistic framework, we illustrate that with significant probability, current prediction models fail to recognize the presence of multiple structures. (Received September 21, 2018)

1145-05-1427 **Ahmad Abdi** and **Gerard Cornuejols***, gc0v@andrew.cmu.edu, and **Dabeen Lee**. *Intersecting restrictions in clutters.* Preliminary report.

A clutter is *intersecting* if the members do not have a common element yet every two members intersect. It has been conjectured that for clutters without an intersecting minor, total primal integrality and total dual integrality of the corresponding set covering linear system are equivalent. In this talk, we present a polynomial characterization of clutters without an intersecting minor. One important class of intersecting clutters comes from projective planes, namely the *deltas*, while another comes from graphs, namely the *blockers of extended odd holes.* Using similar techniques, we will provide a polynomial algorithm for finding a delta or the blocker of an extended odd hole minor. This result is quite surprising as finding a delta or an extended odd hole minor is NP-hard. (Received September 21, 2018)

1145-05-1449 **Tri Lai*** (tlai3@unl.edu), 8110 S 20th Street, Lincoln, NE 68512. *New duals of MacMahon's theorem.*

The enumeration of tilings dates back to the early 1900s when MacMahon proved his classical theorem on boxed plane partitions. The theorem yields an elegant product formula for the number of lozenge tilings of a hexagon on the triangular lattice. Ciucu and Krattenthaler recently found a striking asymptotic pattern of tiling number of hexagons with holes, called a 'dual' of MacMahon's theorem. In this talk, we investigate several new duals of MacMahon's theorem. We also present q-analogs of these results, which enumerate the corresponding plane-partitions-like structures by their volume. (Received September 22, 2018)

1145-05-1451 **Hana Kim*** (hakkai14@skku.edu), **Louis W Shapiro** and **Gi-Sang Cheon**. *Stretched Motzkin paths bounded from below and their applications.*

Let $S = \{(a,0),(b,1),(c,-1)\}$ be a step set where a,b,c are integers such that $a \geq 0$, $b,c > 0$. In this paper we enumerate the lattice paths using the step set S bounded from below by the horizontal line $y = -\alpha$ for a non-negative integer α. In particular, for Motzkin paths, going down to $y = -1$ could be thought of as being on probation in academic circles or being in critical condition in medical terms. We examine four types of probationary conditions which lead to new interesting statistics on several well-known lattice paths. We adopt Riordan group theory to enumerate several statistics on such paths. The enumeration also allows us to prove the conjectures on the recurrence relations of several sequences posed by R. J. Mathar in OEIS. (Received September 24, 2018)

1145-05-1485 **Cheyne Homberger*** (cheyneh@umbc.edu). *A Combinatorial Approach to Software Testing.*

The National Institute of Standards and Technology estimates that $60 billion dollars are spent each year due to inadequate software testing, despite the fact that 50-80% of development budgets go to testing. Testing every possible configuration is unrealistic for all but the smallest system, and so carefully designing a test strategy is essential for identifying and fixing errors. As systems become more complex and interconnected, errors become more difficult to detect.

A system which has thirty parameters has over a billion different configurations which must be tested to be 100% confident that the system is error-free. To reach 90% confidence, however, we need as few as 10 tests (and a few assumptions). Combinatorial testing applies the theory of combinatorial designs to produce series of tests which elicit errors (when they exist) efficiently and effectively. This area combines classical problems in math research — including a centuries old false conjecture by Euler — with real-world applications. (Received September 22, 2018)

1145-05-1496 **Tian-Xiao He*** (the@iwu.edu), Department of Mathematics, P. O. Box 2900, Bloomington, IL 61702. *On Sequence Characterization of Riordan Arrays.*

Abstract

We present the A-sequence characterization of Riordan arrays including the Riordan arrays with B-sequences and Pascal like matrices. The applications of sequence characterization to some centralizers of the Riordan group and some polynomial matrices are given. The subgroups characterized by A-sequences are studied. A combinatorial explanation of A-sequence characterization is also presented. (Received September 22, 2018)

1145-05-1500 **Paul Barry*** (pbarry@wit.ie), School of Science, Waterford Institute of Technology, Waterford, X91 K0EK, Ireland. *Generalized Catalan Numbers Associated with a Family of Pascal-like Triangles.* Preliminary report.

We find closed-form expressions and continued fraction generating functions for a family of generalized Catalan numbers associated with a set of Pascal-like number triangles that are defined by Riordan arrays. We express these generalized Catalan numbers as the moments of appropriately defined orthogonal polynomials. We also describe them as the row sums of related Riordan arrays. Links are drawn to the Narayana numbers and to lattice paths. We further generalize this one-parameter family to a three-parameter family. We use the generalized Catalan numbers to define generalized Catalan triangles. We define various generalized Motzkin numbers defined by these general Catalan numbers. Finally we indicate that the generalized Catalan numbers can be associated with certain generalized Eulerian numbers by means of a special transform. (Received September 22, 2018)

1145-05-1502 **Erik A Metz*** (emetz@umd.edu), 10248 Bristol Channel, Ellicott City, MD 21042. *Upper and Lower Bounds on Zero-Sum Generalized Schur Numbers.*

Let $S_{\mathfrak{z}}(k,r)$ be the least positive integer such that for any r-coloring $\chi : \{1,2,\ldots,S_{\mathfrak{z}}(k,r)\} \longrightarrow \{1,2,\ldots,r\}$, there is a sequence $x_1, x_2, \ldots, x_k$ such that $\sum_{i=1}^{k-1} x_i = x_k$, and $\sum_{i=1}^{k} \chi(x_i) \equiv 0 \pmod r$. We show that when

k is greater than r, $kr - r - 1 \leq S_{\mathfrak{z}}(k,r) \leq kr - 1$, and when r is also an odd prime, $S_{\mathfrak{z}}(k,r)$ is in fact equal to $kr - r$. (Received September 22, 2018)

1145-05-1513 **Aaron Berger*** (bergera@mit.edu), **Caleb Ji** and **Erik Metz**. *On the Distribution of Range for Tree-Indexed Random Walks.*

We study tree-indexed random walks for spiders, trees with one vertex of degree greater than two. Our main result confirms a conjecture of Benjamini, Häggström, and Mossel for such graphs, namely that the distribution of the range for any such tree is dominated by that of a path on the same number of edges. (Received September 22, 2018)

1145-05-1515 **Eldar Fischer*** (eldar@cs.technion.ac.il), Faculty of CS, Technion - Israel Institute of Technology, 3200003 Haifa, Israel. *The robustness framework for strong regularity lemmas and the application for ordered graphs.*

Since (at least) 1999, works in Combinatorics and CS used lemmas that strengthen the original Regularity Lemma of Szemerédi, and extensions of regularity-like concepts to objects other than graphs.

Two general mechanisms have emerged. One of them is the well-known Analytic Regularity Lemma framework, which substitutes arguments about graphs (or other discrete objects) with analytic arguments about the "limit" objects.

Here I'll discuss the other general mechanism, that of partition robustness. For graphs, a vertex partition to k parts is robust with respect to a function f, if it cannot be repartitioned into $f(k)$ parts in a way that significantly raises its index measure.

The robustness mechanism is applicable also to settings where it is hard to define a limit object. On the other hand, it requires explicitly specifying an appropriate f, whereas the analytic framework is "function-free".

Much of the talk will showcase the application of this framework to a recent result from a joint work with Noga Alon and Omri Ben-Eliezer, providing a removal lemma for all hereditary properties of vertex-ordered graphs. Despite these objects admitting no notion of isomorphism, the notion of containment is "graph-like" enough to allow for a regularity-like scheme. (Received September 22, 2018)

1145-05-1520 **Anton Bernshteyn*** (abernsht@math.cmu.edu), **Michelle Delcourt** and **Anush Tserunyan**. *Independent sets in algebraic hypergraphs.*

An active avenue of research in modern combinatorics is extending classical extremal results to the so-called sparse random setting. The basic hope is that certain properties that a given "dense" structure is known to enjoy should be inherited by a randomly chosen "sparse" substructure. One of the powerful general approaches for proving such results is the hypergraph containers method, developed independently by Balogh, Morris, and Samotij and Saxton and Thomason. Another major line of study is establishing combinatorial results for algebraic or, more generally, definable structures. In this talk, we combine the two directions and address the following problem: Given a "dense" algebraically defined hypergraph, when can we show that the subhypergraph induced by a generic low-dimensional algebraic set of vertices is also fairly "dense"? (Received September 22, 2018)

1145-05-1537 **Gi-Sang Cheon**, **Ji-Hwan Jung*** (jh56k@skku.edu), **Bumtle Kang** and **Suh-Ryung Kim**. *Riordan digraphs and their primitivity.*

Two vertices u and v are called *strongly connected* if there are directed walks from u to v and from v to u. A digraph D is strongly connected if each pair in $V(D)$ is strongly connected. A digraph D is called *primitive* if there exists an integer $k > 0$ such that for all ordered pairs of vertices $i, j \in V(D)$, there is a walk from i to j with length k.

In this talk, we use the theory of Riordan matrices to define the notion of Riordan digraphs and then we study their primitivity. (Received September 23, 2018)

1145-05-1539 **Kassie Archer**, **Abigail C. Bishop**, **Alexander Diaz-Lopez**, **Luis D. García Puente**, **Darren Glass** and **Joel Louwsma*** (jlouwsma@niagara.edu), Department of Mathematics, Niagara University, P.O. Box 2044, Niagara University, NY 14109. *Arithmetical structures on Dynkin graphs D_n.* Preliminary report.

An arithmetical structure on a finite graph is a pair $(\mathbf{d}, \mathbf{r})$ of vectors with positive integer entries such that $\mathbf{r}$ is primitive and $(D - A)\mathbf{r} = \mathbf{0}$, where D is the diagonal matrix with entries given by $\mathbf{d}$ and A is the adjacency matrix of the graph. We give a procedure that produces all arithmetical structures on the graph corresponding to the Dynkin diagram D_n for any n. We also prove results about the possible orders of critical groups of arithmetical structures on D_n. (Received September 23, 2018)

1145-05-1556 **Jordan Buhmann**, **Moshe Cohen*** (mcohen@vassar.edu), **Alexander May** and **Shiyu Shu**. *Realization spaces of arrangements of 11 complex projective lines.* Preliminary report.
Given the combinatorial intersection data (or matroid) of a line arrangement, we study its space of geometric realizations in the complex projective plane. We say an arrangement is "interesting" if its realization space has at least two connected components after quotienting out by complex conjugation. The realization spaces of arrangements of 10 and fewer lines have been classified, yielding a list of interesting arrangements; we seek to extend this list to 11 lines. We discuss previous results on such arrangements with only double and triple points and then report on new results for arrangements with quadruple points, as well. (Received September 23, 2018)

1145-05-1561 **Marisa Gaetz*** (mgaetz@mit.edu). *Anti-power j-fixes of the Thue-Morse word.*
Recently, Fici, Restivo, Silva, and Zamboni introduced the notion of a k-anti-power, which is a word of the form $w^{(1)}w^{(2)}\cdots w^{(k)}$, where $w^{(1)}, w^{(2)}, \ldots, w^{(k)}$ are distinct words of the same length. For an infinite word w and a positive integer k, define $AP_j(w,k)$ to be the set of integers m such that $w_{j+1}w_{j+2}\cdots w_{j+km}$ is a k-anti-power, where w_i denotes the i-th letter of w. Define also $\mathcal{F}_j(k) = (2\mathbb{Z}^+ - 1) \cap AP_j(\mathbf{t}, k)$, $\gamma_j(k) = \min(AP_j(\mathbf{t}, k))$, and $\Gamma_j(k) = \sup((2\mathbb{Z}^+ - 1) \setminus \mathcal{F}_j(k))$, where $\mathbf{t}$ denotes the Thue-Morse word. In his 2018 paper, Defant shows that $\gamma_0(k)$ and $\Gamma_0(k)$ grow linearly in k. We generalize Defant's methods to prove that $\gamma_j(k)$ and $\Gamma_j(k)$ grow linearly in k for any nonnegative integer j. In particular, we show that $1/10 \le \liminf_{k\to\infty}(\gamma_j(k)/k) \le 9/10$ and $1/5 \le \limsup_{k\to\infty}(\gamma_j(k)/k) \le 3/2$. Additionally, we show that $\liminf_{k\to\infty}(\Gamma_j(k)/k) = 3/2$ and $\limsup_{k\to\infty}(\Gamma_j(k)/k) = 3$. (Received September 23, 2018)

1145-05-1569 **Melkamu Zeleke*** (zelekem@wpunj.edu), 300 Pompton Road, Wayne, NJ 07470, and **Mahendra Jani** and **Louis W. Shapiro**. *On Combinatorial Interpretations of Shapiro's Identities Involving some Elements of the Bell Subgroup.* Preliminary report.
The motivation for our current work is the combinatorial interpretation given to Shapiro's identity involving the Lagrange subgroup element $(1, zC(z)^2)$, where $C(z)$ is the generating function of the Catalan numbers. In this talk, we provide a combinatorial proof of Shapiro's identity involving the Central Trinomial Numbers and the Bell subgroup element $(M(z), zM(z))$, where $M(z)$ is the generating function of the Motzkin numbers, and settle a uniqueness question Shapiro asked regarding this identity. We then look at the Bell subgroup element $(T(z), zT(z))$, where $T(z)$ is the generating function of the ternary numbers and provide an alternative combinatorial interpretation of some identities involving this array using K-trees. (Received September 23, 2018)

1145-05-1573 **Cyril Banderier** and **Michael Wallner*** (michael.wallner@tuwien.ac.at), 351 Cours de la Libération, France, Talence, 33405. *Limit laws for lattice paths with catastrophes.*
In queuing theory, it is usual to have some models with a "reset" of the queue. In terms of lattice paths or random walks, it is like having the possibility of jumping from any altitude to zero. Because of this we call them "lattice paths with catastrophes". These objects have the interesting feature that they do not have the same intuitive probabilistic behaviour like classical Dyck paths (the typical properties of which are strongly related to Brownian motion theory). In this talk we will quantify some relations between these two types of paths. We give a bijection with some other lattice paths, show a link with a continued fraction expansion, and prove several formulae for related combinatorial structures conjectured in the On-line Encyclopedia of Integer Sequences. Our main tools will be the kernel method and asymptotic transfer theorems from analytic combinatorics. With these we solve the enumeration problem and derive several limit laws for parameters like the number of returns to zero or the size of an average catastrophe. We end with some considerations on uniform random generation. This is joint work with Cyril Banderier. (Received September 23, 2018)

1145-05-1582 **Caroline G Melles***, cgg@usna.edu, and **David Joyner**. *Bent p-ary functions and strongly regular graph decompositions.*
In a 1991 paper, T. S. Michael showed that a decomposition of a complete graph into three isomorphic strongly regular graphs forms an amorphic association scheme. Later, E. R. van Dam and Ja. Ju. Gol'fand, A. V. Ivanov, and M. Klin described further connections between strongly regular graphs and amorphic association schemes. We consider a decomposition of a complete graph on p^n vertices determined by a p-ary function of n variables. We show that if the graphs of the decomposition have feasible degrees and determine an amorphic association scheme, then the function is bent. Bent functions over a finite field can be thought of as maximally non-linear functions. In the Boolean ($p = 2$) case, Dillon discovered a simple combinatorial condition for a function to be bent. In graph-theoretic terms, a Boolean function is bent if and only if its Cayley graph is strongly regular

with feasible Latin or negative Latin square type parameters. For primes $p > 2$, the Cayley graphs associated with a bent p-ary function are not necessarily strongly regular. We prove a generalized Dillon-type theorem in the other direction, giving graph-theoretic conditions which guarantee that a p-ary function is bent. (Received September 23, 2018)

1145-05-1595 **Vaughan K McDonald** (vmcdonald@college.harvard.edu) and **Jiyang Gao*** (gaojy98@mit.edu). *Generating Functions for f-vectors and the cd-index of Weight Polytopes.*

We studied the f-vector and *cd*-index of a weight polytope (or Wythoff polytope), which is the convex hull of the orbit of point in space under the action of a finite reflection group. We show that a formula of Renner for the f-vector in the Weyl group case is also valid for arbitrary reflection groups, via results of Maxwell. We then use this to continue work begun by Golubitsky, giving generating functions for the f-vectors in all of the cases where the weight polytope is simple. We then further apply Maxwell's results to study the *cd*-index in non-simple cases, including giving a generating function that lets one compute the *cd*-indices of all hypersimplices. (Received September 23, 2018)

1145-05-1605 **Alan Krinik*** (ackrinik@cpp.edu), California State Polytechnic University, Pomona, **Gerardo Rubino**, INRIA, Campus de Beaulieu 35042 Rennes, France, and **Chon In (Dave) Luk**, **Jeffrey Yeh**, **Samuel Lyche**, **Lyheng Phey**, **John Kath**, **Christine Hoogendyk** and **Malachi C. Demmin**. *Generalized Ballot Box Problem and Fluctuations Within a Strip.*

The traditional ballot box problem is to determine the probability that candidate A is never behind candidate B during the counting of n ballots. We consider a ballot box problem having probabilities of voting for A, B or abstaining corresponding to one-step transition probabilities of certain types of birth–death Markov chains. Under our assumptions, a formula for the probability that candidate A is never behind candidate B during the counting of n ballots is determined in terms of known eigenvalues of a class of tridiagonal transition matrices P associated with the birth–death chain.

Using explicit formulas for the nth power of P, we discuss the fluctuation probability of certain lattice paths that are restricted to lie within a finite-width strip. We also consider the probability of staying in strip for certain types of circular birth–death chains. If time allows, we explore known eigenvalues of more general Markov chains. (Received September 25, 2018)

1145-05-1611 **Emily J King***, king@math.uni-bremen.de. *Difference Sets and Grassmannian Packings.*

It is often of interest to find redundant sets of vectors which emulate orthonormal bases by having pairwise angles as large as possible and by yielding a resolution of the identity. Such objects are called Grassmannian frames. In this talk, a simple construction of such sets via so-called difference sets will be presented, as well as some novel generalizations. Prior knowledge of frame theory or algebraic combinatorics will not be required to follow the talk. (Received September 23, 2018)

1145-05-1621 **Katherine Perry***, kperry56@du.edu. *Rainbow Spanning Trees in Edge-Colored Complete Graphs.*

A spanning tree of an edge-colored graph is rainbow provided that each of its edges receives a distinct color. In 1996, Brualdi and Hollingsworth conjectured that if K_{2m} is properly $(2m-1)$-edge-colored, then the edges of K_{2m} can be partitioned into m rainbow spanning trees, except when $m = 2$. In this talk, we'll look at the history and recent results concerning this conjecture and related questions and also consider the extremal question of maximizing and minimizing the number of rainbow spanning trees in K_n, given a special type of $(n-1)$-edge-coloring which is surjective and rainbow cycle free, called a *JL-coloring*.

Keywords: edge-coloring, complete graph, rainbow spanning tree (Received September 23, 2018)

1145-05-1639 **Chetak Hossain*** (chetak.hossain@gmail.com), NCSU Dept of Math, BOX 8205 NCSU, Raleigh, NC 27695. *Combinatorics of the Boolean-Catalan Numbers.* Preliminary report.

The sequence OEIS A071356 is the coefficient sequence of an ordinary generating function similar to the Catalan numbers. We show that the sequence counts several families of combinatorial objects using generating function arguments. Specifically, a family of underdiagonal lattice paths, a family of pattern avoiding permutations, and a family of pattern avoiding inversion sequences. Furthermore, we construct bijections between the families. More specifically, we construct two surjective maps from all permutations to the lattice paths, whose fibers are intervals of the weak order and the equivalence classes of an equivalence relation on posets defined using pattern avoidance. In one case, the bottom elements of the interval are the pattern avoiding permutations in question.

In the other case, the reverse Lehmer codes of the top elements of the intervals are the pattern avoiding inversion sequences. (Received September 23, 2018)

1145-05-1669 **Anand Pillay*** (apillay@nd.edu), Department of Mathematics, University of Notre Dame, Notre Dame, IN 46556. *Regularity theorems in group environments.* Preliminary report.

The talk is on work with Gabe Conant and Caroline Terry, and concerns the asymptotic behavior of subsets A of a finite group G, sometimes under additional assumptions on the graph defined by $xy \in A$. I will survey the existing results and methods, and discuss new results if appropriate. (Received September 23, 2018)

1145-05-1677 **Zachary Hamaker*** (hamaker@umich.edu) and **Victor Reiner**. *Weak order and descents for monotone triangles.*

Monotone triangles are a rich extension of permutations that biject with alternating sign matrices. This talk will introduce generalizations of the weak order and descent sets for permutations to monotone triangles. It will then explain why linear extensions of the weak order gives rise to shelling orders on a poset, recently introduced by Terwilliger, whose maximal chains biject with monotone triangles; among these shellings are a family of EL-shellings. The weak order is built via an action of the 0-Hecke algebra of Type A on monotone triangles. This leads to a natural notion of descent set for monotone triangles, which will also be discussed. (Received September 23, 2018)

1145-05-1683 **Olivier Bernardi*** (bernardi@brandeis.edu) and **Philippe Nadeau** (nadeau@math.univ-lyon1.fr). *Negative evaluations of the chromatic polynomial and its derivatives.*

The chromatic polynomial χ_G of a graph G evaluated at positive integer q gives the number of proper colorings of G in q colors. We give an interpretation of the value of the derivatives of χ_G at non-positive integers in terms of acyclic orientations of G. Our result generalize formulas obtained by Stanley, Gessel and Sagan, Gessel and Lass. The proof is an application of heap theory in the spirit of [Gessel 2001].
This is joint work with Philippe Nadeau. (Received September 24, 2018)

1145-05-1692 **Nicole Yamzon*** (nyamzon2@illinois.edu). *Toric Ideals of Tiling Spaces.* Preliminary report.

Consider the set of all domino (2×1) tilings of an $(m \times n)$ rectangle. How can we move from one tiling to another? In 1990 William Thurston proved that the set of two-dimensional domino tilings are connected by flips. We will provide an analogous proof of Thurston's result by using the language of toric ideals. (Received September 23, 2018)

1145-05-1698 **Kaave Hosseini*** (kaave.hosseini@gmail.com), 3869 miramar st. 1912, la jolla, CA 92092, and **Shachar Lovett**, **Guy Moshkovitz** and **Asaf Shapira**. *An Improved Lower Bound for Arithmetic Regularity.*

The arithmetic regularity lemma due to Green [GAFA 2005] is an analogue of the famous Szemerédi regularity lemma in graph theory. It shows that for any abelian group G and any bounded function $f : G \to [0, 1]$, there exists a subgroup $H \leq G$ of bounded index such that, when restricted to most cosets of H, the function f is pseudorandom in the sense that all its nontrivial Fourier coefficients are small. Quantitatively, if one wishes to obtain that for $1 - \epsilon$ fraction of the cosets, the nontrivial Fourier coefficients are bounded by ϵ, then Green shows that $|G/H|$ is bounded by a tower of twos of height $1/\epsilon^3$. He also gives an example showing that a tower of height $\Omega(\log 1/\epsilon)$ is necessary. Here, we give an improved example, showing that a tower of height $\Omega(1/\epsilon)$ is necessary. (Received September 24, 2018)

1145-05-1711 **Ricardo Gómez*** (rgomez@math.unam.mx), Institute of Mathematics, Area de la Investigación Científica, Circuito Exterior, Ciudad Universitaria, 04510 México, Mexico, and **Mark Daniel Ward** (mdw@purdue.edu), 150 North University Street, West Lafayette, IN 47907-2067. *Asymptotic analysis of combinatorial schemas of polylogarithms.*

Motivated from classification problems of countable Markov shifts in symbolic dynamics, we develop an asymptotic analysis program of combinatorial schemas of polylogarithm functions. For example, sequence schemas are resolved using Flajolet's asymptotic analysis of polylogarithms, and the multiset schema approach is to follow the roadmap that utilizes Mellin transforms and saddle point asymptotics that is known to work for integer partitions. In this talk the motivation and a report on the asymptotic equivalences that we have obtained will be presented. (Received September 24, 2018)

1145-05-1713 **Jonathan J Azose** and **Arthur T Benjamin*** (benjamin@hmc.edu), Math Department, Harvey Mudd College, 301 Platt Blvd, Claremont, CA 91711. *A Tiling Interpretation of q-Binomial Coefficients.*

We provide a combinatorial interpretation of the q-binomial coefficients as counting weighted collections of tiled boards. Using this interpretation, we prove a new q-analogue to Lucas' Theorem and new q-analogues to identities on the sums of integer squares and cubes. (Received September 24, 2018)

1145-05-1728 **Rachel Kirsch*** (r.kirsch1@lse.ac.uk). *Many cliques with few edges.* Preliminary report.

The problem of maximizing the number of cliques has been studied within several classes of graphs. For example, among graphs on n vertices with clique number at most r, the Turán graph $T_r(n)$ maximizes the number of copies of K_t for each size t. Among graphs on m edges, the colex graph $\mathcal{C}(m)$ maximizes the number of K_t's for each size t.

In recent years, much progress has been made on the problem of maximizing the number of cliques among graphs with n vertices and maximum degree at most r. The graph $aK_{r+1} \cup K_b$, where $n = a(r+1) + b$ and $0 \leq b \leq r$, was shown to maximize the total number of cliques, and is conjectured to maximize the number of K_t's for $t \geq 3$. This conjecture has been proven in significant cases.

In this talk, we discuss the edge analogue of this problem: which graphs with m edges and maximum degree at most r have the maximum number of cliques? We prove in some cases that the extremal graphs again contain as many disjoint copies of K_{r+1} as can fit, with the leftovers in another component. In the edge analogue, these remaining edges form a colex graph. (Received September 24, 2018)

1145-05-1735 **Huy Tuan Pham*** (huypham@stanford.edu). *Tower-type bounds for Roth's theorem with popular differences.*

A famous theorem of Roth states that for any $\alpha > 0$ and n sufficiently large in terms of α, any subset of $[n]$ with density α contains a 3-term arithmetic progression. Green developed an arithmetic analogue of Szemerédi's regularity lemma to prove that not only is there one arithmetic progression, but in fact there is some integer $d > 0$ for which the density of 3-term arithmetic progressions with common difference d is at least roughly what is expected in a random set with density α. In particular, for any $\in > 0$, there is some $n_\in$ such that for all $n > n_\in$ and any subset A of $[n]$ with density α, there is some integer $d > 0$ for which the number of 3-term arithmetic progressions in A with common difference d is at least $(\alpha^3 - \epsilon)n$. We prove that $n_\in$ grows as an exponential tower of 2's of height on the order of $\log\left(\frac{1}{\in}\right)$. We show that the same is true if we replace the interval $[n]$ by any abelian group of odd order n. These results are the first applications of regularity lemmas for which the tower-type bounds are shown to be necessary.

The results are joint work with Jacob Fox and Yufei Zhao. (Received September 24, 2018)

1145-05-1736 **Michael T Engen*** (engenmt@ufl.edu). *Universal Permutations.*

The problem of finding a shortest permutation which contains all permutations of length n dates to 1999. While its length is known to be asymptotically quadratic in n, surprisingly little else is known. We prove a new constructive upper bound, as well as prove a formula for the exact length of the shortest permutation containing all emphlayered permutations of length n. (Received September 24, 2018)

1145-05-1750 **Jim Haglund*** (jhaglund@math.upenn.edu) and **Emily Sergel**. *Ordered Set Partitions and the Delta Conjecture.* Preliminary report.

In 2002 the speaker and N. Loehr showed that a conjectured combinatorial formula for the bigraded Hilbert series of the space of diagonal harmonics can be expressed more compactly as a sum over permutations. This uses Haiman's Theorem that the bigraded character is a certain symmetric function defined using Macdonald polynomial operators. In this talk we show that there is a corresponding formula associated to the Delta Conjecture of the speaker, Remmel, and Wilson. The formula says that a certain sum over parking functions with q,t weight equals a more compact sum over ordered set partitions. (Received September 24, 2018)

1145-05-1753 **Nima Anari**, **KuiKui Liu**, **Shayan Oveis Gharan** and **Cynthia Vinzant*** (clvinzan@ncsu.edu). *Completely log-concave polynomials and applications to matroids.*

A completely log-concave polynomial is a real polynomial whose logarithm defines a concave function over the positive orthant and whose derivatives also have this property. Examples include stable polynomials and the basis-generating polynomials of matroids. Complete log-concavity is preserved under several operations and implies strong inequalities on the coefficients of polynomials. We use this to find inequalities on numbers of independent sets of matroids and an approximation algorithm for counting the number of bases in polynomial time. (Received September 24, 2018)

1145-05-1784 **Megan A. Martinez*** (mmartinez@ithaca.edu), mmartinez@ithaca.edu. *On the enumeration of pattern-avoiding inversion sequences.*

Permutations that avoid given patterns have been studied in great depth for their connections to other fields of mathematics, computer science, and biology. From a combinatorial perspective, permutation patterns have served as a unifying interpretation that relates a vast array of combinatorial structures. Recently, the study of patterns has been applied to inversion sequences; these are integer sequences $(e_1, \ldots, e_n)$ with $0 \leq e_i < i$ for each i. This application is motivated by the natural correspondence between permutations and inversion sequences, where for each $\pi_1\pi_2 \ldots \pi_n \in S_n$, we can associate an inversion sequence $(e_1, e_2, \ldots, e_n)$ such that $e_i = |\{j \mid j < i, \pi_j > \pi_i\}|$. In this talk, we will discuss the recent advancements in the enumeration of pattern-avoiding inversion sequences, introduce new bijections between permutations and inversion sequences, and present remaining open questions. (Received September 24, 2018)

1145-05-1794 **Michael C. Strayer*** (mcs80@live.unc.edu). *Minuscule Kac-Moody settings unified by new poset coloring properties.*

R.M. Green axiomatically defined full heap posets and used them to build elegant minuscule-like doubly infinite representations of many affine Kac-Moody algebras. Two other classes of colored posets, namely minuscule and d-complete posets, have also been used in many applications to Lie theory. For instance, the d-complete posets correspond to "dominant λ-minuscule" elements of Kac-Moody Weyl groups. We present new poset coloring properties that unify the above three classes of colored posets. They can be used to characterize various Kac-Moody (sub)algebra representations. These include the full heap representations of Green, the minuscule representations of semisimple Lie algebras, and the Demazure modules of dominant minuscule Weyl group elements. We give the Dynkin diagram-indexed classifications of the colored posets that satisfy the two most important sets of these properties. (Received September 24, 2018)

1145-05-1806 **Carolyn Mayer*** (cdmayer@wpi.edu) and **William J. Martin**. *A Graph Connectivity Problem Based on Low-degree Luby Transform Codes.* Preliminary report.

Luby Transform (LT) codes are a class of rateless erasure codes in which information is encoded by constructing a bipartite graph dynamically according to a specified degree distribution. The efficiency of an LT code varies with the design of the degree distribution. We investigate a graph connectivity problem related to the decodability of an LT code with a degree distribution restricted to low degrees. (Received September 24, 2018)

1145-05-1861 **Laura Eslava*** (laura.eslava@math.gatech.edu), 686 Cherry St. NW, Atlanta, GA 30313, and **Louigi Addario-Berry** (louigi.addario@mcgill.ca), 1005-805 Rue Sherbrooke O., Montreal, Quebec H3A 2K6, Canada. *Top-down or bottom-up: A tale of correspondences.*

In this talk, we compare two random processes that start with isolated components and output a single connected entity. More precisely, tree-growth processes – a top-down construction– and discrete coalescents –a bottom-up construction.

The main subject is a correspondence between a non-binary tree representation of Kingman's coalescent and recursive trees; both are uniform outputs in their respective combinatorial classes. Surprisingly, this instance of fragmentation/coagulation duality requires that we break the natural symmetry in coalescent processes, which contrasts with a well-know bijection between recursive trees and binary search trees (rotation correspondence).

We conclude by introducing a non-increasing tree-growth process that opens exciting avenues of research. This talk is based on joint work with Louigi Addario-Berry. (Received September 24, 2018)

1145-05-1876 **Keith J. Copenhaver*** (keithc@ufl.edu). *Vertical Paths in Simple Varieties of Trees.*

We will call a path between v_1 and v_2 in a rooted tree *vertical* if v_2 is contained in the subtree rooted at v_1, or vice versa. Many different tree statistics pertain to the length of vertical paths with restricted endpoints; height is the length of the longest vertical path, the depth of a vertex is the length of the (necessarily vertical) path from the root to that vertex, path length is the sum of the lengths of all vertical paths starting at the root, and rank is the length of the shortest vertical path from a vertex to a leaf.

We will examine the expected length of vertical paths in simply generated trees and how this expectation changes if we impose restrictions upon the endpoints of the paths. How much longer can we expect a uniformly selected path to be if we insist the bottom vertex is a leaf? What about if the top vertex is the root? How does this vary in different tree structures? We also give asymptotic formulas for the kth moment of the length of a uniformly selected vertical path. (Received September 24, 2018)

1145-05-1877 **Chen Wang*** (chen.wang@univie.ac.at). *The Borwein Conjecture: An exercise in utilizing the saddle point method.* Preliminary report.

In this talk, I will describe some observations, heuristics, and techniques involved in my proof of the Borwein Conjecture, in the framework of the saddle point method. (Received September 24, 2018)

1145-05-1886 **Jennifer J Quinn*** (jjquinn@uw.edu), 1900 Commerce Street, Box 358436, Tacoma, WA 98402. *A Singular Way with Words.*

T. S. Michael will be particularly remembered for his precise exposition both as a presenter and an author. This talk will explore T.S.'s remarkable wordsmithing skills from his use of language in mathematical contexts to childhood combinatorial word puzzles. (Received September 24, 2018)

1145-05-1888 **Zhu Cao*** (zcao@kennesaw.edu), Department Of Mathematics, Kennesaw State University, Marietta, GA 30060. *An Unusual Identity from Ramanujan's Notebooks.*

In this talk, we discuss a unique identity, Entry 27 in Ramanujan's notebook IV. We give natural representations of both sides of the identity in terms of different binary quadratic forms. By finding a symmetric property between different quadratic forms, we derive a list of beautiful identities. As applications, we provide the proofs of two identities among Ramanujan's forty identities for the Rogers-Ramanujan functions in a similar way. At the end of the talk, We present some new identities for the Rogers-Ramanujan functions using quadratic forms. (Received September 24, 2018)

1145-05-1908 **Addie E. R. Armstrong*** (aarmstro@norwich.edu), Department of Mathematics, 158 Harmon Drive, Northfield, VT 05663. *Steinberg's Conjecture is almost true?*

A famous conjecture of Steinberg posited that all planar graphs containing no 4-cycles or 5-cycles are 3-colorable. The conjecture was demonstrated to be false in 2016 by Cohen-Addad et. al. This begs the question: How close to 3-colorable are Steinberg-type graphs? In this talk, we introduce a stronger form of defective coloring, discuss its application to Steinberg-type graphs, and demonstrate that the known counterexample to the conjecture is, in fact, colorable with this new form of defective coloring, hinting at the fact that Steinberg's original conjecture was very close to true. (Received September 24, 2018)

1145-05-1909 **Sören Berg**, **Katharina Jochemko** and **Laura Silverstein*** (laura.silverstein@tuwien.ac.at), 39 E 12th Street #811, New York, NY 10003. *Ehrhart Tensor Polynomials.*

Ehrhart tensor polynomials, a natural generalization of the Ehrhart polynomial of a lattice polytope, were introduced in a joint paper with Monika Ludwig. Here we investigate their coefficients and give Pick-type formulas, for the vector and matrix cases, in terms of triangulations of the given lattice polygon. The notion of the Ehrhart h^*-polynomial is extended to h^r-tensor polynomials and, for matrices, their coefficients are studied for positive semidefiniteness. In contrast to the classic h^*-polynomial, the coefficients are not necessarily monotone with respect to inclusion. Positive semidefiniteness is still proven in dimension two and, based on computational results, conjectured in higher dimensions. This work was done jointly with Sören Berg (TU Berlin) and Katharina Jochemko (KTH Stockholm). (Received September 24, 2018)

1145-05-1917 **Julie Yuan***, yuanx254@umn.edu, and **Teresa Yu**, **Frances Dean** and **Ivan Aidun**. *Graphs of Gonality Three.*

In 2013, Chan classified all metric hyperelliptic graphs, proving that divisorial gonality and geometry gonality are equivalent in the hyperelliptic case. We show that such a classification extends to combinatorial graphs of gonality three, under certain edge-connectivity assumptions. We also give a construction for graphs of gonality three, and provide conditions for determining when a graph is not of gonality three. This work was done this summer as part of the SMALL REU in Mathematics. (Received September 24, 2018)

1145-05-1920 **Jinha Kim**, **Ryan M. Martin**, **Tomas Masarik**, **Warren Shull**, **Heather C Smith*** (hcsmith@davidson.edu), **Andrew Uzzell** and **Zhiyu Wang**. *Local Dimension of a Poset.* Preliminary report.

The original notion of poset dimension is due to Dushnik and Miller (1941). In 2016, Uerckerdt proposed a variant, called local dimension, which has garnered considerable interest. A local realizer of a poset P is a collection of partial linear extensions of P that cover its comparabilities and incomparabilities. The local dimension of P is the minimum frequency of a local realizer where frequency is the maximum multiplicity of an element of P.

We survey a number of recent results for local dimension, highlighting the following. Hiraguchi (1955) proved that any poset with n points has dimension at most $n/2$, which is sharp. We prove that the maximum local dimension of a poset with n points is $\Theta(n/\log n)$. Our lower bound uses probabilistic methods to extend a theorem of Chung, Erdős, and Spencer (1983): There is an n-vertex bipartite graph in which each difference graph cover of the edges also covers one of the vertices $\Omega(n/\log n)$ times. (Received September 24, 2018)

1145-05-1926 **Charles J. Kicey*** (ckicey@valdosta.edu), Valdosta, GA , and **Shaun V. Ault** (svault@valdosta.edu), Valdosta, GA. *Fourier Methods to Analyze Lattice Path Progressions.*

We use the most basic Fourier methods to analyze the detail and asymptotic behavior for certain restricted lattice path progressions. We will see how the method accepts various types of path moves, and generalizes nicely to higher dimensions. (Received September 24, 2018)

1145-05-1932 **Shaun V. Ault*** (svault@valdosta.edu), Valdosta, GA , and **Joanne A. Wardell** (jawardell@valdosta.edu), Valdosta, GA. *Toward an Understanding of Skewed-Top Corridors.* Preliminary report.

Consider lattice paths in $\mathbb{Z}^2$ starting at the point $(0,1)$ that remain strictly above the x-axis, below a line of positive slope in the first quadrant, and whose allowable moves are up-right and down-right. We say that such lattice paths exist within a skewed-top corridor. The number such paths ending at each point within the skewed-top corridor may be arranged into an array. We have found that the diagonal sequences within a dualized version of this array exhibit a predictable pattern in which certain subsequences have degree given by an explicit formula. The formulas for starting/ending points of each subsequence and degree depend only on the parameters of the skewed-top corridor and not the values of the corridor numbers themselves. (Received September 24, 2018)

1145-05-1933 **Michael Ferrara**, **Bill Kay**, **Lucas Kramer**, **Ryan M. Martin**, **Benjamin Reiniger**, **Heather C. Smith*** (hcsmith@davidson.edu) and **Eric Sullivan**. *Saturation for Induced Subposets.*

Graph saturation was first introduced in 1964 by Erdős, Hajnal, and Moon. The notion of saturation can be extended to posets as follows: Fix a target poset P. A family $\mathcal{F}$ of points in the Boolean lattice is called P-saturated if (1) $\mathcal{F}$ contains no copy of P as an subposet and (2) every strict superset of $\mathcal{F}$ contains a copy of P as an subposet. For each n, the saturation number for P is the size of the smallest family in $\mathcal{B}_n$ which is P-saturated.

Gerbner et. al. (2013) first studied saturation for the chain. We bound the induced saturation number for several small posets and prove a logarithmic lower bound for the saturation number for posets from a rich infinite family. (Received September 24, 2018)

1145-05-1934 **Louis Deaett*** (louis.deaett@quinnipiac.edu). *Matroids and the minimum rank of a matrix pattern.* Preliminary report.

If we don't know the entries of a matrix, but we do know which of them are zero, what can we say about the rank of the matrix? Depending on the pattern of zeros and non-zeros, sometimes we can give the rank exactly. If not, we can still ask how small the rank could be. This is a combinatorial question about rank, so it's natural to ask what what we can find out from the perspective of matroid theory. The answer, as it turns out, is quite a bit. And by taking this perspective, we can gain a better understanding of some previous results about this problem, extend them a bit, and even generalize the question itself to different matroid-theoretic contexts. (Received September 24, 2018)

1145-05-1951 **Songul Aslan*** (sonas@vt.edu), 1828 Grayland Srtreet Apt 6, Blacksburg, VA 24060. *Combinatorial curve neighborhoods of the affine flag variety of type A_n^1.*

Let X be a flag manifold. Given a (multi)degree d and a subvariety Ω of X, the curve neighborhood of Ω is the union of all rational curves in X of degree d incident to Ω. Buch and Mihalcea introduced this notion in order to study the quantum cohomology and quantum K theory rings of the flag manifold X. Calculations of curve neighborhoods are equivalent to the combinatorial problem of finding certain maximal paths in the Bruhat graph of X. This combinatorial point of view extends beyond the ordinary flag manifolds, and I will explain how one can calculate curve neighborhoods of Schubert varieties in the affine flag variety of Lie type A_n^1. In general, the curve neighborhood of a given Schubert variety is a union of 'larger' Schubert varieties. In many cases we prove that all these Schubert varieties have the same dimension, and they are enumerated by certain roots in the affine root system. This is a joint work with Leonardo Mihalcea. (Received September 24, 2018)

1145-05-1953 **Anastasia Chavez*** (anachavez@math.ucdavis.edu), **Jesús A. De Loera**, **Ana Paulina Figueroa**, **Yuanbo Li**, **Edgar Possani** and **Lingyun Ye**. *Polyhedral cones generated by cycles of a graph.*

The cycles of a graph G generate two combinatorial objects:

(1) a polyhedral cone $\mathcal{C}_G$ we call the *cone of cycles of* G, where cycles are the extreme rays of $\mathcal{C}_G$, and

(2) an integral semigroup $Sg(G)$ we call the *semigroup of cycles of* G, where cycles of G are the generators of $Sg(G)$.

Studying these objects is motivated by the simplicity that a cone and semigroup perspective can offer for several open questions in graph theory. For example, the Double Cover conjecture asserts any graph G has a cycle covering such that every edge of G is contained in exactly two cycles. In terms of semigroups, this simplifies to the equivalent statement that $(2,\dots,2)\in Sg(G)$ for all G.

In this talk we describe some properties and algorithms of the cone and semigroup for an undirected graph. (Received September 24, 2018)

1145-05-1958 **Runrun Liu**, **Sarah Loeb*** (sloeb@hsc.edu), **Martin Rolek**, **Yuxue Yin** and **Gexin Yu**. *DP-coloring of planar graphs without 4-,9-cycles and two cycles from* $\{5,6,7,8\}$.

A generalization of list-coloring, now known as DP-coloring, was recently introduced by Dvořák and Postle. In list coloring, adjacent vertices cannot receive identical colors. In the assignment for a DP-coloring, this restriction is replaced by a restriction given by an arbitrary matching between the lists of available colors. Although list-coloring results do not always extend to DP-coloring results, several results on list-coloring of planar graphs have been extended to the setting of DP-coloring. We prove that if $\{a,b\}$ is one of $\{5,6\},\{5,7\},\{6,7\},\{6,8\}$, or $\{7,8\}$, then every planar graph without cycles of lengths $\{4,a,b,9\}$ is DP-3-colorable. (Received September 24, 2018)

1145-05-1959 **Catherine Lee*** (catherine.lee@yale.edu), 206 Elm Street #203555, New Haven, CT 06520-3555, and **Henry Reichard**, **David Townley**, **Ross Berkowitz** and **Patrick Devlin**. *Expected Chromatic Number of Random Subgraphs.*

Given a graph G and $p\in[0,1]$, let G_p denote the random subgraph of G obtained by keeping each edge independently with probability p. Alon, Krivelevich, and Sudokov proved $\mathbb{E}[\chi(G_p)]\geq C_p\frac{\chi(G)}{\log|V(G)|}$, and Bukh asked if this could be improved to $\mathbb{E}[\chi(G_p)]\geq C_p\frac{\chi(G)}{\log\chi(G)}$. We propose the stronger conjecture that if $p\leq 1/2$, then among all graphs of fixed chromatic number, the quantity $\mathbb{E}[\chi(G_p)]$ is minimized by the complete graph. We prove this stronger conjecture when G is planar or $\chi(G)<4$. We also consider weaker lower bounds on $\mathbb{E}[\chi(G_p)]$ proposed in a recent paper by Shinkar. We answer two open questions posed by Shinkar negatively and consider a possible refinement of one of them. We conclude with an original spectral lower bound on $\mathbb{E}[\chi(G_p)]$. (Received September 24, 2018)

1145-05-1977 **Alexander Burstein** (aburstein@howard.edu), Department of Mathematics, Howard University, Washington, DC 20059, **Hana Kim** (hakkai14@skku.edu), Department of Mathematics, Sungkyunkwan University, South Korea, and **Louis W. Shapiro*** (lshapiro@howard.edu), Department of Mathematics, Howard University, Washington, DC 20059. *Involutions and Pseudoinvolutions in the Riordan Group.* Preliminary report.

We start with the basic definitions and the reasons to study pseudoinvolutions. Included are my favorite top ten pseudoinvolutions. We then look at some recent elementary methods for creating involutions and pseudoinvolutions. The first introduces palindromes, and this unified approach yields the classical cases as well as bringing in new examples, some with interesting combinatorial interpretations. The second approach generalizes the Lah numbers with every Riordan group element producing two pseudoinvolutions. Finally, we look at the relevant A- and B-sequences, where we have a mix of new results and open questions. (Received September 24, 2018)

1145-05-1991 **Daryl R. DeFod*** (ddeford@mit.edu), MIT Stata Center, 32 Vassar St., 32-D475A, Cambridge, MA 02139. *Matched Products and Stirling Numbers of Graphs.*

In this talk I will introduce the *matched product* for graphs, motivated by a popular construction for modeling multiplex networks. The matched product depends on consistent labelings of the nodes in the component graphs and recovers the Cartesian, rooted, and hierarchical products as special cases. I will prove conditions for the product to be planar, Hamiltonian, and Eulerian in terms of the corresponding properties of the component graphs and consider the related problem of computing the probability that a random relabeling of a given graph preserves each property. For example, the number of path labelings whose product is planar is given by the square permutations.

In addition to these traditional graph-theoretic properties, the matched product naturally defines several families of graphs whose Stirling numbers of the first kind can be enumerated in terms of the layer values. We provide explicit examples of these families and provide combinatorial proofs in terms of the Pell numbers. (Received September 24, 2018)

1145-05-2013 **Seungho Lee*** (slee.ngc224@gmail.com), Pine Brook, NJ 07058. *Combinatorial Identities in Graph Theory.*

By simple counting arguments, we will prove a few novel combinatorial identities. One has to do with writing an integer power as a sum of multinomial coefficients. The others are about the number of connected labeled graphs. (Received September 24, 2018)

1145-05-2030 **Kenneth Barrese*** (barresek@alma.edu). *Adjusting p, q-analogues of m-level Rook Placements.*

Karen Briggs and Jeff Remmel proposed a p, q-analogue of the m-level rook numbers which extended to an analogue of the m-level hit numbers. For singleton boards, a special subset of Ferrers boards, they proved that the p,q m-hit polynomial has non-negative coefficients. By adjusting the definition of the p and q statistics slightly, we can extend the conclusion, establishing that the p,q m-hit polynomials of all Ferrers boards will contain only non-negative coefficients. Furthermore, although the adjustment changes the p,q m-level rook numbers of singleton boards, it does preserve the equivalence classes of singleton boards established by the traditional definitions of the p and q statistics. (Received September 24, 2018)

1145-05-2041 **Bin Yeh*** (byeh@vcu.edu) and **Chris Rodger** (rodgec1@auburn.edu). *The Intersection Problem for Latin Rectangles.*

For positive integers r, n with $r \leq n$, a latin rectangle is an $r \times n$ array of n symbols in which each symbol occurs exactly once in each row and at most once in each column, and each cell contains exactly one symbol. If L is a latin rectangle then let $L_{i,j}$ denote the symbol in cell (i, j) of L. Let R and Q be $r \times n$ latin rectangles. The intersection number of R and Q is defined to be $I(R, Q) = |\{(i, j) \mid 1 \leq i \leq r, 1 \leq j \leq n, R_{i,j} = Q_{i,j}\}|$. The problem of determining the set of all the possible intersection numbers is referred as the intersection problem. In this paper the intersection problem for latin rectangles is completely solved. (Received September 24, 2018)

1145-05-2051 **Frederic Meunier** and **Shira Zerbib*** (zerbib@umich.edu), University of Michigan, Department of Mathematics, Ann Arbor, MI 48109. *Envy-free division of a cake without the "hungry players" assumption.*

Consider n players having preferences over a rectangular cake, identified with the interval [0,1]. A classical theorem due to Stromquist ensures that under some conditions it is possible to divide the cake into n interval pieces and assign one piece to each player in an envy-free manner, such that no player strictly prefers a piece that has not been assigned to him. One of these conditions, which has been always considered as crucial, is that the players are "hungry": in every partition of the cake, every player prefers a non-empty piece. We prove that it is still possible to get an envy-free division even if this condition is not satisfied, when the number of players is prime or equal to 4. This was conjectured by Erel Segal-Halevi, who proved it for at most 3 players. The main step in our proof is a new combinatorial lemma in topology, which is reminiscent of the Sperner lemma: Instead of restricting the labels that can appear on each face of the simplex, the lemma considers labelings that enjoy a certain symmetry on the boundary. (Received September 24, 2018)

1145-05-2059 **Katie Haymaker*** (kathryn.haymaker@villanova.edu). *Counting restricted tilings of rectangular arrays and applications.*

How many ways are there to tile a rectangular board with a variety of tiles? In this talk we will derive a recursive formula for the number of tilings of a $2 \times n$ board with squares, dominoes, and I-trominoes, along with a formula for the $3 \times n$ board tiled with squares and dominoes. We will then consider restricted tilings of an $m \times n$ board and discuss applications to a particular problem in coding theory. (Received September 24, 2018)

1145-05-2066 **Edinah K. Gnang***, Johns Hopkins University, Whiting School, of Engineering, Baltimore, MD 21218-2608. *Growing Graceful Trees.*

We describe constructions based on Gaussian elimination for listing and enumerating special induced edge label sequences of graphs. We also describe and algorithm for obtaining all graceful labelings of a given graphs. This talk is based on joint work with Isaac Wass. (Received September 24, 2018)

1145-05-2073 **Susan Margulies***, margulie@usna.edu, and **Angelika Wiegele**, **Elisabeth Gaar** and **Daniel Krenn**. *Hilbert's Nullstellensatz, the Positivstellensatz and Vizing's Conjecture.* Preliminary report.

Vizing's conjecture (open since 1968) states that the product of the domination numbers is less than or equal to the domination number of the product graph. In this talk, we report on progress modeling this conjecture as a system of polynomial equations, and then computing via both linear algebra and Hilbert's Nullstellensatz and semi-definite programming and the Positivstellensatz. (Received September 24, 2018)

1145-05-2103 **Caroline J Klivans*** (klivans@brown.edu). *Geometric and topological combinatorics in chip-firing.*

Chip-firing processes are discrete dynamical systems. A commodity (chips, sand, dollars) is exchanged between sites of a network according to simple local rules. Although governed by local rules, the long-term global behavior of the system reveals unexpected properties. I will discuss some of the ways in which geometric and topological combinatorics arise in the theory of chip-firing. (Received September 24, 2018)

1145-05-2118 **Larry Ericksen*** (larryericksen@gmail.com), P.O. Box 172, Millville, NJ , and **Karl Dilcher**. *The combinatorics of lattice paths and tilings associated with b-ary Stern polynomials.*

A b-ary Stern sequence is defined as the number of ways of writing a positive integer as the sum of powers of an integer b, with each power being used at most b times. As analogues of these number sequences, we create polynomials which explicitly encode these hyper b-ary representations.

Recursive Lucas sequences, like the Fibonacci numbers, are identified as subsequences in these b-ary sequences. We then interpret their associated combinatorics in terms of lattice paths, tilings and posets. The tilings use squares and dominoes, while the lattices include steps of weighted Delannoy paths. (Received September 24, 2018)

1145-05-2158 **Kaitlyn B. Myers***, 201 Mullica Hill Road, Glassboro, NJ 08028, and **Madeline P. Crews**, **Michael T. Urbanski** and **Breeann M. Wilson**. *The Game of Best Choice and Some Variations.*

In the famous Secretary Problem, it is known that the optimal strategy is a positional strategy. More precisely, the interviewer should reject approximately the first 1/e or 37% of the candidates and then choose the next best person. We present various non-uniform distributions of the Secretary Problem by changing its constraints. One variation will be a pattern avoidance that keeps a positional strategy, but changes the probability of winning, while another allows for ties among the candidates. (Received September 24, 2018)

1145-05-2165 **Charles Camacho**, **Silvia Fernández-Merchant**, **Marija Jelic**, **Rachel Kirsch**, **Linda Kleist**, **Elizabeth Bailey Matson** and **Jennifer White*** (jennifer.white@stvincent.edu). *Bounding the tripartite-circle crossing number of complete tripartite graphs.* Preliminary report.

A tripartite-circle drawing of the complete tripartite graph $K_{m,n,p}$ is a drawing in the plane, where each part of the vertex partition is placed on one of three disjoint circles, and the edges do not cross the circles. The tripartite-circle crossing number $\mathrm{cr}_{c3}(K_{m,n,p})$ of $K_{m,n,p}$ is the minimum number of crossings among all tripartite cylindrical drawings of $K_{m,n,p}$. We bound $\mathrm{cr}_{c3}(K_{m,n,p})$ and $\mathrm{cr}_{c3}(K_{n,n,n})$. (Received September 24, 2018)

1145-05-2170 **Lily Silverstein*** (lsilver@math.ucdavis.edu). *Random Monomial Ideals.*

Probability is a now-classic tool in combinatorics, especially graph theory. Some applications of probabilistic techniques are: describing the typical/expected properties of a class of objects, uncovering phase transitions and sudden thresholds in the dependence of one property on another, and producing examples of extremal or conjectured objects.

I'll introduce some random models for monomial ideals, which generalize existing models for graphs and simplicial complexes, and give a sample of results from the three categories mentioned above. In particular, I'll describe several algebraic invariants (e.g., Krull dimension and projective dimension) which exhibit interesting thresholds in the model parameters.

This talk is based on two papers:

Random Monomial Ideals, with Jesús A. De Loera, Sonja Petrović, Despina Stasi, and Dane Wilburne. Preprint: arXiv:1701.07130, to appear in *Journal of Algebra*, and

Average Behavior of Minimal Free Resolutions of Monomial Ideals, with Jesús A. De Loera, Serkan Hoşten, and Robert Krone. Preprint: arXiv:1802.06537, to appear in *Proceedings of the AMS*. (Received September 24, 2018)

1145-05-2188 **Christopher Hoffman**, **Douglas Rizzolo*** (drizzolo@udel.edu) and **Erik Slivken**.
Probabilistic aspects of pattern avoiding permutations.

This talk will discuss recent work connecting random pattern avoiding permutations to classical universal objects in probability. We will focus on connections between patterns avoiding a monotone pattern and random walks in cones and how this connection can be exploited to analyze the structure of typical large permutations avoiding a monotone pattern. Emphasis will be given to the enumerative implications of the resulting probabilistic statements. (Received September 25, 2018)

1145-05-2195 **Ae Ja Yee***, 327 McAllister, State College, PA 16801. *Euler's partition theorem for all moduli and a generalization of the lecture hall partition theorem.* Preliminary report.

One of the well-known partition theorems is Euler's theorem on partitions into distinct parts and partitions into odd parts. Various refinements and generalizations of the theorem can be found in the literature. For instance, the lecture hall partition theorem is its finite version. Recently, Keith and Xiong showed another generalization of Euler's theorem. Motivated by their work, we consider a finite version of their generalization, which yields the lecture hall partition theorem. This talk is based on joint work with S. Fu and D. Tang. (Received September 25, 2018)

1145-05-2238 **Lauren Keough***, keoulaur@gvsu.edu. *A Collection of Extremal Problems for Counting Parameters of Graphs.*

In 1941 Turán proved a result about the maximum number of edges in an n vertex, K_r-free graph - that is, a graph that has no complete subgraph on r vertices. One could ask instead for the maximum number of K_r's possible in an n vertex graph with e edges. We focus on results of this type, including minimizing matchings in graphs with n vertices and e edges and maximizing independent sets in hypergraphs with n vertices and e edges. Open problems will be mentioned. (Received September 25, 2018)

1145-05-2243 **Emina Soljanin*** (emina.soljanin@rutgers.edu). *The Service Rates of Codes and Vertex Covers of Graphs.*

Coding has traditionally been used in transmission and storage of data to provide reliability in a more efficient way than simple replication. The traditional performance indicators of codes are the minimum distance and the code rate. More recently, special codes have been developed that also provide efficient maintenance of storage under node failures. In addition to the traditional performance indicators, the properties of codes that matter in such scenarios are the code locality and availability. Emerging applications, such as distributed learning and fog computing, are adding yet another use for coding. In these applications, the goal is to maximize the number of users that can be simultaneously served by the system. One such service is simultaneous download of different jointly coded data blocks by many users competing for the system's resources. Here, coding affects the rates at which users can be served. This talk will define the service rates of codes as new performance indicators, survey the existing literature, and show a connection between optimizing the code service rates to the graph vertex cover problem. (Received September 25, 2018)

1145-05-2246 **Melanie Dennis***, 27 N Main Street, Kemeny Hall, Hanover, NH 03755. *Lewis Carroll and the Red Hot Potato.*

The Lewis Carroll identity expresses the determinant of a matrix in terms of subdeterminants obtained by deleting one row and column or a pair of rows and columns. Using the matrix tree theorem, we can convert this into an equivalent identity involving sums over pairs of forests. Unlike the Lewis Carroll Identity, the Forest Identity involves no minus signs. Using the Involution Principle, we can pull back Zeilberger's proof of the Lewis Carroll Identity to a bijective proof of the Forest Identity. This bijection is implemented by the Red Hot Potato algorithm, so called because the way edges get tossed back and forth between the two forests is reminiscent of the children's game of hot potato. (Received September 25, 2018)

1145-05-2268 **Alexander Diaz-Lopez*** (diazlopezalexander@gmail.com), 800 Lancaster Ave, Villanova, PA 19006. *Peak polynomials and their coefficients.*

We say that a permutation $\pi = \pi_1\pi_2\cdots\pi_n \in \mathfrak{S}_n$ has a peak at index i if $\pi_{i-1} < \pi_i > \pi_{i+1}$. Let $\mathcal{P}(\pi)$ denote the set of indices where π has a peak. Given a set S of positive integers, we define $\mathcal{P}(S;n) = \{\pi \in \mathfrak{S}_n : \mathcal{P}(\pi) = S\}$. In 2013 Billey, Burdzy, and Sagan showed that for subsets of positive integers S and sufficiently large n, $|\mathcal{P}(S;n)| = p_S(n)2^{n-|S|-1}$ where $p_S(x)$ is a polynomial depending on S called the peak polynomial associated to S. In this talk we will study peak polynomials, their roots, peak positivity conjecture, as well as a combinatorial interpretation for the coefficients of $p_S(x)$ when written in a binomial basis. (Received September 25, 2018)

1145-05-2293 **Naiomi T. Cameron*** (ncameron@lclark.edu). *Riordan Group Techniques on Linear Chord Statistics.* Preliminary report.
A linear chord diagram is a partition of $\{1, 2, 3, \dots, 2n\}$ into n blocks of size two called chords. By counting linear chord diagrams by the number of blocks containing consecutive elements, or "short chords," we obtain an exponential Riordan array which can be thought of as a generalization of the Narayana number triangle. We show that this array is indeed Riordan and use it as a vehicle to make a number of other observations about linear chord statistics. (Received September 25, 2018)

1145-05-2328 **Kassie Archer*** (karcher@uttyler.edu), 3900 University Blvd., Tyler, TX 75799, and **Megan Martinez**. *Statistics on rooted trees.* Preliminary report.
We say a labelled tree is a rooted tree if there is a special vertex designated to be the root. Various statistics on rooted trees have been studied, including inversions, descents, leaders, and more. It is known that certain statistics are equally distributed among the set of rooted trees. In this talk, we discuss certain statistics and use bijective techniques to show that they are equally distributed on the set of rooted trees. (Received September 25, 2018)

1145-05-2357 **Therese Aglialoro** and **Robert Hochberg*** (hochberg@udallas.edu), 1845 E. Northgate Drive, Irving, TX 75062. *Snakes: Legal, Illegal and Dodecahedral.*
The Megaminx puzzle is a dodecahedral variant of the Rubik's cube. We characterize the snakes that can be obtained on the Megaminx puzzle, as well as those that cannot, unless one swaps two edges when nobody is looking, which we have done. The solution makes use of linear algebra, polygon geometry and group theory, all accessible to a bright undergraduate. (Received September 25, 2018)

1145-05-2359 **Oscar Levin*** (oscar.levin@unco.edu), University of Northern Colorado, School of Mathematical Sciences, Greeley, CO 80639. *Coloring hypergraphs is harder than coloring graphs.*
To measure the complexity of graph coloring problems for infinite graphs, you can restrict to *computable* graphs and ask whether there is a *computable* coloring of optimal size. For example, it has long been known that there is a computable connected graph with chromatic number 3 with no computable 3-coloring (indeed with no computable k-coloring for any k). However, any computable connected graph with chromatic number 2 does have a computable 2-coloring. In this talk we will consider another way in which 3 is more complicated than 2: what happens when the number of vertices per edge increases to 3? We consider 3-uniform hypergraphs with (weak) chromatic number 2 and see that even if the hypergraph is *highly* computable, there need not be a computable 2-coloring. (Received September 25, 2018)

1145-05-2408 **Xiao Xie***, xxie6@jhu.edu, and **Elanor West**. *Multi-Step Strategies for Rendezvous Search on the Platonic Solids.* Preliminary report.
The Astronaut Problem is an open problem in the field of rendezvous search. The premise is two astronauts randomly land on a planet and want to find each other. Research explores what strategies accomplish this in the least expected time. To investigate this problem, we create a discrete model which takes place on the edges of the Platonic solids. Some baseline rules of the model are (1) the agents can see all of the faces around them. (2) they travel along the edges from node to node and cannot jump. (3) they move at a rate of one edge length per unit time. We first explore an unbiased random walk strategy where the agents move randomly on each turn. We then explore multi-step strategies, which are strategies where both agents move randomly for one step, and then follow a pre-determined sequence. We compare the performance of these strategies on all of the solids. For the cube and octahedron specifically, we are able to prove optimality of the "Left Strategy", in which the agents move randomly and then turn left. In addition, we compare results across the solids, looking for patterns that can give insight into a possibly optimal strategy for the sphere. Most of the calculations were done using first-order Markov Chains. (Received September 25, 2018)

1145-05-2411 **Berit Nilsen Givens*** (bngivens@cpp.edu). *A sequence of integrals of Fibonacci polynomials.* Preliminary report.
The Fibonacci polynomials, by analogy with Fibonacci numbers, are defined recursively: $F_1(x) = 1, F_2(x) = x$, and $F_n(x) = xF_{n-1}(x) + F_{n-2}(x)$. Unsurprisingly, the Fibonacci polynomials $F_n(x)$ have many interesting properties. Here we consider the sequence of numbers $e(n) = \int_0^\infty F_n(x)e^{-x}\,dx$, whose first few terms are $1, 1, 3, 8, 31, 147$. We give an overview of some basic facts about the sequence $e(n)$, including both recursive and nonrecursive formulas. Finally, we investigate the sequences obtained by considering $e(n)$ modulo a prime p and compute the p-adic valuation of $e(n)$ for a few example values of p. (Received September 25, 2018)

1145-05-2459 **Mark Budden** and **Elijah DeJonge*** (ehdejonge1@catamount.wcu.edu). *Destroying the Ramsey Property by the Removal of Edges.*

If the Ramsey number of two graphs G and H is n, then a two-coloring of a K_n (using red and blue) will contain either a red copy of G or a blue copy of H. However, there exists a two coloring of K_{n-1} that does not contain a red G or blue H. So, the removal of a vertex from a two-colored K_n is enough to destroy the Ramsey Property. In this talk, we will examine the destruction of the property by the removal of edges from K_n. (Received September 25, 2018)

1145-05-2463 **Anna C. Truman*** (trumanac1@gcc.edu), **Grace C. Shook** and **Caleb T. Scutt**. *Number Sequences for Truncated and Bitruncated Cross-Polytopes.*

Polytope numbers are sequences of nonnegative integers constructed from the geometry of a polytope. Truncation is a geometric process that cuts each vertex of a polytope along adjacent edges until one-third of each edge remains. Building on prior research and geometric processes presented by Dr. H.K. Kim, we find formulae which generate the polytope numbers for truncated and bitruncated cross-polytopes in any dimension. In addition, we explore higher truncation of cross-polytopes to introduce ideas for further research. (Received September 25, 2018)

1145-05-2480 **Bonnie C Jacob*** (bcjntm@rit.edu), **Abraham Glasser**, **Emily Lederman** and **Stanislaw Radziszowski**. *Failed power domination: complexity and other select results.*

Let G be a simple graph with vertex set V and edge set E, and let $S \subseteq V$. The *open neighborhood* of $v \in V$, $N(v)$, is the set of vertices adjacent to v; the *closed neighborhood* is given by $N[v] = N(v) \cup \{v\}$. The *open neighborhood* of S, $N(S)$, is the union of the open neighborhoods of vertices in S, and the *closed neighborhood* of S, is $N[S] = S \cup N(S)$. The sets $\mathcal{P}^i(S), i \geq 0$, of vertices *monitored* by S at Step i are given by $\mathcal{P}^0(S) = N[S]$ and $\mathcal{P}^{i+1}(S) = \mathcal{P}^i(S) \bigcup \{w : \{w\} = N[v] \backslash \mathcal{P}^i(S) \text{ for some } v \in \mathcal{P}^i(S)\}$. If there exists j such that $\mathcal{P}^j(S) = V$, then S is called a *power dominating set*, PDS, of G.

In this talk, I introduce the *failed power domination number* of a graph G, $\bar{\gamma}_p(G)$, the largest cardinality of a set that is not a PDS. I sketch a proof that $\bar{\gamma}_p(G)$ is NP-hard to compute and determine graphs in which any single vertex is a PDS. (Received September 25, 2018)

1145-05-2487 **Thomas Quint*** (quint@unr.edu), Department of Mathematics and Statistics, University of Nevada Reno, Reno, NV 89557. *Sphere-of-Influence Graphs, and Reminiscences of working with TS Michael.*

In this talk, I will present highlights of some of my joint work with TS Michael. The main focus will be on sphere-of-influence graphs, which are a special type of proximity graph introduced by Toussaint in 1980. (Received September 25, 2018)

1145-05-2499 **Nigel Boston** and **Jing Hao*** (jing.hao@wisc.edu). *Weight distribution of quasi-quadratic residue codes.*

Quasi-quadratic residue codes (QQR codes) are a family of binary linear codes. We are interested in these codes mainly for two reasons: Firstly, they have close relations with hyperelliptic curves and Goppa's Conjecture, and serve as a strong tool in studying those objects. Secondly, they are very good codes. Computational results show they have large minimum distances when $p \equiv 3 \pmod 8$.

We will prove that $PSL_2(p)$ acts on these codes and use this to prove a new discovery about their weight polynomials, i.e. they are divisible by $(x^2 + y^2)^{d-1}$, where d is the corresponding minimum distance. The proof uses shadows of codes, a powerful tool to study weight polynomials. We also apply this idea to quadratic residue codes, and prove that their weight polynomials are divisible by $(x + y)^d$, with d being the minimum distance.

These results impose strong conditions on the weight polynomials of quadratic residue codes and QQR codes. Combining the divisibility result and Gleason's Theorem, we can derive an efficient algorithm to compute the weight polynomials of QQR codes. We also use these results to correct the existing computational results for the weight polynomials of quadratic residue codes that were on OEIS. (Received September 25, 2018)

1145-05-2517 **Brant Jones*** (jones3bc@jmu.edu). *Avoiding Patterns and Making the Best Choice.*

The game of best choice (also known as the secretary problem) has been studied since at least the 1950's and was widely popularized in a 1960 column of Martin Gardner. In the classical setup, a player conducts "interviews" with a fixed number of "candidates." After each interview, the player ranks the current candidate against all of the candidates that have been considered so far (without ties). The player must then decide whether to accept the current candidate and end the game or, alternatively, whether to reject the current candidate forever and continue playing in the hope of obtaining a better candidate in the future. In this talk, we use enumerative combinatorics to investigate variations where permutation pattern-avoidance is used to restrict the interview orderings that can occur and to describe strategies that maximize the chance of hiring the best candidate. (Received September 25, 2018)

1145-05-2593 **Gene B. Kim*** (genebkim@usc.edu), 3620 S Vermont Ave, Department of Mathematics, University of Southern California, Los Angeles, CA 90089, and **Sangchul Lee**. *A bivariate central limit theorem for descents and major indices in fixed conjugacy classes.*

The distribution of descents in fixed conjugacy classes of S_n has been studied, and it is shown that its moments have interesting properties. Kim and Lee showed, by using Curtiss' theorem and moment generating functions, to prove a central limit theorem for descents in arbitrary conjugacy classes of S_n. In this paper, we prove a modified version of Curtiss' theorem to shift the interval of convergence in a more convenient fashion and use this to show that the joint distribution of descents and major indices is asymptotically bivariate normal. (Received September 25, 2018)

1145-05-2673 **Arthur L Gershon*** (alg125@case.edu), 2103 Cornell Road, Office 6122, Cleveland, OH 44121. *Strip Tilings on Square Chessboards.* Preliminary report.

We address the problem of finding the number of ways to place $1 \times k$ strips, where k can be any positive integer, on a rectangular lattice or chessboard such that no two overlap, and that there is at most one horizontal strip in each row and at most one vertical strip in each column (with alignments corresponding to the side of length k). Previous efforts have computed generating functions for counts $T(m, n)$ of such arrangements on chessboards of size $m \times n$ for some fixed side length m and letting n go off to infinity. Another problem of interest, however, is counting the arrangements $T(n, n)$ when the ambient chessboard is an $n \times n$ square, which is not addressed by the previous generating function approach. In this talk, we will discuss some of the advances in this latter direction, including the use of analytic techniques to prove an asymptotic formula for $\log T(n, n)$. If possible, we will also address the related problem of counting the number of strip tilings on square chessboards without the restriction in rows and columns. (Received September 25, 2018)

1145-05-2688 **Jineon Baek**, **Hayan Nam*** (hayann@uci.edu) and **Myungjun Yu**. *Order ideals, lattice paths, and core partitions.*

In this talk, we discuss the relationship between order ideals in a poset, lattice paths, and simultaneous core partitions. Exploiting this new perspective allows us to prove formulas for several classes of simultaneous core partitions with various restrictions. (Received September 25, 2018)

1145-05-2690 **Andrew Beveridge**, **Ian Calaway** and **Kristin Heysse*** (kheysse@macalester.edu), Department of Mathematics, Statistics and, Computer Science, 1600 Grand Avenue, Saint Paul, MN 55105. *Connecting partial orderings and alternating sign matrices.*

A square matrix with entries 0, 1, and -1 is an alternating sign matrix if all rows and columns sum to one and the nonzero entries in each row and column alternate in sign. Well studied as combinatorial objects, the alternating sign matrices were enumerated by Zeilberger in 1992. Here we prove a bijection between Zeilberger's magog triangles to pre-partial orderings of singleton and doubleton sets. These partial orderings arise from a relaxation of the definition of completely separable voting preferences.

Based on joint work with Andrew Beveridge and Ian Calaway. (Received September 25, 2018)

1145-05-2739 **Adam Buck*** (adambuck@uwm.edu). *The Probability Four Lines in $\mathbb{F}_q\mathbb{P}^3$ Meet Two Lines.*

Given four "random" lines in $\mathbb{RP}^3$, the probability that exactly two lines intersect all four is 1. Replacing the field of real numbers by the field with q elements, this probability is a rational function in q which approaches 1 as q approaches infinity. I will discuss this probability and related notions, such as the expected number of lines that intersect four random lines. Higher dimensional analogues of this problem will also be discussed. (Received September 25, 2018)

1145-05-2810 **Kendra E Pleasant*** (kendra.pleasant@morgan.edu), 11401 Hershey Red Place, Clinton, MD 20735. *Inscribing n-gons.*

In how many ways can we place a three sided figure completely inside an polygon? We will formalize this count and discuss its connection with the Delannoy sequence of integers. While solidifying our count, we will also explore the little Schröder numbers and the Catalan numbers. (Received September 25, 2018)

1145-05-2824 **Irina Gheorghiciuc*** (gheorghi@andrew.cmu.edu), 5000 Forbes Ave, Department of Mathematical Sciences, Carnegie Mellon University, Pittsburgh, PA 15213, and **Emily Allen**. *On Gessel super Catalan Polynomials.*

The integers $S(m,n) = \frac{\binom{2m}{m}\binom{2n}{n}}{\binom{m+n}{n}} = \frac{(2m)!(2n)!}{m!n!(m+n)!}$ were first studied by Eugene Catalan in 1874. Gessel refers to them as super Catalan numbers. In this paper we present two q-analogs of the super Catalan numbers, which also generalize Carlitz's q-Catalan numbers $c_n(\lambda)$ for $\lambda = 0$ and $\lambda = 1$. We give a combinatorial interpretation for one of these analogs when $m = 2$. In the process we introduce several q-Ballot numbers and give their combinatorial interpretation. (Received September 25, 2018)

1145-05-2830 **Braxton Carrigan**, **David Diaz** and **James M Hammer*** (jmhammer@cedarcrest.edu), 100 College Drive, Curtis 219, Allentown, PA 18104. *Sudoku Pair Latin Squares.*

A (a,b)-Sudoku pair latin square is a latin square that is simultaneously a (a,b)-Sudoku latin square and a (b,a)-Sudoku latin square. This presentation provides constructions for many arbitrary classes of positive integer pairs. Specifically we complete the construction of a $(3,b)$-Sudoku pair latin square for any positive integer b. Moreover, this implies that there exist factor pair latin squares of order $3p$ for any prime p, answering a question posed by Hammer and Hoffman. (Received September 25, 2018)

1145-05-2842 **Toufik Mansour**, **Howard Skogman** and **Rebecca Smith*** (rnsmith@brockport.edu). *Stack sorting tiers and r-tiers.*

Knuth showed that a permutation π can be sorted by a stack (meaning that by applying push and pop operations to the sequence of entries $\pi(1), \ldots, \pi(n)$ we can output the sequence $1, \ldots, n$) if and only if π avoids the permutation 231, i.e., if and only if there do not exist three indices $1 \leq i_1 < i_2 < i_3 \leq n$ such that $\pi(i_1), \pi(i_2), \pi(i_3)$ are in the same relative order as 231.

When passing a permutation through a stack a single time, the priority of outputting the identity function aligns with not placing larger entries on top of smaller ones within the stack. However, if there is an opportunity to use the stack multiple times, this is no longer always the case. Our work considers algorithms that prioritize outputting the maximum number of entries towards obtaining the identity function without regard to the sequence formed within the stack. Depending on how we rerun the remaining entries, the enumeration of permutations sortable by k passes through the stack leads to some interesting combinatorial bijections involving integer sequences studied by Parker and alternating permutations. (Received September 25, 2018)

1145-05-2844 **Carolina Benedetti**, , Colombia, **Rafael González D'León**, , Colombia, and **Christopher R. H. Hanusa**, **Pamela E. Harris** and **Apoorva Khare**, , India, **Alejandro H. Morales***, Department of Mathematics and Statistics, Lederle Graduate Research Tower, UMass, Amherst, Amherst, MA 01002, and **Martha Yip**. *A combinatorial model for computing volumes of flow polytopes.*

Flow polytopes of a graph are an important family of polytopes whose lattice points and volumes are of interest in representation theory. Baldoni and Vergne; and Postnikov and Stanley gave remarkable positive sum formulas for their volumes, generalizing a result of Lidskii. We introduce new families of combinatorial objects that provide an interpretation to this formula and thus computes volumes of flow polytopes. We recover known flow polytope volume formulas and prove new volume formulas for flow polytopes. A highlight of our model is an elegant formula for the flow polytope of a graph we call the caracol graph (snail in Spanish). (Received September 25, 2018)

1145-05-2868 **Anisah N. Nu'Man*** (anuman@ursinus.edu). *Counting Rainbow Triples.* Preliminary report.

Let $S = [n]$. Given the equation $(eq) : c_1x + c_2y = c_3z$, for constants c_1, c_2, and c_3, let T be the subset of $[n]$ consisting of all solutions to the equation (eq). For $r \in \mathbb{N}$, an exact r-coloring of $[n]$ is a surjective map $c : [n] \to [r]$. We say that a subset of T is *rainbow* if every element in the subset has a different color. The *rainbow number of* n *with respect to the equation* eq, denoted $rb(n, eq)$, is the minimum number of colors needed to guarantee that any (exact) coloring of $[n]$ has a rainbow in T. Thus, $\mathrm{rb}(n, c_1x_1 + c_2x_2 = c_3x_3) = r$ implies that there exists an exact $(r-1)$-coloring of $[n]$ that contains no rainbow solutions and that *any* exact r-coloring of $[n]$ will contain a rainbow solution. Within this talk we will discuss upper and lower bounds for the rainbow number of $\mathrm{rb}([n], x_1 + kx_2 = x_3)$, where $k \geq 1$. (Received September 25, 2018)

1145-05-2869 **Charles Burnette*** (charles.burnette@slu.edu), **Eric Schmutz** (eschmutz@math.drexel.edu) and **James Thomas** (jjt94@drexel.edu). *Permutations with equal orders.*

Let $F_{\mathbf{T}}(n)$ be the probability that two independent, uniformly random permutations of $[n]$ have the same order, and let $F_{\mathbf{K}}(n)$ be the probability that two independent, uniformly random permutations of $[n]$ are in the same conjugacy class. It is well known that $F_{\mathbf{K}}(n) \sim \frac{\Delta}{n^2}$ for a rather explicit constant Δ, and it is not hard to show that $\liminf \frac{F_{\mathbf{T}}(n)}{F_{\mathbf{K}}(n)} > 1$. We prove here that $F_{\mathbf{T}}(n) = O(\frac{\log\log n}{\log n})$ as $n \to \infty$. (Received September 25, 2018)

1145-05-2876 **Radmila Sazdanovic** and **Victor William Summers*** (vwsummer@ncsu.edu), 7102 Plumleaf Road, Apt. 234, Raleigh, NC 27613. *Magnitude Homology: Structure and Torsion.*

Many mathematical constructions come equipped with a canonical measure of size; the cardinality of a set, Euler characteristic of a topological space, dimension of a vector space, to name just three. T. Leinster added magnitude of a metric space to the list of cardinality-like invariants. Graphs may be viewed as metric spaces with the shortest-path metric, and as such they have magnitude. R. Hepworth and S. Willerton went on to categorify the magnitude of graphs, realizing the power series invariant as the graded Euler characteristic of a bigraded homology theory; magnitude homology. In this talk I will begin by constructing magnitude homology and describing various properties of magnitude which lift to the level of homology. Then I will discuss some results on the existence and structure of torsion in magnitude homology. (Received September 25, 2018)

1145-05-2881 **Nathan Reff*** (nreff@brockport.edu), 350 New Campus Drive, Brockport, NY 14420, and **Luke Duttweiler** (ldutt2@brockport.edu), 350 New Campus Drive, Brockport, NY 14420. *Spectra of oriented hypergraphs.*

An oriented hypergraph is a hypergraph where each vertex-edge incidence is given a label of $+1$ or -1. The adjacency and Laplacian eigenvalues of an oriented hypergraph are studied. In particular, combinatorial bounds are found which relate structural parameters to these eigenvalues. Some hypergraph cycle and path families will have their spectra fully determined. (Received September 25, 2018)

1145-05-2894 **Scott M LaLonde*** (slalonde@uttyler.edu), University of Texas at Tyler, Department of Mathematics, 3900 University Boulevard, Tyler, TX 75799, and **Kassie Archer**. *Investigating Allowed Patterns in Dynamical Systems Using Commuter Functions.*

Given a map $f : [0,1] \to [0,1]$, a permutation $\pi \in \mathcal{S}_n$ is called an *allowed pattern* for f if there exists $x \in [0,1]$ such that the iterates $x, f(x), f^2(x), \ldots, f^{n-1}(x)$ are in the same relative order as the entries of π (when written in one-line notation). Otherwise, we say that π is *forbidden* by f. We will discuss our investigation into the allowed and forbidden patterns for the family of symmetric tent maps $T_\mu : [0,1] \to [0,1]$, where $1/2 < \mu \leq 1$. One can build a relationship between the allowed patterns of two different tent maps using *commuter functions*, which result from relaxing the notion of topological conjugacy between dynamical systems. In particular, if a commuter is strictly increasing (i.e., order preserving), then it maps allowed patterns of one dynamical system to allowed patterns of the other. We will discuss several results in this realm, along with some open questions regarding forbidden patterns and certain properties of commuter functions. (Received September 25, 2018)

1145-05-2904 **Amanda Burcroff*** (burcroff@umich.edu). *Domination Parameters of the Unitary Cayley Graph of $\mathbb{Z}/n\mathbb{Z}$.*

The unitary Cayley graph of $\mathbb{Z}/n\mathbb{Z}$, denoted X_n, is the graph on $\{0, \ldots, n-1\}$ where vertices a and b are adjacent if and only if $\gcd(a-b, n) = 1$. The total domination number of a graph G, denoted $\gamma_t(G)$, is the minimum cardinality of a set of vertices S such that every vertex of G is adjacent to a vertex of S. We answer a question of Defant and Iyer by constructing a family of infinitely many integers n such that $\gamma_t(X_n) \leq g(n) - 2$, where $g(n)$, the Jacobsthal function, is the minimum m such that every set of m consecutive integers contains an integer coprime to n. We determine the irredundance number, domination number, and lower independence number of certain direct products of complete graphs and give bounds for these parameters for any direct product of complete graphs. We provide upper bounds on the size of irredundant sets in direct products of balanced, complete multipartite graphs which are asymptotically correct for the unitary Cayley graphs of integers with a bounded smallest prime factor. (Received September 25, 2018)

1145-05-2915 **Chen Xie*** (chen.xie@edu.uwaterloo.ca). *Bounds on Quantum Chromatic Number and New Nontrivial Colorings.*

Colorings and homomorphisms are central topics in graph theory. Their quantum analogues, quantum colorings and quantum homomorphisms, can be formulated with only linear algebra, and have strong connections with the classical ideas. There are no known algorithms for generating nontrivial quantum colorings, and all known examples arose from ad-hoc constructions. I will show that a number of classical bounds are also bounds to their quantum analogues, and present new examples of nontrivial quantum colorings of graphs. (Received September 25, 2018)

1145-05-2923 **Olga Blyum** (oblyum@smith.edu), Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, **Dayln Gillentine** (dgillentine@smith.edu), Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, **Alex Perry*** (akperry@smith.edu), Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, **Taylor Stefovic** (tstefovic@smith.edu), Smith College, Department of Mathematics and Statistics, Northampton, MA 01063, and **Nancy Yun** (nyun@smith.edu), Smith College, Department of Mathematics and Statistics, Northampton, MA 01063. *Further results in generalized splines.* Preliminary report.

Suppose you have an edge-labeled graph. A spline is a way of labeling the vertices so that each pair of adjacent vertices differ by a multiple of the corresponding edge. Splines come up naturally in many different applications, including numerical analysis, data interpolation, computer graphics, and engineering; the edge-labels roughly correspond to the slopes between two observed points.

We describe research into several questions, including some related to representation and others to applications from analysis (with edges labeled by polynomials). (Received September 25, 2018)

06 ► Order, lattices, ordered algebraic structures

1145-06-509 **Gezahagne Mulat Addis*** (buttu412@yahoo.com), University of Gondar, Gondar, Amhara, Ethiopia. *Sheaf Representation of De Morgan Algebras.*

In this paper we give the sheaf representation of De Morgan algebras. (Received September 08, 2018)

1145-06-1114 **Jason R Elsinger***, jelsinger@flsouthern.edu. *Representations of Lattice Vertex Algebras, Trace Functions, and Modular Transformations: Examples in order 3.*

Every isometry σ of a positive-definite even lattice Q can be lifted to an automorphism of the lattice vertex algebra V_Q. An important problem in vertex algebra theory and conformal field theory is to classify the representations of the σ-invariant subalgebra V_Q^σ of V_Q, known as an orbifold. Under certain assumptions, all irreducible V^σ-modules are obtained by restriction from twisted or untwisted V-modules, proved in a series of papers by M. Miyamoto. Previously we have described explicitly the orbifold modules in the case when σ is an isometry of Q of order two. In our study of extending our work to prime order, we have worked out several examples in the case when σ has order 3. Here we show how we define trace functions on the irreducible V_Q-modules to achieve tranformations laws for the characters of irreducible V_Q^σ-modules. The example where Q is the root lattice D_4 and σ is the permutation which fixes the central node in the Dynkin diagram will be discussed in detail. We also discuss the S-matrix and T-matrix describing the modular group in this case. (Received September 19, 2018)

1145-06-1614 **Jean S. Joseph*** (jjose107@fau.edu). *The Real Numbers as Completions of Linearly Ordered Sets: A Constructive Study.*

We will present two notions of completion of a linearly ordered set. These two completions are generalizations of the canonical constructions of the real numbers as a set of Dedekind cuts of rational numbers and as equivalence classes of Cauchy sequences of rational numbers. Also we will discuss to what extent these completions are order isomorphic. (Received September 23, 2018)

1145-06-1936 **Ting Gu*** (gut@etown.edu). *Correlation immune functions with respect to the q-transform.*

Correlation immunity is an important property of Boolean functions that are used in stream ciphers. The Walsh transform has traditionally been used to study properties of Boolean functions, especially correlation immunity. The q-transform is a generalization of the Walsh transform that was introduced by Klapper in 2014, and a recent paper by Gu et al. has introduced two notions of q-correlation immunity. This talk will discuss the number of q-correlation immune functions with minimal Hamming weight in n variables. (Received September 24, 2018)

1145-06-2079 **Zeinab Bandpey*** (zeinab.bandpey@morgan.edu), 1700 E cold Spring Lane, Baltimore, MD 21251. *Jonathan Farley's Mathematical Terror Theory: The Structure of Perfect Terrorist Cells with a Single Leader.*

Terrorist cells are modeled as finite partially ordered sets. This paper determines the structure of the terrorist cell most likely remain intact if a subset of its members is captured at random, provided that the cell has a single leader and no member has more than b immediate subordinates. Farley solved the problem for the case b=2, and Campos, Chvátal, Devroye, and Taslakian (the chairman of Stanford University's Computer Science Department at one time called Vasek Chvátal "one of the two best young combinatorialists in the world") solved the problem for class of trees. (Received September 24, 2018)

1145-06-2701 **L. Markowsky*** (lmarkowsky@gmail.com) and **G. Markowsky**. *The Lattice Data Analytics Toolkit.* Preliminary report.

The Lattice Data Analytics Toolkit is made available to support the use and visualization of two novel lattice-theoretic data exploration and analytic algorithms, to be called lattice data analytics. This free, open-source Python toolkit (with underlying implementation of key functions in C/C++), features tools for lattice data analytics as well as interactive visualization methods for lattices and posets, and will enable researchers and developers to rapidly produce systems that leverage the novel data analysis technique. The Carver2 target rating program, which includes a small dataset of partially ordered potential targets, is used to illustrate the functionality of the toolkit, producing publication-quality visualizations of the lattice and the poset of irreducibles (PoI) generated by the dataset. Future work includes the production of similar toolkits for the Octave/MATLAB and R environments. (Received September 25, 2018)

1145-06-2799 **G. Markowsky*** (markowsky@gmail.com), markowsky@gmail.com, and **L. Markowsky**. *Lattice Data Analytics: Adding Understanding to Machine Learning.* Preliminary report.

Automated and semi-automated systems that derive actionable information from massive, heterogeneous datasets have become essential in many domains, and the reasoning of such systems must be as clear as possible to earn our trust. A new approach to temporal data analysis, which we call lattice data analytics, extends the current bounds of lattice theory and its applications. We describe two novel information-awareness algorithms based on three lattice-theoretic concepts: the event lattice, the temporal poset of irreducibles, and lattice entropy. The two lattice-theoretic algorithms are capable of detecting structure in temporal, multivariate datasets. The algorithms tolerate missing, messy, or otherwise incomplete data and use the concept of a Dedekind-MacNeille completion to clarify important predictive relationships between lattice nodes, which will represent real or virtual events. Markowsky's Poset of Irreducibles will be used to compress the data and will enable the modified Dedekind-MacNeille completion algorithm to run on massive datasets in near-real time. Finally, the algorithm will have a just-in-time component that can produce only those sections of the lattice that show anomalies or display development. (Received September 25, 2018)

1145-06-2804 **Bal K Khadka*** (bkhadka@gmc.edu) and **Spyros Magliveras**. *Random walks vs Spoke Hub distribution models on a Lattice Basis Reduction under a projective special linear group $PSL_2(q)$.*

We present a study on the Lattice Basis Reduction using the famous LLL algorithm. For these experiment, we have used results of our experiments based on permutation techniques of basis reduction. We select permutations from a small subgroup $G < S_m$, where G is isomorphic to a projective special linear group $PSL_2(q)$. Then we use random walks and spoke hub distribution models to permute the lattice basis B using elements of G to get an *Approximated Shortest Vector* in a given lattice.

This study relies on the sensitivity of LLL to permutations of the input lattice basis B, and optimization ideas over the symmetric group S_m viewed as a metric space.

Keywords: LLL Lattice Basis Reduction, permutation matrix, Integer unimodular matrix, random walks, spoke-hub distribution, projective special linear group. (Received September 25, 2018)

1145-06-2948 **Alice Chudnovsky**, **Jake Januzelli*** (jaj226@cornell.edu) and **Jacob Brazeal**. *Obstructions to LWE-based Homomorphic Encryption with Uniform Error.* Preliminary report.

The Learning With Errors (LWE) problem was introduced by Regev in 2009 and asks that an adversary, given a uniformly chosen matrix A and $As+e$ where e has is drawn from a probability distribution with small entries on average, can recover s. The best hardness results known currently for LWE rely on the error distribution being Gaussian distributed: however, sampling from Gaussian's can be quite computationally expensive. A natural

modification is to choose a bounded uniform distribution instead, being extremely easy to sample from. There are some known hardness reductions ([?]) for bounded uniform, but the parameters needed aren't sufficient for instantiation of practical encryption schemes. We present compelling evidence that the techniques used in the Gaussian case cannot be adapted to a bounded uniform distribution. (Received September 25, 2018)

08 ► General algebraic systems

1145-08-461 **Joshua R Edge*** (josedge@indiana.edu). *Classification of spin models on Yang-Baxter planar algebras.*

After the discovery of the Jones polynomial in the 1980s, many mathematicians were interested in finding sources for more invariants of knots and links. One promising method pursued by Kauffman, Jaeger, et al was via so-called spin models, whose original purpose was to explain magnetism in certain physical models. The classification of such models for the Jones polynomial was first noted by Kauffman in 1986, which Jaeger then generalized to the classification of spin models for the Kauffman polynomial (or BMW algebra) in 1995 by connecting the existence of such a model to graphs satisfying certain properties. In 2015, Liu finished the classification began by Bisch and Jones of so-called Yang-Baxter planar algebras (YBPAs), planar algebras that satisfy a generalization of the Reidermeister moves. In this talk, we will use the classification of YBPAs to generalize Jaeger's result about spin models of the Kauffman polynomial (which itself is a YBPA) to classify all spin models of Yang-Baxter planar algebras by making a connection to graphs similar to Jaeger. In particular, we will demonstrate that aside from the spin models arising from BMW classified by Jaeger, the only other YBPAs giving spin models are the Bisch-Jones algebra and the Jones polynomial at a discrete sets of values. (Received September 06, 2018)

11 ► Number theory

1145-11-27 **Badih N. Ghusayni*** (bgou@ul.edu.lb). *A Couple of Results in Analytic Number Theory.*

First, we find a series representation of the zeta function at 3 and outline a strategy to obtain an Euler-type formula. Next, we obtain a product representation of the zeta function which is explicit in the sense that, among its factors, one factor is relevant to the trivial zeros of the zeta function and another to the nontrivial ones. To my pleasant surprise the famous Wallis Formula follows from this representation as an easy corollary. (Received June 20, 2018)

1145-11-33 **Benedict H. Gross*** (gross@math.harvard.edu), University of California San Diego. *Complex multiplication: past, present, future.*

The theory of complex multiplication, which studies both the arithmetic of elliptic curves and orders in imaginary quadratic fields, has a distinguished history. In the first lecture, I will recall the roots of this theory, starting with the ideas of Euler, Lagrange, and Gauss. I will review the main results obtained in the nineteenth century, and will end with a discussion of Heegner's paper on the class number one problem. (Received June 27, 2018)

1145-11-34 **Benedict H. Gross*** (gross@math.harvard.edu), University of California San Diego. *Complex multiplication: past, present, future.*

In this talk, I will discuss major developments in the theory of complex multiplication which occurred in the second half of the twentieth century. These involve the L-functions of elliptic curves, as well as the study of special points on modular curves. I will review the conjecture of Birch and Swinnerton-Dyer, and discuss several ways that the theory of complex multiplication has been used to provide strong evidence for it. (Received June 27, 2018)

1145-11-35 **Benedict H. Gross*** (gross@math.harvard.edu), University of California San Diego. *Complex multiplication: past, present, future.*

In this talk, I will present some of the exciting developments which have occurred in the theory of complex multiplication in the twenty-first century. In particular, I hope to show that this venerable subject is still very much alive. (Received June 27, 2018)

1145-11-45 **Robert D Hough*** (robert.hough@stonybrook.edu), Department of Mathematics, SUNY Stony Brook, 100 Nicolls Road, Stony Brook, NY 11794. *The shape of cubic and quartic number fields.*

Sato and Shintani defined ζ functions enumerating integral orbits in prehomogeneous vector spaces. Recently I have introduced a twisted version of this construction, in which an automorphic form is evaluated at each orbit representative. Combined with work of Bhargava, Taniguchi-Thorne and Yukie this construction has applications to studying the lattice shape of the ring of integers of cubic and quartic number fields embedded in the canonical embedding. As part of this program, an exact formula for the Fourier transform of the indicator function of maximal quartic rings over $\mathbb{Z}_p$ has also been obtained, extending earlier work of Taniguchi-Thorne in the cubic case. (Received June 29, 2018)

1145-11-46 **Rich Burge*** (rchrdbrg@gmail.com). *Some Experimental Evidence Supporting the Littlewood Conjecture.* Preliminary report.

This talk will present a two-dimensional continued fraction algorithm. Among other observations, two hypotheses about the behavior of the algorithm are noted from which the Littlewood conjecture can be deduced. Some experimental evidence supporting the hypotheses will be presented. (Received July 01, 2018)

1145-11-49 **Kannan Soundararajan** and **Jesse Thorner*** (jthorner@stanford.edu). *Weak subconvexity without a Ramanujan hypothesis.*

In 2008, Soundararajan obtained a weak subconvexity bound for central values of a large class of L-functions, assuming a weak Ramanujan hypothesis on the size of Dirichlet series coefficients of the L-function. If C denotes the analytic conductor of the L-function in question, then $C^{1/4}$ is the size of the convexity bound, and the weak subconvexity bound established there was of the form $C^{1/4}/(\log C)^{1-\epsilon}$ for any $\epsilon > 0$. I will describe a weak subconvexity bound of the shape $C^{1/4}/(\log C)^{\delta}$ for some small $\delta > 0$, but with a much milder hypothesis on the size of the Dirichlet series coefficients. In particular, our results will apply to all automorphic L-functions, and (with mild restrictions) to the Rankin-Selberg L-functions attached to two automorphic representations. (Received July 06, 2018)

1145-11-58 **Noah Lebowitz-Lockard*** (noah.lebowitzl25@uga.edu). *Irreducible quadratic polynomials and Euler's function.*

Let $V(x)$ be the number of $n \leq x$ for which $\varphi(m) = n$ for some n, where φ is Euler's totient function. In 1929, Pillai proved that $V(x) = o(x)$, i.e. that almost all numbers lie outside the range of the totient function. We discuss a generalization of this result, specifically that for a given irreducible quadratic polynomial $P(x)$, almost all numbers of the form $P(n)$ lie outside the range of the totient function as well. We put bounds on the number of $n \leq x$ with this property and show how we can improve them assuming the abc and Bateman-Horn Conjectures. (Received July 11, 2018)

1145-11-63 **Chad Awtrey*** (cawtrey@elon.edu). *Cyclic Eisenstein polynomials of p-power degree.*

Let p be an odd prime number and $\mathbf{Q}_p$ the field of p-adic numbers. For a positive integer n, local class field theory shows that there are precisely p^n nonisomorphic totally ramified Galois extensions of $\mathbf{Q}_p$ of degree p^n. Moreover, each extension has a cyclic Galois group. It is therefore natural to ask for polynomials which define each extension. When $n = 1$, such polynomials are known from the the work of Amano (1971). In this talk, we give analogous results for $n = 2$ and $n = 3$. (Received July 18, 2018)

1145-11-76 **Harsh A Mehta***, hmehta@math.sc.edu. *Malle's conjecture on Frobenius groups.*

We let a group G act on the set of d letters, $[d]$, by the induced left multiplication of action of the symmetric group S_d acting on $[d]$. We attain upper bounds for the number of degree d algebraic extensions K/k with Galois group G as the norm of the discriminant $\mathcal{N}_{k/\mathbb{Q}}(d_{K/k})$ is bounded above by $x \to \infty$. We attain upper bounds for the number of such extensions for groups of the form $G = F \rtimes H$ with certain conditions on F and H. Malle made a conjecture about what the asymptotic of this quantity should be as $\mathcal{N}_{k/\mathbb{Q}}(d_{K/k}) \to \infty$. We show that under a conjecture of Cohen and Lenstra, the upper bounds we achieve match the prediction of Malle. (Received July 22, 2018)

1145-11-111 **Jim Brown**, **Hugh Geller**, **Rico Vicente** and **Alexandra Walsh*** (alexandra_walsh@brown.edu), Box 5949, 69 Brown Street, Providence, RI 02906. *Eigenform Product Identities for Degree-Two Siegel Modular Forms.* Preliminary report.

In his paper "On Eigenform Relations Between Monomial Series" (2000), Eknath Ghate proves that there are finitely many pairs of full-level, degree-one eigenforms f and g whose product fg is also an eigenform. We prove a partial generalization of this theorem for degree-two Siegel modular forms. When FG is an Eisenstein series, we use the Siegel Φ operator, a mapping from Siegel degree-two to degree-one modular forms, to show that there is only one pair of Eisenstein series eigenforms F and G for which FG is an eigenform. When FG is a cusp form, we use the Rankin-Selberg method to give a condition under which FG cannot be an eigenform. We provide one example of an eigenform product for which FG is a cusp form, and we conjecture that this is the only such example. (Received August 01, 2018)

1145-11-200 **Jennifer Noelle Kampe*** (jenniferkampe@gmail.com) and **Artem Vysogorets**. *Predicting Zeros of the Riemann Zeta Function Using Machine Learning: A Comparative Analysis.* Preliminary report.

In this study, we evaluate the predictive performance of Neural Network Regression in locating non-trivial zeros of the Riemann zeta-function relative to Support Vector Machines Regression. We provide a brief summary of the fundamental properties of the zeta-function and use the analysis therein to identify relevant features and reformulate the given regression problem as a time-series prediction problem. Next, we provide a basic introduction to the architecture and use of Neural Networks. Model design is implemented as a six stage process including: (i) input selection, (ii) data splitting, (iii) model architecture selection, (iv) model structure selection, (v) model calibration, and (vi) model validation. The range of zeta-function zeros used is 1001 to 100,000. Model training is performed on data with 99,000 observations for each of the 50 feature variables selected. Multilayer Perceptron and Recurrent Neural Network architectures are chosen and implemented in the R programming language. Finally, the replicative and predictive accuracies of the two neural networks are evaluated against those of a Support Vector Machine Regression.

Keywords: Riemann Zeta zeros, Riemann Hypothesis, recurrent neural network, SVR, machine learning prediction. (Received August 18, 2018)

1145-11-231 **Nitya Mani***, nityam@stanford.edu, and **Asra Ali**. *Shifted Convolution L-Series Values for Elliptic Curves.*

Using explicit constructions of the Weierstrass mock modular form and Eisenstein series coefficients, we obtain closed formulas for the generating functions of values of shifted convolution L-functions associated to certain elliptic curves. These identities provide a surprising relation between weight 2 newforms and shifted convolution L-values when the underlying elliptic curve has modular degree 1 with conductor N such that $\mathrm{genus}(X_0(N)) = 1$. (Received August 23, 2018)

1145-11-249 **John R Greene*** (jgreene@d.umn.edu), Department of Mathematics and Statistics, 1117 University Drive, Duluth, MN 55812, and **Kalani Thalagoda**, Department of Mathematics and Statistics, 1117 University Drive, Duluth, MN 55812. *Nonstandard continued fractions with irrational numerator.* Preliminary report.

The simple continued fraction of $\sqrt{n}$ has very nice periodic and palindromic properties. Expansions of the form

$$\sqrt{n} \;=\; c_0 + \cfrac{z}{c_1 + \cfrac{z}{c_2 + \cfrac{z}{\ddots}}}$$

have the same palindromic properties provided z is a positive integer which is not too large and the expansion is periodic. When z is rational, the palindromic properties are only guaranteed when the expansion is periodic and the c's are sufficiently large compared to z. Here we investigate continued fraction expansions for $\sqrt{a+b\sqrt{m}}$ in the form

$$\sqrt{a+b\sqrt{m}} \;=\; c_0 + \cfrac{\sqrt{m}}{c_1 + \cfrac{\sqrt{m}}{c_2 + \cfrac{\sqrt{m}}{\ddots}}}\,.$$

In this cases, when the expansion is periodic, it appears to mimic the simple continued fraction expansion of $\sqrt{n}$ more closely than the two previously mentioned cases. (Received August 24, 2018)

1145-11-276 **Vishal Arul**, **Alex Best**, **Edgar Costa**, **Richard Magner** and **Nicholas Triantafillou*** (ngtriant@mit.edu). *Computing Zeta Functions of Superelliptic Curves in Large Characteristic.*

We describe an algorithm to compute the zeta function of a cyclic cover of the projective line over a finite field of characteristic p that runs in time $p^{1/2+o(1)}$. The algorithm extends both Gonçalves's generalization of Kedlaya's algorithm for cyclic covers, and Harvey's work on Kedlaya's algorithm for large characteristic. We confirm its practicality and effectiveness by reporting on the performance of our SageMath implementation on a range of examples.

Our work provides a valuable tool for the study of superelliptic curves over local and global fields by providing data which, among other things, helps to understand their Galois representations, the torsion subgroups of their Jacobians, and analogues of the Lang-Trotter conjecture. (Received August 28, 2018)

1145-11-278 **Nicholas Triantafillou*** (ngtriant@mit.edu). *Variants of Chabauty's Method and the Thrice-Punctured Projective Line.* Preliminary report.

Chabauty's method is a powerful tool for bounding/enumerating the number of integral/rational points on arithmetic curves. Unfortunately, it requires the curve's Jacobian to have rank less than its dimension. This condition frequently fails, especially for number fields of high degree. Several techniques have been proposed to augment the classical Chabauty, including descent, restriction of scalars, the Mordell-Weil sieve and Kim's non-abelian Chabauty. We study the power of various combinations of these techniques, mostly in the context of computing S-integral points of number fields on the thrice-punctured projective line. Among other things, our work gives bounds on the number of solutions to S-unit equations and a strategy for counting solutions without using strong results from transcendental number theory. This work has applications to other counting problems in number theory, like enumerating elliptic curves over numer fields with prescribed primes of bad reduction. (Received August 28, 2018)

1145-11-295 **Orli Herscovici*** (orli.herscovici@gmail.com), 3200003 Haifa, Israel. *New degenerate Bernoulli and Euler polynomials arising from non-classical Umbral Calculus.* Preliminary report.

We introduce new generalizations of the Bernoulli and Euler polynomials based on the degenerate exponential function and concepts of the Umbral Calculus associated with it. We present generalizations of some familiar identities and connection between these kinds of Bernoulli and Euler polynomials which we have established in our preliminary work. (Received August 29, 2018)

1145-11-330 **Alexander J Barrios*** (abarrios@carleton.edu), Carleton College, Department of Mathematics and Statistics, One North College Street, Northfield, MN 55057. *Lower Bounds on the Modified Szpiro Ratio.*

The modified Szpiro conjecture, which is equivalent to the ABC Conjecture, states that for each $\epsilon > 0$ there are finitely many rational elliptic curves E satisfying $N^{6+\epsilon} < \max\{|c_4^3|, c_6^2\}$ where N is the conductor of E and c_4 and c_6 are the invariants associated to a minimal model of E. In this talk we will show that for a rational elliptic curve E with torsion subgroup $E(\mathbb{Q})_{\text{tors}} \cong T$, there is an explicit lower bound l_T on the modified Szpiro ratio which depends only on T, i.e., $l_T < \frac{\log \max\{|c_4^3|, c_6^2\}}{\log N}$ for all $E/\mathbb{Q}$ with $T \hookrightarrow E(\mathbb{Q})$. The techniques of the proof rely on a careful analysis of the minimal models of E and Tate's algorithm. (Received September 01, 2018)

1145-11-349 **Steven H. Weintraub*** (shw2@lehigh.edu), Dept. of Mathematics, Lehigh University, Bethlehem, PA 18015. *Periodicity of Certain Generalized Continued Fractions.*

We have previously considered continued fractions with "numerator" a positive integer N, which we refer to as cf_N expansions. In particular, let E be a positive integer that is not a perfect square. For $N > 1$, $\sqrt{E}$ has infinitely many cf_N expansions. There is a natural notion of the "best" cf_N expansion of $\sqrt{E}$. We have conjectured, based on extensive numerical evidence, that such a best expansion is not always periodic. From this evidence, it is difficult to predict for which N this expansion will be periodic. We show here that for any such E, there are infinitely many values of N for which this expansion is indeed periodic, more precisely, periodic of period 1 or 2, and we obtain formulas for a subset of these expansions in terms of solutions to Pell's equation $x^2 - Ey^2 = 1$. (Received September 03, 2018)

1145-11-364 **Madeline Locus Dawsey*** (madeline.locus@emory.edu) and **Ken Ono**. *CM Evaluations of the Goswami-Sun Series.*

In recent work, Sun constructed two q-series identities whose limits as $q \to 1$ give new derivations of the Riemann-zeta values $\zeta(2)$ and $\zeta(4)$. Goswami extended these identities by obtaining an infinite family of q-series which analogously lead to new derivations of $\zeta(2k)$ for every $k \in \mathbb{Z}^+$. Using the fact that $\Gamma\left(\frac{1}{2}\right) = \sqrt{\pi}$, it follows that $\zeta(2k) \in \mathbb{Q} \cdot \Gamma\left(\frac{1}{2}\right)^{4k}$. Therefore, it is natural to seek further specializations of these series which involve special values of the Γ-function. We show that the values of these series at all CM points τ, where $q := e^{2\pi i\tau}$, are algebraic expressions in terms of specific ratios of Γ-values. (Received September 04, 2018)

1145-11-385 **Maarten Derickx*** (drx@mit.edu). *A-gonality and points of degree d on curves.* Preliminary report.

The gonality of a curve C over the rational numbers $\mathbb{Q}$ is defined to be the smallest integer d for which there exist a map of degree d to $\mathbb{P}^1$. If a map of degree d exists on C then $C(\overline{\mathbb{Q}})$ contains infinitely many points defined over number fields of degree d. It is a theorem of Frey that a converse also holds, namely if $C(\overline{\mathbb{Q}})$ contains infinitely many points of degree d, then there exists a map of degree at most $2d$ to $\mathbb{P}^1$. This means that the gonality determines the smallest degree for which there exists infinitely many points up to a factor of two. The main subject of this talk is the notion of A-gonality. This is a generalisation of the clasical gonality and additionally shares much of the same nice properties as gonality. In certain situations it gives more information about the existence of points of degree d then the classical gonality. (Received September 04, 2018)

1145-11-398 **Wei Zhang*** (weizhang@mit.edu), 77 Massachusetts Avenue, cambridge, MA 02139. *Algebraic cycles and L-functions: a relative trace formula approach.*

We review conjectures and theorems on special cycles on Shimura varieties, and their connection to central values of L-functions and their derivatives. We focus on the global Gan–Gross–Prasad conjectures, their arithmetic versions and some variants in the author's joint work with Rapoport and Smithling. (Received September 05, 2018)

1145-11-416 **Michael F Singer*** (msinger@msri.org), MSRI, 17 Gauss Way, Berkeley, CA 94720. *The 2020 MSRI program "Decidability, Definability and Computability in Number Theory".*

From August 17, 2020 to December 18, 2020, the Mathematical Sciences Research Institute (MSRI) in Berkeley, CA will host a program titled "Decidability, Definability and Computability in Number Theory Program". I will describe some aspects of the program, how one applies, and services that MSRI offers (visa, housing, family services, ...). (Received September 05, 2018)

1145-11-417 **Tonghai Yang*** (thyang@math.wisc.edu), Department of Mathematics, University of Wisconsin, Madison, WI 53706, and **Hongbo Yin** (yinhongbo0218@126.com) and **Peng Yu** (pyu@amss.ac.cn). *The Lambda invariant and its CM values.*

In this talk, we will show that the usual lambda invariant $\lambda(\tau)$ is a good choice among its 6 possible counterparts for the CM points $\tau^0 = \frac{d+\sqrt{d}}{2}$ by showing that the CM value $\lambda(\tau_0)$ is an algebraic integer and can be used to easily construct units. We also give a factorization formula for the norm of $\lambda(\frac{d_1+\sqrt{d_1}}{2}) - \lambda(\frac{d_2+\sqrt{d_2}}{2})$, similar to the beautiful Gross-Zagier factorization formula of singular moduli. (Received September 05, 2018)

1145-11-426 **Victor Rotger*** (victor.rotger@upc.edu), Campus Nord, Edifici Omega Despatx 413, C/ Jordi Girona, 1-3, Barcelona, 08034. *On a conjecture of Harris and Venkatesh.*

A. Venkatesh has proposed a conjecture which explicates the symultaneous presence of a system of eigenvalues in several degrees of the cohomology of a symmetric domain in terms of derived Hecke operators and motivic cohomology. The simplest non-trivial case of this phenomenon arises for classical modular forms of weight 1, and the conjecture has been made explicit by Harris and Venkatesh. In this setting it predicts a relationship between mod p Rankin triple-products and Stark units. In this lecture I will describe recent progress towards proving this conjecture in joint work with Darmon, Harris and Venkatesh, and a p-adic version of the conjecture in joint work with my student Rivero. (Received September 06, 2018)

1145-11-428 **Mahesh R Kakde*** (mahesh.kakde@kcl.ac.uk), King's College London, Mathematics department, Strand, London, WC2R2LS, United Kingdom. *Explicit formulae for Gross-Stark units and Hilbert's 12th problem.*

In this talk I will report on my joint work with Samit Dasgupta on the tower of fields conjecture first formulated by Gross. This conjecture proves a conjecture of Dasgupta on explicit p-adic analytic formulae for Gross-Stark units. These units, when considered for all primes of a totally real number field F, generate the maximal abelian CM extension of F and therefore our work can be considered as giving a p-adic analytic solution to Hilbert's 12th problem. Further, the tower of fields conjecture also proves a conjecture of Dasgupta and Spiess which gives a p-adic analytic formulae, in terms of Eisenstein cocycles, for the characteristic polynomial of the Gross regulator matrix. (Received September 06, 2018)

1145-11-429 **Alice Pozzi*** (alice.pozzi89@gmail.com), Flat 34, Bullen House, Collingwood Street, London, E1D5Y. *The eigencurve at weight one Eisenstein points.* Preliminary report.

In 1972, Serre observed that the Hecke eigenvalues of Eisenstein series can be p-adically interpolated. In other words, Eisenstein series can be viewed as a p-adic family parametrized by the weight. The notion of p-adic variations of modular forms was later generalized by Hida to include families of ordinary cuspforms. In 1998, Coleman and Mazur defined the eigencurve, a rigid analytic space that, loosely speaking, encodes much more general p-adic families of Hecke eigenforms parametrized by the weight. However, many geometric properties of the eigencurve are still misterious. In this talk, we will describe the local nature of the eigencurve at some particular points corresponding to weight one forms. We consider weight one Eisenstein series that are irregular at a fixed prime p. Such forms are not cuspidal in a classical sense, but they become cuspidal when viewed as p-adic modular forms. Thus, they give rise to points that belong to the intersection of the Eisenstein locus and the cuspidal locus of the eigencurve. Following the approach of Bellaiche and Dimitrov in the weight one cuspidal case, we study this intersection via deformations of Galois representations. (Received September 06, 2018)

1145-11-430 **Yingkun Li*** (li@mathematik.tu-darmstadt.de), Schlossgartenstrasse 7, 64289 Darmstadt, Hessen, Germany. *Average values of higher Green's functions and their factorizations.*

By the classical theory of complex multiplication, the Klein j-invariant takes algebraic values at CM points. In their seminal work on singular moduli, Gross and Zagier gave a factorization of the difference between two such values, which can be viewed as the exponential of a special value of a Green's function on the upper half plane. From numerical computations, they conjectured that the special values of certain higher Green's functions also enjoy similar algebraicity property. We will revisit this conjecture and discuss some recent progress. (Received September 06, 2018)

1145-11-438 **Vinayak Vatsal*** (vatsal@math.ubc.ca), UBC Math Department, Vancouver, BC , Canada. *A new direction in the theory of complex multiplication.*

I will report on some of my recent work, with special emphasis on the aspects which suggest new directions in the theory of complex multiplication. (Received September 06, 2018)

1145-11-444 **Carrie E. Finch-Smith*** (finchc@wlu.edu). *Riesel and Sierpiński numbers in special sequences.* Preliminary report.

In 1956, H. Riesel noticed that 509203 has a special property: the sequence $509203 \cdot 2^n - 1$ (where $n = 1, 2, 3, \ldots$) contains no primes. A few years later, W. Sierpiński found a similar sequence; $78557 \cdot 2^n + 1$ also comprises only composite integers. The integers 509203 and 78557 are called Riesel and Sierpiński numbers, respectively. In this talk, we will discuss familiar sequences of integers that contain infinitely many Riesel or Sierpiński numbers. (Received September 06, 2018)

1145-11-454 **Amir Akbary** and **Alia Hamieh*** (alia.hamieh@unbc.ca). *Value-distribution of cubic Hecke L-functions.*

A significant part of the research in number theory studies the values of L-functions in the critical strip $0 < \Re(s) < 1$. The L-functions in their value-distribution cary important information about the underlying structures. In this talk, we survey some recent value-distribution results. We also describe a value-distribution theorem for the logarithms and logarithmic derivatives of a family of L-functions attached to cubic Hecke characters. As a corollary of our results, we establish the existence of an asymptotic distribution function for the error term of the Brauer-Siegel asymptotic formula for a certain family of cubic extensions of $\mathbb{Q}(\sqrt{-3})$. We also deduce a similar result for the Euler-Kronecker constants of this family. This is joint work with Amir Akbary. (Received September 06, 2018)

1145-11-459 **Eva G Goedhart*** (goedhart@lvc.edu) and **Helen G Grundman**. *Using Continued Fractions to Solve a Family of Diophantine Equations.*

For positive integers a, b, c, k with $k \geq 7$, I will show how the family of Diophantine equations $(a^2cX^k - 1)(b^2cY^k - 1) = (abcZ^k - 1)^2$ has no integer solutions x, y, $z > 1$ with $a^2x^k \neq b^2y^k$ by using the simple continued fraction expansion of possible solutions to contradict known results. While this will be my focus for this presentation, the proof also uses a Diophantine approximation theorem. (Received September 06, 2018)

1145-11-490 **Jan Vonk*** (jan.vonk.jv@gmail.com), Mathematical Institute, University of Oxford, Woodstock Road, Oxford, Oxfordshir OX2 6GG, United Kingdom. *Non-abelian Chabauty and rational points on curves.*

In this talk, I will report on some recent progress on the subject of the non-abelian method of Chabauty-Kim for the explicit determination of the set of rational points on curves of higher genus. In joint work with Jennifer Balakrishnan, Netan Dogra, Steffen Müller, and Jan Tuitman, this lead to the explicit determination of the rational points on the 'cursed' modular curve with non-split Cartan structure of level 13. (Received September 07, 2018)

1145-11-491 **David Zureick-Brown*** (dzb@mathcs.emory.edu), 400 Dowman Drive, Atlanta, GA 30322, and **Jordan Ellenberg** and **Matthew Satriano**. *Counting points, counting fields, and heights on stacks.*

A folklore conjecture is that the number $N_d(K, X)$ of degree-d extensions of K with discriminant at most d is on order c_d X. In the case K = Q, this is easy for d=2, a theorem of Davenport and Heilbronn for d=3, a much harder theorem of Bhargava for d=4 and 5, and completely out of reach for $d > 5$. More generally, one can ask about extensions with a specified Galois group G; in this case, a conjecture of Malle holds that the asymptotic growth is on order $X^a(logX)^b$ for specified constants a,b.

The form of Malle's conjecture is reminiscent of the Batyrev–Manin conjecture, which says that the number of rational points of height at most X on a Batyrev–Manin variety also grows like $X^a(logX)^b$ for specified constants a,b. What's more, an extension of Q with Galois group G is a rational point on a Deligne-Mumford stack called BG, the classifying stack of G. A natural reaction is to say "the two conjectures is the same; to count number fields is just to count points on the stack BG with bounded height?" The problem: there is no definition of the height of a rational point on a stack. I'll explain what we think the right definition is, and explain how it suggests a heuristic which has both the Malle conjecture and the Batyrev–Manin conjecture as special cases. (Received September 07, 2018)

1145-11-492 **David Zureick-Brown*** (dzb@mathcs.emory.edu), 400 Dowman Drive, Atlanta, GA 30322. *Progress on Mazur's Program B.*

I'll discuss recent progress on Mazur's "Program B" – the problem of classifying all possibilities for the "image of Galois" for an elliptic curve over Q (equivalently, classification of all rational points on certain modular curves X_H).

This will including my own recent work with Jeremy Rouse which completely classifies the possibilities for the 2-adic image of Galois associated to an elliptic curve over the rationals. I will also discuss a large number of other very recent results by many authors. (Received September 07, 2018)

1145-11-493 **Stanley Yao Xiao*** (stanley.xiao@utoronto.ca), Department of Mathematics, University of Toronto, 40 St. George Street, Toronto, Ontario M5S 2E4, Canada. *Binary quartic forms with vanishing J-invariant.*

In this talk we enumerate $\mathrm{GL}_2(\mathbb{Z})$-equivalence classes of totally real integral binary quartic forms with vanishing J-invariant with bounded discriminant. Time permitting, we will also discuss applications to enumerating 2-Selmer elements of elliptic curves with a marked two torsion point. (Received September 07, 2018)

1145-11-495 **Jan Vonk*** (jan.vonk.jv@gmail.com), Mathematical Institute, University of Oxford, Woodstock Road, Oxford, Oxfordshir OX2 6GG, United Kingdom, and **Henri Darmon**. *Towards a p-adic theory of singular moduli for real quadratic fields.*

In recent work with Henri Darmon, the notion of a "Rigid meromorphic cocycle" was introduced, to provide an analogue for real quadratic fields of singular moduli, which occupy centre stage in CM theory. I will discuss recent progress towards proving certain aspects of the largely conjectural "RM theory" that results. (Received September 07, 2018)

1145-11-508 **Watson Bernard Ladd*** (watsonbladd@gmail.com), 1704 63rd Street #F, Berkeley, CA 94703, and **Jeffery Hein** and **Gonzalo Tornaria**. *Algebraic modular forms on* $\mathbf{SO}_5(\mathbb{Q})$ *and the computation of paramodular forms.*

Until recently, examples of paramodular forms with many Euler factors were very hard to find. This talk discusses how algebraic modular forms can be used to compute paramodular forms using a conjecture of Ibukiyama and some computer time we have produced tables of some paramodular forms of prime levels between 3 and 400 and weight 3. These results were published in the presenter's dissertation. (Received September 08, 2018)

1145-11-520 **Padmavathi Srinivasan*** (psrinivasan41@math.gatech.edu) and **Andrew Obus**. *Conductors and minimal discriminants of hyperelliptic curves in odd residue characteristic.* Preliminary report.

Conductors and minimal discriminants are two measures of degeneracy in a family of hyperelliptic curves. We will outline recent progress in extending Liu's inequality in genus 2 relating these two invariants to hyperelliptic curves of arbitrary genus when the residue characteristic is odd. This is joint work with Andrew Obus. (Received September 08, 2018)

1145-11-522 **John Friedlander***, Department of Mathematics, University of Toronto, 40 St. George Street, Toronto, Ontario M5S 2E4, and **Henryk Iwaniec**. *Coordinate distribution of Gaussian primes.* Preliminary report.

We are interested in counting the frequency of "Gaussian" primes $a + 2bi$ when both a and b are taken from arithmetically interesting sequences. In particular, we can succeed if we take a to be prime and b to be an "almost-prime" having no more than seven prime factors. (Received September 08, 2018)

1145-11-523 **Kamal Khuri-Makdisi***, Mathematics Department, American University of Beirut, Beirut, Lebanon. *Jacobian group operations for typical divisors on curves.*

Consider the question of efficiently implementing Jacobian group arithmetic for a curve C of genus g, over a finite field K with very large cardinality $q = |K| \gg g$. Many algorithms to do this are formulated for the "typical" case, which holds for "most" divisors once q is very large; so one is in practice very unlikely to encounter a nontypical divisor. This talk presents an explicit characterization of typical divisors for an arbitrary genus g curve with a rational point, with a precise bound on how unlikely a nontypical divisor is over a finite field. The main result is algorithms which succeed if and only if the input is typical, and which therefore provide a certificate that the input was typical in case of success. (Received September 08, 2018)

1145-11-546 **Wanlin Li***, UW-Madison Department of Mathematics, Van Vleck Hall, 480 Lincoln Drive, Madison, WI 53706. *Vanishing of Hyperelliptic L-functions at the Central Point.*

We obtain a lower bound on the number of quadratic Dirichlet L-functions over the rational function field which vanish at the central point $s = 1/2$. This is in contrast with the situation over the rational numbers, where a conjecture of Chowla predicts there should be no such L-functions. The approach is based on the observation that vanishing at the central point can be interpreted geometrically, as the existence of a map to a fixed abelian variety from the hyperelliptic curve associated to the character. (Received September 09, 2018)

1145-11-559 **Sun Kim*** (`ssunny8079@hanmail.net`). *Ramanujan's modular equations and colored partition identities.*

Ramanujan's modular equations of prime degrees 3, 5, 11, 7 and 23 are associated with elegant colored partition theorems. In 2005, S. O. Warnaar established a general identity which implies the modular equations of degrees 3 and 7. In this talk, we discuss a generalization of the remaining modular equations of degrees 5, 11 and 23. We also derive many other partition identities from this generalization. (Received September 10, 2018)

1145-11-565 **Mutasim Mim*** (`mutasim.mim16@stjohns.edu`), 300 Howard Ave., New York, NY 10301. *On a generalization of Wilson's Theorem.* Preliminary report.

Wilson's Theorem says that for every prime number n we have a congruence $(n-1)! \equiv -1(\bmod n)$. We generalize this result for any integer number n. (Received September 10, 2018)

1145-11-567 **Lin Jiu***, Department of Mathematics & Statistics, Dalhousie University, 6316 Coburg Road, Halifax, NS B3H 4R2, Canada, and **Diane Shi**, School of Mathematics, Tianjin University, No.135 Yaguan Road, Tianjin, 300350, Peoples Rep of China. *Matrix Representation for Higher-Order Euler Polynomials.*

We study the Euler polynomials of order p, which are denoted by $E_n^{(p)}(x)$. Define a doubly infinite band matrix

$$RE^{(p)} := \begin{pmatrix} x-\frac{p}{2} & -\frac{p}{4} & 0 & 0 & \cdots & 0 & \cdots \\ 1 & x-\frac{p}{2} & -\frac{p+1}{2} & 0 & \cdots & 0 & \cdots \\ 0 & 1 & x-\frac{p}{2} & \ddots & \ddots & \vdots & \cdots \\ 0 & 0 & 1 & \ddots & -\frac{n(n+p-1)}{4} & 0 & \cdots \\ \vdots & \vdots & \vdots & \ddots & x-\frac{p}{2} & -\frac{(n+1)(n+p)}{4} & \cdots \\ 0 & 0 & 0 & \ddots & 1 & \ddots & \ddots \\ \vdots & \vdots & \vdots & \cdots & \vdots & \ddots & \ddots \end{pmatrix}.$$

Then, the left upper $m \times m$ block of $RE^{(p)}$ generates all $E_n^{(p)}(x)$ through its powers, for $n \leq m$.

To obtain this matrix representation, the key theorem is to connect the moments of a random variable and the generalized Motzkin numbers, through the same J-fractions. Since recent result recognize $E_n^{(p)}(x)$ as moments of certain random variable, by the key theorem, we can view them also as generalized Motzkin numbers. Then, the matrix representation follows naturally from the lattice path interpretation.

Analogue for the Bernoulli polynomials, $B_n(x)$, is also obtained. (Received September 10, 2018)

1145-11-596 **Jayce Robert Getz*** (jgetz@math.duke.edu). *Secondary terms in asymptotics for the number of zeros of quadratic forms over number fields.*

Let Q be a nondegenerate quadratic form on a vector space V of even dimension n over a number field F . Via the circle method or automorphic methods one can give an asymptotic formula for smoothed sums over the number of zeros of the quadratic form whose coordinates are of size at most X (properly interpreted). We refine these results to obtain a secondary term in the expansion. (Received September 11, 2018)

1145-11-627 **Jared Duker Lichtman** and **Carl Pomerance***, carl.pomerance@dartmouth.edu. *The Erdős conjecture for primitive sets.*

A subset of the integers larger than 1 is *primitive* if no member divides another. Erdős proved in 1935 that the sum of $1/(a\log a)$ for a running over a primitive set A is universally bounded over all choices for A. In 1988 he asked if this universal bound is attained for the set of prime numbers. In this paper we make some progress on several fronts, and show a connection to certain prime number "races" such as the race between $\pi(x)$ and $\mathrm{li}(x)$. (Received September 11, 2018)

1145-11-633 **David P. Roberts*** (roberts@morris.umn.edu), Division of Science and Mathematics, University of Minnesota Morris, Morris, MN 56267. *Quadratic relations between Feynman integrals.*

The theory of periods in arithmetic geometry provides a general framework for understanding the transcendence properties of a broad class of integrals. A genus g curve over $\mathbf{Q}$ gives a classical instance of this theory. It has a $2g$-by-$2g$ matrix of periods P. While the entries of this matrix are expected to be transcendental numbers, they satisfy quadratic relations of the form

$$PDP^t = B.$$

Here D and P are antisymmetric matrices with rational entries, coming from "de Rham" and "Betti" cohomology respectively.

The talk will explain how integrals arising in quantum field theory conjecturally also fit into this framework. The integrals in question are moments of classical Bessel functions,

$$\int_0^\infty I_0^a K_0^b t^c dt.$$

We explain how we were led to package these integrals into an infinite sequence of square matrices P_k, and how we found explicit formulas for associated rational-entry matrices D_k and B_k so that conjecturally $P_k D_k P_k^t = B_k$ always holds.

The talk will be accessible to undergraduates, but will also give brief indications of deeper number-theoretic content, such as connections with special values of L-functions. This is joint work with David Broadhurst. (Received September 11, 2018)

1145-11-673 **Stephan Ramon Garcia*** (stephan.garcia@pomona.edu), 610 N College Ave, Claremont, CA 91711. *Mean, median, and mode factorization lengths in numerical semigroups.*

A numerical semigroup is an additive subsemigroup of $(\mathbb{N},+)$. If $n_1, n_2, \ldots, n_k$ are generators for a numerical semigroup S, then a *factorization* of n is an expression $n = a_1n_1 + \cdots + a_kn_k$, in which the natural number $a_1 + \cdots + a_k$ is the *length* of the factorization. Much of the literature deals with extremal factorization behavior, such as the maximum and minimum factorization lengths. Quantities of intermediate size, such as the mean, median, and mode factorization lengths are more subtle. We use techniques from analysis and probability to describe the asymptotic behavior of these quantities. Surprisingly, the asymptotic median factorization length is described by a number that is usually irrational. This is joint work with Christopher O'Neill and Samuel Yih. (Received September 12, 2018)

1145-11-687 **Darren B Glass*** (dglass@gettysburg.edu), 300 N Washington Street, Gettysburg, PA 17325. *Arithmetical Structures on Graphs.*

Given a finite connected simple graph, we define an arithmetical structure on the graph to be a labelling of the vertices with positive integers so that the label of each vertex is a divisor of the sum of the labels of its neighbors. Lorenzini showed that any graph has a finite number of arithmetical structures but his proof did not give insight into the actual number of structures. In this talk, we discuss results with various coauthors that make this number explicit for certain families of graphs. (Received September 12, 2018)

1145-11-744 **Byungchul Cha*** (cha@muhlenberg.edu), 2400 W Chew st, Allentown, PA 18104, and **Dong Han Kim**. *The Lagrange and Markov Spectra of Pythagorean triples.*

Call (p,q) a Pythagorean pair if p and q are positive integers such that p^2+q^2 is a perfect square. Draw a line ℓ from the origin into the first quadrant of the xy-plane. Suppose we want ℓ to avoid all but finitely many

Pythagorean pairs with as large a margin as possible. What is the greatest possible margin? What is the second greatest?

In 2008, Romik used a certain ternary tree consisting of Pythagorean triples to define a dynamical system on the unit quarter circle. We will study a Lagrange spectrum arising from Romik's dynamical system. This provides a natural setting for intrinsic Diophantine approximation on the unit circle. Our result gives a complete answer to the questions posed above. In addition, we obtain an analogue in this context to a classical theorem on Lagrange and Markoff spectra, which was first proved by Markoff in 1879. (Received September 13, 2018)

1145-11-761 **Michele Fornea*** (`michele.fornea@mail.mcgill.ca`). *Growth of the analytic rank of rational elliptic curves over quintic fields.*

We show that the analytic rank of a rational elliptic curve, with odd conductor and at least one prime of multiplicative reduction, grows over a positive proportion of quintic fields. (Received September 14, 2018)

1145-11-776 **Robert Hines*** (`robert.hines@colorado.edu`). *Examples of badly approximable vectors over number fields.* Preliminary report.

We consider approximation of vectors $\mathbf{z} \in F \otimes \mathbb{R} \cong \mathbb{R}^r \times \mathbb{C}^s$ by elements of a number field F and construct examples of badly approximable vectors. These examples come from compact subspaces of $SL_2(\mathcal{O}_F)\backslash SL_2(F \otimes \mathbb{R})$ naturally associated to (totally indefinite, anisotropic) binary quadratic and Hermitian forms, a generalization of the well-known fact that quadratic irrationals are badly approximable over $\mathbb{Q}$. (Received September 14, 2018)

1145-11-777 **Robet Hines*** (`robert.hines@colorado.edu`). *Badly approximable numbers over imaginary quadratic fields.* Preliminary report.

We recall the notion of nearest integer continued fractions over the Euclidean imaginary quadratic fields K and characterize the "badly approximable" numbers, (z such that there is a $C = C(z) > 0$ with $|z - p/q| \geq C/|q|^2$ for all $p/q \in K$), by boundedness of the partial quotients in the continued fraction expansion of z. Applying this algorithm to "tagged" indefinite integral binary Hermitian forms demonstrates the existence of entire circles in $\mathbb{C}$ whose points are badly approximable over K, with effective constants.

By other methods (the Dani correspondence), we prove the existence of circles of badly approximable numbers over *any* imaginary quadratic field. Among these badly approximable numbers are algebraic numbers of every even degree over $\mathbb{Q}$, which we characterize. All of the examples we consider are associated with cocompact Fuchsian subgroups of the Bianchi groups $SL_2(\mathcal{O})$, where $\mathcal{O}$ is the ring of integers in an imaginary quadratic field. (Received September 14, 2018)

1145-11-793 **John Cullinan***, Department of Mathematics, Bard College, Annandale-On-Hudson, NY 12401. *A probabilistic local-global principle for torsion on elliptic curves.*

Fix an integer $m > 1$. Let E be an elliptic curve over $\mathbf{Q}$ with the property that $\#E(\mathbf{F}_p)$ is divisible by m for all but finitely many primes p. While E is isogenous to an elliptic curve E' such that $\#E'(\mathbf{Q})_{\text{tors}}$ is divisible by m, but it may not be the case that $\#E(\mathbf{Q})_{\text{tors}}$ is divisible by m. Ordered by height, we show the probability that a curve with $m \mid \#E(\mathbf{F}_p)$ also has $m \mid \#E(\mathbf{Q})_{\text{tors}}$ is nonzero and we compute the probability explicitly in several cases. This is joint work with John Voight. (Received September 14, 2018)

1145-11-797 **Marc Chamberland*** (`chamberl@grinnell.edu`), 1116 8th Ave., Grinnell, IA 50112, and **Eugene Herman** (`eaherman@gmail.com`). *Factoring $m^2 + 1$.* Preliminary report.

Dirichlet's Theorem on Arithmetic Progressions, an important result in prime number theory, states that any linear sequence $\{an + b : n \text{ a positive integer}\}$ with $\gcd(a, b) = 1$ contains infinitely many primes. However, very little is known about nonlinear polynomial sequences. In this talk, we look at how m^2+1 factors when m is chosen to be an appropriate polynomial. This includes the use of continuants, a tool usually seen in conjunction with continued fractions, and Keller maps, polynomial maps associated with the famous Keller Jacobian Conjecture. (Received September 14, 2018)

1145-11-806 **Leo Goldmakher***, Williams College, Williamstown, MA 01267, and **Greg Martin**, UBC, Vancouver, BC , Canada. *Some refinements of Artin's conjecture.*

In 1927, Artin gave a heuristic argument that 2 is a primitive root (mod p) approximately 37% of the time. No one has been able to make his argument rigorous, and even the weaker problem of showing that 2 is a primitive root (mod p) for infinitely many p remains open.

Artin's initial heuristic has been generalized, giving rise to conjectures on the proportion of primes p for which any given integer is a primitive root (mod p); the most general form of this is now known as Artin's conjecture. In this talk I will describe several new conjectures (joint with Greg Martin, UBC) on the proportion of the time a given integer is "almost" a primitive root (mod p). Our conjectures subsume Artin's conjecture, and are borne out in computations. I'll also prove that our conjectures hold on average, and derive some consequences of this. For example, we obtain a new proof that Artin's conjecture holds on average, a result originally due to Goldfeld. (Received September 15, 2018)

1145-11-820 **Eun Hye Lee*** (elee211@uic.edu), 851 S Morgan St., Chicago, IL 60607, and **Ramin Takloo-Bighash** (rtakloo@uic.edu), 851 S Morgan St., Chicago, IL 60607. *On certain multiple Dirichlet series.* Preliminary report.

In this talk, I will be talking about the analytic properties of multiple Dirichlet series defined using the space of binary cubic forms. First I will construct the double zeta function from the 2 (out of 4) semi-invariants of the binary cubic forms, and then I will prove its meromorphic continuation to the whole $\mathbb{C}^2$ via sufficiently many functional equations and show where the poles are. This work is joint with Ramin Takloo-Bighash. (Received September 15, 2018)

1145-11-826 **Sergiy Koshkin*** (koshkins@uhd.edu). *Linear divisibility sequences and cyclotomic polynomials.*

Divisibility sequences are defined by the property that if $m|n$ then $a_m|a_n$. Those of them that also satisfy a linear recurrence, like the Fibonacci numbers, are generated by polynomials that divide themselves composed with every positive integer power. We completely characterize such polynomials and their factorizations into cyclotomic polynomials in terms of simple diagrams. We also determine when they generate strong divisibility sequences, i.e. $\gcd(a_m, a_n) = a_{\gcd(m,n)}$. (Received September 15, 2018)

1145-11-889 **Jeffrey Yelton*** (jeffery.yelton@unimi.it). *Galois actions associated to hyperelliptic curves over local fields.*

To any hyperelliptic curve C over a field K, we consider the ℓ-adic representation coming from the natural Galois action on the ℓ-adic Tate module of its Jacobian. When K is a local field with residue characteristic $p \geq 0$, I will discuss an approach to determining the restriction of this ℓ-adic action to the inertia subgroup I for each prime $\ell \neq p$, using a joint result with H. Hasson that describes the action of I on the prime-to-p étale fundamental group of a punctured projective line. I will finish by presenting some results on global ℓ-adic Galois images which arise as direct applications of such a description of the inertia action at various primes. (Received September 17, 2018)

1145-11-907 **George E Andrews*** (gea1@psu.edu), 306 McAllister Bldg., Math Dept, Pennsylvania State University, University Park, PA 16802. *Dyson's Favorite Identity and Chebyshev Polynomials.*

During World War ii, Freeman Dyson and W. N. Bailey corresponded on generalizations of the Rogers-Ramanujan identities. Dyson found many such, and in his 1988 article, A Walk Through Ramanujan's Garden, named the Rogers-Ramanujan type expansion for the generating function of partitions into parts not divisible by 9 as his favorite. In this talk, we shall consider generalizations of Dyson's favorite identity related to the Chebyshev polynomials of the third kind. We obtain some surprising new identities as well as applications to 9-th order mock theta functions. (Received September 17, 2018)

1145-11-910 **Chantal David**, **Ayla Gafni*** (agafni@ur.rochester.edu), **Amita Malik**, **Neha Prabhu** and **Caroline Turnage-Butterbaugh**. *Extremal primes for elliptic curves without complex multiplication.*

Fix an elliptic curve E over $\mathbb{Q}$. An *extremal prime* for E is a prime p of good reduction such that the number of rational points on E modulo p is maximal or minimal in relation to the Hasse bound. In this talk, I will discuss what is known and conjectured about the number of extremal primes $p \leq X$, and give the first non-trivial upper bound for the number of such primes when E is a curve without complex multiplication. The result is conditional on the hypothesis that all the symmetric power L-functions associated to E are automorphic and satisfy the Generalized Riemann Hypothesis. In order to obtain this bound, we use explicit equidistribution for the Sato-Tate measure as in recent work of Rouse and Thorner, and refine certain intermediate estimates taking advantage of the fact that extremal primes have a very small Sato-Tate measure. (Received September 17, 2018)

1145-11-956 **Alexander Weston Walker*** (alexander.walker@rutgers.edu), Hill Center for the Mathematical Sciences, 110 Frelinghuysen Road, Piscataway Township, NJ 08854.
Cancellation in the Partial Sums of Fourier Coefficients of Modular Forms.

Many arithmetic problems concern the degree of cancellation in a partial sum. For example, the Riemann hypothesis is equivalent to square-root cancellation in the partial sums of the Möbius function. In many cases, greater-than-squareroot cancellation is known to fail.

Greater-than-squareroot cancellation can be found in the error estimates for both Gauss' Circle Problem and Dirichlet's Divisor Problem. In this talk, I show how both of these problems may be addressed by studying the partial sums of Fourier coefficients of modular forms. In this way, we create a large class of partial sums which exhibit extraordinary cancellation. (Received September 17, 2018)

1145-11-960 **Katherine Gallagher*** (kgalla17@nd.edu), **Katja Vassilev** and **Lucia Li**. *Lacunarity of Han-Nekrasov-Okounkov q-series.*

A power series is called lacunary if "almost all" of its coefficients are zero. Integer partitions have motivated the classification of lacunary specializations of Han's extension of the Nekrasov-Okounkov formula. More precisely, we consider the modular forms

$$F_{a,b,c}(z) := \frac{\eta(24az)^a \eta(24acz)^{b-a}}{\eta(24z)},$$

defined in terms of the Dedekind η-function, for integers $a, c \geq 1$ where $b \geq 1$ is odd throughout. Serre determined the lacunarity of the series when $a = c = 1$. Later, Clader, Kemper, and Wage extended this result by allowing a to be general, and completely classified the $F_{a,b,1}(z)$ which are lacunary. Here, we consider all c and show that for $a \in \{1, 2, 3\}$, there are infinite families of lacunary series. However, for $a \geq 4$, we show that there are finitely many triples (a, b, c) such that $F_{a,b,c}(z)$ is lacunary. In particular, if $a \geq 4$, $b \geq 7$, and $c \geq 2$, then $F_{a,b,c}(z)$ is not lacunary. Underlying this result is the proof the t-core partition conjecture proved by Granville and Ono. (Received September 17, 2018)

1145-11-986 **Naveen Somasunderam*** (somasunn@oregonstate.edu) and **Clayton Petsche**.
Equidistribution of sequences on the p-adic unit ball.

Techniques from harmonic analysis play a crucial role in understanding problems in analytic number theory. For example, in 1916 Hermann Weyl initiated the study of the equidistribution of sequences on the additive circle, connecting Fourier analysis to number theoretic dynamics.

Such techniques can be extended to other locally compact abelian groups. We look at the p-adic unit ball Zp as one such example, and show how Fourier analytic techniques can give us an understanding of the distribution of sequences. We show a LeVeque type inequality for the discrepancy and use it look at the quantitative behavior of the linear sequence na +b, where a is a unit in Zp. (Received September 18, 2018)

1145-11-988 **Naveen Somasunderam*** (somasunn@oregonstate.edu). *Harmonic analysis on the p-adic unit ball.*

The p-adic fields play a central role in modern number theory, and hence the behavior of sequences over these fields are of considerable interest.

We show how fourier analysis on the circle can be extended to the p-adic unit ball Zp, and use it to analyze the behavior of sequences.

The techniques we consider are easily accessible to undergraduates who have taken a semester of advanced calculus and algebra. We shall conclude with some interesting open questions. (Received September 18, 2018)

1145-11-1030 **Asif Ali Zaman*** (aazaman@stanford.edu), Stanford University. *Primes represented by positive definite binary quadratic forms.*

The distribution of primes represented by positive definite integral binary quadratic forms is a classical topic within number theory and has been intensely studied over centuries. We will investigate counting the number of primes up to x represented by a given form when x is close to the conjectural threshold of equidistribution. Several different flavors will be discussed: unconditional, conditional on the Grand Riemann Hypothesis, and on average over discriminants. One key feature will be that non-trivial upper bounds are obtained when the size of x is a small power of the discriminant and, in many cases, this size will be essentially optimal. (Received September 18, 2018)

1145-11-1033 **Katharine Woo***, katywoo@stanford.edu, and **Naomi Sweeting**, nsweeting@uchicago.edu. *Formulas for Chebotarev densities of Galois extensions of number fields.*

We generalize the Chebotarev density formulas of Dawsey (2017) and Alladi (1977) to the setting of arbitrary finite Galois extensions of number fields L/K. In particular, if $C \subset G = \mathrm{Gal}(L/K)$ is a conjugacy class, then we establish that the Chebotarev density is the following limit of partial sums of ideals of K:

$$-\lim_{X\to\infty} \sum_{\substack{2\leq N(I)\leq X \\ I\in S(L/K;C)}} \frac{\mu_K(I)}{N(I)} = \frac{|C|}{|G|},$$

where $\mu_K(I)$ denotes the generalized Möbius function and $S(L/K;C)$ is the set of ideals $I \subset \mathcal{O}_K$ such that I has a unique prime divisor $\mathfrak{p}$ of minimal norm and the Artin symbol $\left[\frac{L/K}{\mathfrak{p}}\right]$ is C. To obtain this formula, we generalize several results from classical analytic number theory, as well as Alladi's concept of duality for minimal and maximal prime divisors, to the setting of ideals in number fields. (Received September 18, 2018)

1145-11-1039 **Asif Ali Zaman*** (aazaman@stanford.edu), Stanford University. *Moments of other random multiplicative functions.*

Random multiplicative functions naturally serve as models for number theoretic objects such as the Mobius function. After fixing a particular model, there are many interesting questions one can ask. For example, what is the distribution of their partial sums? Harper has recently made remarkable progress for partial sums of random multiplicative functions with values that lie on the complex unit circle. He settled the correct order of magnitude of their qth moments for all real $q \geq 0$ and surprisingly established that one expects better than square-root cancellation in their partial sums. We extend Harper's analysis to a wider class of multiplicative functions such as those modeling the coefficients of higher degree L-functions. (Received September 18, 2018)

1145-11-1041 **Bruce C Berndt*** (berndt@illinois.edu), Department of Mathematics, University of Illinois, 1409 W. Green St., Urbana, IL 61801, **George E Andrews** (andrews@math.psu.edu), Dept. of Mathematics, Pennsylvania State University, University Park, PA, **Song Heng Chan** (chansh@ntu.edu.sg), School of Physical and Mathematical Sciences, Nanyang Technological University, 21 Nanyang Link, Singapore, Singapore, **Sun Kim** (skim@uni-koeln.de), Mathematical Institute, University of Cologne, Weyertal 86-90 50932, Cologne, Germany, and **Amita Malik** (amita.malik@rutgers.edu), Department of Mathematics, Rutgers University, 110 Frelinghuysen Rd, Piscataway, NJ 08854. *Identities for Third Order Mock Theta Functions from Ramanujan's Lost Notebook.*

Using the famous Atkin–Swinnerton-Dyer Lemma, Hamza Yesilyurt provided very nice proofs of four identities for third order mock theta functions found on pages 2 and 17 in Ramanujan's Lost Notebook. Since it is unlikely that Ramanujan used this Lemma from complex analysis, there is motivation to find proofs using the theory of q-series. In collaboration with George Andrews, Song Heng Chan, Sun Kim, and Amita Malik, such proofs have now been given. As corollaries, new relations for ranks are established. (Received September 18, 2018)

1145-11-1074 **Steven M Gonek*** (gonek@math.rochester.edu), Department of Mathematics, University of Rochester, Rochester, NY 14627. *The Lindelöf hypothesis for primes is equivalent to the Riemann hypothesis.*

The classical Lindelöf hypothesis is equivalent to a certain estimate for the sums $\sum_{n\leq x} n^{it}$. We propose that a more general form of the Lindelöf hypothesis is true, one involving similar estimates for sums of the type

$$\sum_{\substack{n\leq x \\ n\in\mathcal{N}}} n^{it},$$

where $\mathcal{N}$ can be a rather general sequence of real numbers. We support this with various examples and show that when $\mathcal{N}$ is the sequence of prime numbers, the truth of our conjecture is equivalent to the Riemann hypothesis. Moreover, if our conjecture holds when $\mathcal{N}$ is the sequence of primes congruent to $a(\mathrm{mod} q)$, with a coprime to q, then the Riemann hypothesis holds for all Dirichlet L-functions with characters modulo q, and conversely. These results suggest that a general form of the Lindelöf hypothesis may be true that is in some sense more fundamental than either the classical Lindelöf hypothesis or the Riemann hypothesis. This is joint work with Sid Graham and Yoonbok Lee. (Received September 18, 2018)

1145-11-1079 **Fatma Cicek*** (fcicek@ur.rochester.edu), 60 Crittenden Blvd Apt 326, Rochester, NY 14620, and **Steve Gonek**. *The distribution of* $\log \zeta(s)$ *near its zeros.*

Selberg's central limit theorem asserts that the distribution of the logarithm of the Riemann zeta-function near the critical line is an approximate two-dimensional normal distribution. Selberg's method and later Hejhal's work

on the distribution of $\log\zeta'(s)$ used continuous moments to obtain results about the distribution. In this talk, we will investigate the distribution of the zeta-function and its derivative by calculating the following discrete moments

$$\sum_{T\leq\gamma<2T}\big(\log|\zeta(\rho+w)|\big)^k \qquad \text{and} \qquad \sum_{T\leq\gamma<2T}\big(\log|\zeta'(\rho)|\big)^k.$$

Our results are conditional on the Riemann Hypothesis together with a zero-spacing hypothesis. This is joint work with Steve Gonek. (Received September 18, 2018)

1145-11-1084 **Zane Kun Li*** (zkli@math.ucla.edu). *An l^2 decoupling interpretation of efficient congruencing in 2D.*

There are two apriori different looking proofs of Vinogradov's mean value theorem. One is Wooley's number theoretic efficient congruencing approach and the other is Bourgain, Demeter, and Guth's harmonic analysis approach by proving an l^2 decoupling theorem for the moment curve. In two dimensions, we give a precise interpretation of efficient congruencing using decoupling. Quantitative estimates will also be given which yields an application to the sixth-order correlation of integer points on a circle recovering unconditionally a result of Bombieri and Bourgain. (Received September 18, 2018)

1145-11-1102 **David Lowry-Duda*** (d.lowry@warwick.ac.uk). *Zeroes of L-functions associated to half-integral weight modular cusp forms.* Preliminary report.

Automorphic L-functions are expected to satisfy a Riemann hypothesis and a Lindelof Hypothesis. But L-functions associated to half integral weight L-functions do not generally satisfy the Riemann Hypothesis. In this talk, we examine ongoing work to study the behaviour and distribution of zeroes of these half integral weight L-functions. (Received September 19, 2018)

1145-11-1123 **Christelle Vincent*** (christelle.vincent@uvm.edu), Department of Mathematics and Statistics, 16 Colchester Avenue, Burlington, VT 05401. *Computing hyperelliptic modular invariants from period matrices.* Preliminary report.

We define the modular invariants of a hyperelliptic curve to be the value of certain Siegel modular functions that correspond to classical invariants of hyperelliptic curves, evaluated at a period matrix of the Jacobian of the curve. In this talk, we discuss this correspondence between modular functions and invariants of curves, as well as certain computational considerations that arise when recognizing the invariants as algebraic numbers from their floating point approximation. This is joint work with Ionica, Kilicer, Lauter, Lorenzo Garcia, Massierer, and Manzateanu. (Received September 19, 2018)

1145-11-1168 **Xuancheng Shao*** (fernandoshao@gmail.com). *Gowers uniformity of primes in arithmetic progressions and in short intervals.*

A celebrated theorem of Green-Tao asserts that the set of primes is Gowers uniform (after W-trick). In this talk I will discuss results of this type for primes restricted to either arithmetic progressions or short intervals. As applications, these results will allow us to count linear equations in primes restricted to arithmetic progressions or short intervals. (Received September 19, 2018)

1145-11-1172 **Alia Hamieh** and **Naomi Tanabe*** (ntanabe@bowdoin.edu), Brunswick, ME 04011. *Additive Twists of Fourier Coefficients.*

In this talk, we study the sum of additively twisted Fourier coefficients of modular forms over totally real number fields. We also survey some results pertaining to cancellation in the twists. This is an ongoing project. (Received September 19, 2018)

1145-11-1190 **Jeff Hoffstein***, Mathematics Department, Brown University, Providence, RI 02912, and **Maria Nastasecu** (maria_nastasescu@brown.edu), Mathematics Department, Brown University, Providence, RI 02912. *Hybrid estimates for quadratic twists of holomorphic L-series.* Preliminary report.

We build on an exact formula of Michel and Ramakrishnan derived from the relative trace formula and obtain, via the analysis of multiple shifted convolution Dirichlet series some hybrid (in the level and the conductor of the twist) estimates for holomorphic L-series. (Received September 19, 2018)

1145-11-1196 **Amita Malik*** (amita.malik@rutgers.edu) and **Arindam Roy**. *Zeros of the derivatives of the completed Riemann zeta function.*

In this talk, we discuss some results on the distribution of imaginary parts of zeros of the derivatives of the completed Riemann zeta function. This is joint work with Arindam Roy. (Received September 19, 2018)

1145-11-1201 **Isabel Vogt***, MIT Department of Mathematics, 77 Massachusetts Ave, Bldg 2-106, Cambridge, MA 02139. *A local-global principle for isogenies of composite degree.*

Let E be an elliptic curve defined over a number field. In this talk, we will address the following question: if the reduction of E modulo almost all primes has a rational cyclic isogeny of degree N, is E forced to as well? Building on the work of Sutherland, Anni, and Banwait–Cremona when N is prime, we will focus on the case that N is composite. (Received September 20, 2018)

1145-11-1207 **Steven J Miller***, Department of Mathematics and Statistics, Williamstown, MA 01267. *Rank and Bias in Families of Curves via Nagao's Conjecture.* Preliminary report.

Let $\mathcal{X} : y^2 = x^{2g+1} + A_{2g}(T)x^{2g} + \cdots + A_0(T)$ be a nontrivial one-parameter family of hyperelliptic curves of genus g over $\mathbb{Q}(T)$ with $A_i(T) \in \mathbb{Z}[T]$. Denote by $\mathcal{X}_t$ the specialization of $\mathcal{X}$ to an integer t, $a_t(p)$ its trace of Frobenius, and $A_{r,\mathcal{X}}(p) = \sum_{t(p)} a_t(p)^r$ its r-th moment. The first moment is related to the rank of the Jacobian by the generalized Nagao conjecture. Generalizing a result of Arms, Lozano-Robledo, and Miller, we compute first moments for various families resulting in infinitely many hyperelliptic curves over $\mathbb{Q}(T)$ with Jacobian of moderately large rank; by the specialization theorem, this yields hyperelliptic curves over $\mathbb{Q}$ with large rank Jacobian. When $\mathcal{X}$ is an elliptic curve, Michel proved $A_{2,\mathcal{X}} = p^2 + O\left(p^{3/2}\right)$. For the families studied, we observe the same second moment expansion. Furthermore, we observe the largest lower order term that does not average to zero is on average negative, a bias first noted by Miller in the elliptic curve case. We prove this bias for a number of families. This is joint work with Scott Arms, Trajan Hammonds, Seoyoung Kim, Ben Logsdon, and Alvaro Lozano-Robledo. (Received September 20, 2018)

1145-11-1217 **Paul Pollack*** (pollack@uga.edu). *Some algebraic contributions to Waring's problem.*

"Waring's problem", first settled by Hilbert in 1909, is the task of showing that for every positive integer k, there is a finite $g(k)$ such that every nonnegative integer is a sum of $g(k)$ kth powers of nonnegative integers. For example, we can take $g(2) = 4$, since every nonnegative integer is a sum of four squares. While today the circle method is the principal tool used to study Waring's problem and its variants, Hilbert's solution was more algebraic, depending on the existence of certain polynomial identities. I will survey work on variants of Waring's problem where the algebra comes back into focus. Two examples from the work of the speaker: (1) an analogue of Waring's problem in the ring of (Lipshitz) integral quaternions, (2) a proof that a certain number field analogue of $g(k)$ — while always finite — cannot be bounded solely in terms of k. (Received September 20, 2018)

1145-11-1271 **Niven T Achenjang*** (nachenjang@gmail.com), P.O. Box 13884, Stanford, CA 94309, and **Aaron Berger**. *On Gaps in the Closures of Images of Divisor Functions.*

Given a complex number c, define the divisor function $\sigma_c : \mathbb{N} \to \mathbb{C}$ by $\sigma_c(n) = \sum_{d|n} d^c$. In this paper, we look at $\overline{\sigma_{-r}(\mathbb{N})}$, the topological closures of the image of σ_{-r}, when $r > 1$. We exhibit new lower bounds on the number of connected components of $\overline{\sigma_{-r}(\mathbb{N})}$, bringing this bound from linear in r to exponential. Finally, we discuss the general structure of gaps of $\overline{\sigma_{-r}(\mathbb{N})}$ in order to work towards a possible monotonicity result. (Received September 20, 2018)

1145-11-1283 **Luis Garcia***, Department of Mathematics, University of Toronto, 40 St. George Street, #6290, Toronto, M5S 2E4, Canada. *Eisenstein cohomology and equivariant transgressions of the Euler class.*

I will this discuss work in progress giving a new construction of Eisenstein classes on GL(n) first defined by Nori and Sczech, based on results of Bismut and Cheeger providing canonical transgressions of Euler forms. Our method realises these Eisenstein classes as regularised theta lifts for the dual pair (GL(1),GL(n)) and admits a natural extension to the pair (GL(r),GL(n)) for r > 1. I will describe the resulting generalisation of the Eisenstein cocycle and its relation with GL(r,Z) equivariant cohomology of the universal bundle of metrized tori. Joint work with Nicolas Bergeron, Pierre Charollois and Akshay Venkatesh. (Received September 20, 2018)

1145-11-1313 **Ari Shnidman*** (ari.shnidman@gmail.com). *Intersections of Heegner-Drinfeld cycles.*

I'll discuss some formulas relating intersections of Heegner-Drinfeld cycles to higher order central derivatives of automorphic L-functions, in the function field setting. This is based on joint works with Ben Howard and Spencer Leslie. (Received September 20, 2018)

1145-11-1319 **Vorrapan Chandee*** (chandee@ksu.edu), Mathematics Department, Kansas State University, 138 Cardwell Hall, Manhattan, KS 66506, and **Yoonbok Lee** (leeyb@inu.ac.kr), Department of Mathematics and, Research Institute of Natural Sciences, Incheon National University, Incheon, Incheon 22012, South Korea. *n-level density of the low lying zeros of primitive Dirichlet L-functions.*

In 1996, Rudnick and Sarnak computed n-correlation of the zeros of the Riemann zeta function when the Fourier transform $\hat{f}(u_1, ..., u_n)$ of a test function f is supported in the region $\sum_{j=1}^{n} |u_j| < 2$. The restriction of the support of the Fourier transform of f is required so that the contribution from the off diagonal terms can be ignored. However, a good conjecture for n-correlation for arbitrary support is available through random matrix theory. Using a technique from Conrey, Iwaniec and Soundararajan's work on asymptotic large sieve, we will investigate the n-level density of low lying zeros of primitive Dirichlet L-functions in the case that the Fourier transform $\hat{f}(u_1, ..., u_n)$ of a test function f is supported in the region $\sum_{j=1}^{n} |u_j| < 4$. This is the first time for unitary ensemble that the n-correlation conjecture is verified for a wider range, where off-diagonal terms start contributing. (Received September 20, 2018)

1145-11-1324 **Guillermo Mantilla-Soler*** (gmantelia@gmail.com). *An $\ell - p$ switch trick to obtain a new proof of a criterion for arithmetic equivalence.*

Two number fields are called *arithmetically equivalent* if they have the same Dedekind zeta function. In the 1970's Perlis showed that this is equivalent to the condition that for almost every rational prime ℓ the arithmetic type of ℓ is the same in each field. In the 1990's Perlis and Stuart gave an unexpected characterization for arithmetic equivalence; they showed that to be arithmetically equivalent it is enough for almost every prime ℓ to have the same number of prime factors in each field. Here, using an $\ell - p$ switch trick, we provide an alternative proof of that fact based on a classical elementary result of Smith from the 1870's. Furthermore, we will explain how our study of the zeta function gives and answer to an open question regarding ramification invariants posted by Perlis and Stuart. Parts of this work is Joint with Tristram Bogart. (Received September 21, 2018)

1145-11-1363 **Seoyoung Kim*** (seoyoung_kim@brown.edu), 189 Waterman Street, Unit 3, Providence, RI 02906. *The Sato-Tate conjecture and Nagao's conjecture.*

Nagao's conjecture relates the rank of an elliptic surface to a limit formula arising from a weighted average of fibral Frobenius traces, and it is further generalized for smooth irreducible projective surfaces by Hindry and Pacheco. We show that the Sato-Tate conjecture for abelian surfaces studied by Fité, Kedlaya, Rotger, Sutherland implies Nagao's conjecture for certain twist families hyperelliptic curves of genus 2. Moreover, one can relate analogous discussions for higher genus g to the nonvanishing result on the symmetric power L-functions, from which analogous proof will hold for certain cases. (Received September 25, 2018)

1145-11-1410 **Alexander J Barrios*** (abarrios@carleton.edu), Carleton College, Department of Mathematics and Statistics, One North College Street, Northfield, MN 55057. *Minimal Models of Rational Elliptic Curves with non-Trivial Torsion.*

The Frey curve $y^2 = x(x + a)(x - b)$ for relatively prime integers a and b comes equipped with an easily computable minimal discriminant. In this talk, we will extend the ideas of the Frey curve by classifying the minimal discriminant of all rational elliptic curves with non-trivial torsion. (Received September 21, 2018)

1145-11-1412 **Geremias Polanco*** (gpens@hampshire.edu), 893 West St, Hampshire college, School of Natural Science, Amherst, MA 01002, and **Daniel Schultz** and **Alexandru Zaharescu**. *On the average spacing of fractional parts of sequences generated by irrational numbers.*

In this talk we review some results of the nearest neighbor distribution for the sequence of fractional parts given by $n^k\alpha$, where α is an irrational number. We will show a distribution arising from the case $k = 1$ that is directly derived from the three distance theorem. (Received September 21, 2018)

1145-11-1422 **Jim Brown*** (jimlb@oxy.edu), 1600 Campus Road, Los Angeles, CA 90041, and **Hugh Geller** (hgeller@g.clemson.edu), **Rico Vicente** (ricoevicente@gmail.com) and **Alexandra Walsh** (alexandra_walsh@brown.edu). *When is the product of two Siegel eigenforms an eigenform?*

In the theory of modular forms, a very natural question to ask is when is the product of two eigenforms again an eigenform? The answer to this question in the case of elliptic modular forms was provided independently by Duke and Ghate; they proved there are only finitely many such pairs and gave a complete list. The case of elliptic modular forms with non-trivial level was handled by Johnson. In REU work this past summer we considered this question for genus two Siegel modular forms. This case has added difficulties due to the fact there are not nice clean relations between the Fourier coefficients and Hecke eigenvalues. The REU students provided a complete list when the two eigenforms are taken to be Eisenstein series (there is only one pair.) We conjecture there are no cases where both eigenforms are cuspforms and provided a necessary condition for the product of two cuspidal eigenforms to be an eigenform. These two cases will be presented in a separate talk by the students. This talk will focus on work since the completion of the REU on the remaining cases where one eigenform is a cuspform and one is an Eisenstein series. There is one example in this case and we conjecture it is the only example. We provide easily checkable necessary conditions for this remaining case. (Received September 21, 2018)

1145-11-1426 **Robert M. Sulman*** (sulmanrm@oneonta.edu). *Linear Functions (modulo n) and Associated Algebraic Structure.* Preliminary report.

We consider linear maps f(x) = ax+b (mod n) and explore the variety of orbit graphs produced. These graphs will sometimes have "whiskers" (when gcd(a,n)>1), although these whisker structures will be much simpler than those found in quadratic orbits (mod n), which will be seen in several examples as well. We will also see symmetry in the distribution of inverse-pairs (in orbit graph) among the units of the ring of integers modulo n. Finally, we examine the groups whose elements are linear maps (mod n). (Received September 24, 2018)

1145-11-1439 **Manami Roy*** (manami.roy.90@gmail.com). *Elliptic Curves and Paramodular Forms.*

In my talk, I will discuss a connection between elliptic curves and paramodular forms. For an elliptic curve E over $\mathbb{Q}$ with conductor N, there exists a paramodular form (Siegel modular form with respect to the paramodular subgroup) F of weight 3 such that $L(s,F) = L(s,E,\mathrm{sym}^3)$. Moreover, the level of this paramodular form F can be determined in an explicit and elementary way in terms of the coefficients of the Weierstrass equation of E. To find an explicit formula for the level of the paramodular form F, one needs to find an exact description of the underlying local representations of $\mathrm{GL}(2,\mathbb{Q}_p)$ attached to E, and understand Langlands functoriality for sym^3. I will explain these phenomena without going into much technical detail. Also, we will see some computational aspects of this problem as well. (Received September 21, 2018)

1145-11-1443 **Jeffrey C Lagarias*** (lagarias@umich.edu), Dept. of Mathematics, Univ. of Michigan, 530 Church Street, Ann Arbor, MI 48109-1043. *Generalized Farey Sequences.* Preliminary report.

Generalized Farey Sequences are sequences $\{G_n : n \geq 1\}$ consisting of finite sets of rational numbers, in which $G_0 = \{\frac{0}{1}, \frac{1}{1}\}$ and each sequence G_n is obtained from the preceding one G_{n-1} by splitting certain of the subintervals that it determines at their mediants. The usual Farey sequence and the Farey tree (at level n) are special cases of this general construction. We study various limiting statistical properties of the resulting sequences, scaled by their cardinalities. (Received September 21, 2018)

1145-11-1467 **Gulhan Ayar** (gulhanayar@kmu.edu.tr), Karamanoglu Mehmetbey University, Karaman, Turkey, **Kubra Nari*** (nari15@itu.edu.tr), Istanbul Technical University, Istanbul, Turkey, and **Enver Ozdemir** (ozdemiren@itu.edu.tr), Istanbul Technical University, Istanbul, Turkey. *Primality Test with Singular Curves.* Preliminary report.

In this work, we develop a method to determine a given odd integer $n = 3 \mod 4$ is prime or not. The method will be based on already presented an algorithm for he integers $n = 1 \mod 4$. Prime integers are main ingredient of the most popular public key cryptosystems like RSA and Elliptic Curve Cryptosystem. For example, a secure design of an RSA cryptosystem requires prime integers with at least 300 digits. After being employed in cryptography, the prime integers and primality test has been rigorously studied by many researchers. Even though, there are 3 main algorithms being used in practice, finding a practical and deterministic primality test is still considered to be an important problem. In this work, we extend the primality test algorithm for $n = 1 \mod 4$ to cover all integers i.e. for $n = 3 \mod 4$. (Received September 22, 2018)

1145-11-1483 **Matt Larson*** (matthew.larson@yale.edu), **Sam Payne** and **Alan Stapledon**. *Local h polynomials and the monodromy conjecture.*

For a polynomial $f \in \mathbb{Z}[x_1, x_2, \ldots, x_n]$ and a prime p, we define the local zeta function $Z_f(s)$ as the integral of $|f|^s$ over $\mathbb{Z}_p^n$. Igusa's monodromy conjecture predicts that the singularities of f control the poles of $Z_f(s)$. More precisely, if p is a pole of $Z_f(s)$, then $\exp(2\pi i \mathrm{Re}(p))$ is an eigenvalue of the monodromy transformation of the Milnor fibration at some point in the singular locus of f.

Assuming f is Newton nondegenerate, both the poles and eigenvalues have combinatorial formulas in terms of the Newton polyhedron of f. To each facet of the Newton polyhedron, one naturally associates both a candidate pole p and a contribution to the multiplicity of $\exp(2\pi i \mathrm{Re}(p))$ as an eigenvalue of monodromy. The contribution to this multiplicity is the value at 1 of a combinatorially defined polynomial, which is a relative version of Stanley's local h polynomial. By studying combinatorial conditions that are necessary for the vanishing of these relative local h-polynomials, we prove several new cases of Igusa's monodromy conjecture. (Received September 22, 2018)

1145-11-1487 **Angelica Castillo** (angelica.castillo01@utrgv.edu), Department of Mathematics, University of Texas Rio Grande Valley, Edinburg, TX 7839-2999, and **Brandt Kronholm*** (brandt.kronholm@utrgv.edu), Department of Mathematics, University of Texas Rio Grande Valley, Edinburg, TX 7839-2999. *A Technique in Partitions.*

In a 1974 paper titled *"A Technique in Partitions"*, H. Gupta describes "...a remarkably simple method of dealing with generating functions..." with the goal of establishing closed-term formulas for partition functions restricted to parts from a finite set. Gupta writes "...this leads to a formula which establishes a perfect relationship between the number of partitions and a linear combination of certain combinatory functions in which the coefficients are nonnegative integers." The formula that Gupta describes is known as a constituent of a quasipolynomial.

The main result of Gupta's paper shows that the sums of the previously mentioned coefficients for the constituents from a given quasipolynomial are the same.

In this talk we first revisit Gupta's proof in order to bring needed clarity to it. We then make use of the result and establish an infinite family of congruences for a family of restricted partition functions. The family of restricted partition functions in question is closely related to $\nu_k(n)$, the number of partitions of n into k part sizes and our result may offer further insight into recent work of William Keith. (Received September 22, 2018)

1145-11-1497 **Brandt Kronholm*** (brandt.kronholm@utrgv.edu), Department of Mathematics, University of Texas Rio Grande Valley, Edinburg, TX 7839-2999, and **Arturo J. Martinez** (arturo.j.martinez01@utrgv.edu), Department of Mathematics, University of Texas Rio Grande Valley, Edinburg, TX 7839-2999. *A Quasipolynomial Decomposition of Partitions into at most m parts and the Coefficients of Gaussian Polynomials.* Preliminary report.

The goal of this presentation is to show that for a fixed N, all Gaussian polynomials $\left[{N+m \atop m}\right]$ come in exactly $\frac{2lcm(m)}{m}$ varieties, where $lcm(m)$ represents the least common multiple of the numbers from 1 through m.

It is clear that for a fixed N, the set of partitions of n into at most m parts; $p(n,m)$ can be decomposed into two collections; partitions with parts not larger than N, denoted $p(n,m,N)$ and partitions with parts larger than N, denoted $P(n,m,N)$. In short,

$$p(n,m) = p(n,m,N) + P(n,m,N).$$

We note that $p(n,m,N)$ corresponds to the coefficients of $\left[{N+m \atop m}\right]$.

It is well known that the quasipolynomial for $p(n,m)$ is periodic with period $lcm(m)$. The period for $P(n,m,N)$ is shorter. Strangely, the quasipolynomial for $p(n,m,N)$ appears not be periodic at all. We will discuss these observations and other peculiar behaviour of these functions. (Received September 22, 2018)

1145-11-1508 **Antonino Leonardis*** (a.leonardis@gmail.com), Via Aosta, 17, 20155 Milano, MI, Italy. *Hybrid Continued Fractions and p-adic algorithms, with some applications to cryptography and "unimaginable" numbers.*

This work will continue the author's previous studies on continued fractions and Heron's algorithm, as from his former JMM2017 presentation. Extending the notion of continued fraction to the p-adic fields, one can find continued fractions which converge in both real and p-adic topologies to the "same" quadratic irrational number, some of which are given by the Heron's algorithm. The definition can be possibly generalized to other global fields, as left as an open question. We will end the part on hybrid convergence with many numerical examples. After that, we will recall the basic algorithms on the p-adic fields studied by the author and see some applications of theirs to computer science: applying Heron's algorithm to quickly compute p-adic square roots, finding new elementary cryptography procedures and some methods to get pseudo-random numbers, calculate last digits of some peculiar very big numbers. (Received September 22, 2018)

1145-11-1529 **Sarah Peluse*** (speluse@stanford.edu). *Bounds for sets without polynomial progressions.*

Let $P_1, \dots, P_m \in \mathbb{Z}[y]$ be polynomials with zero constant term. Bergelson and Leibman's generalization of Szemerédi's theorem to polynomial progressions states that any $A \subset [N]$ lacking nontrivial progressions of the form $x, x+P_1(y), \dots, x+P_m(y)$ satisfies $|A| = o(N)$. Proving quantitative bounds in the Bergelson–Leibman theorem is a difficult generalization of the problem of proving reasonable quantitative bounds in Szemerédi's theorem, and results are known in only a very small number of special cases. In this talk, I will discuss recent progress on this problem, including work of mine on long polynomial progressions in finite fields and work of mine with Sean Prendiville on the progression $x, x+y, x+y^2$ in the integers. (Received September 23, 2018)

1145-11-1532 **Michael J Seaman*** (mseaman@caltech.edu), 1200 E California Blvd, Pasadena, CA 91125. *A Formula for the Number of Monic Degree m Polynomials in $\mathbb{F}_q[x]$ with Discriminant d.*

We show a formula for the distribution of discriminants of monic polynomials over a finite field. For an odd prime power q, integer $m \geq 2$, and $d \in \mathbb{F}_q$, let $|V_d^m(\mathbb{F}_q)|$ be the number of monic polynomials in $\mathbb{F}_q[x]$ of degree m with discriminant d. We express $|V_d^m(\mathbb{F}_q)|$ as a discrete Fourier transform of Gauss sums, computable in polynomial time.

For $d \neq 0$, we show

$$|V_d^m(\mathbb{F}_q)| = \chi(d) \sum_{c=1}^{q-1} \frac{G_{\mathbb{F}_q}(c)^{m \frac{qB_{m-1}(c)-B_m(c)}{q}} \tau_q(-1)^{\frac{cm(m-1)}{2}} \tau_q(d)^c}{G_{\mathbb{F}_q}(cm)}$$

where τ_q is a multiplicative character of order $q-1$, ψ a nontrivial additive character, $G_{\mathbb{F}_q}(c)$ is the Gauss sum $G_{\mathbb{F}_q}(\tau_q^c, \psi)$, χ is the quadratic character, and

$$B_k(c) = \begin{cases} q^{\frac{k \gcd(c,q-1)}{q-1}}, & \text{if } (q-1)|ck \\ 0, & \text{otherwise} \end{cases}$$

For the discriminant, we compute the local L-functions, explicitly verify the Weil Conjectures, express the global L-function in terms of Hecke-characters, and deduce classical and new discriminant distribution results. (Received September 23, 2018)

1145-11-1566 **Joshua Harrington** and **Lenny Jones*** (lkjone@ship.edu). *A New Condition Equivalent to the Ankeny-Artin-Chowla Conjecture.*

Let $p \equiv 1 \pmod 4$ be prime, and let $\epsilon = (t + u\sqrt{p})/2$ be the fundamental unit of $\mathbb{Q}\left(\sqrt{p}\right)$. In 1952, Ankeny, Artin and Chowla asked if ϵ always has the property that $u \not\equiv 0 \pmod p$. The conjecture that the answer to this question is affirmative is known as the *Ankeny-Artin-Chowla (AAC) conjecture*, and is still unresolved. In this presentation, we present a new condition that is equivalent to the AAC-conjecture. (Received September 23, 2018)

1145-11-1571 **Wen-Ching Winnie Li**, **Ling Long** and **Fang-Ting Tu*** (ftu@lsu.edu), 303 Lockett Hall, Louisiana State University, Baton Rouge, LA 70803. *Computing Special L-Values of Certain Modular Forms with Complex Multiplication.*

In this talk, we will illustrate two explicit methods which lead to special L-values of certain modular forms admitting complex multiplication, motivated in part by properties of L-functions obtained from Calabi-Yau manifolds defined over $\mathbb{Q}$. (Received September 23, 2018)

1145-11-1572 **Aaron Landesman*** (aaronlandesman@stanford.edu). *The geometric average size of Selmer groups over function fields.*

We discuss the problem of computing the average size of the n-Selmer group of elliptic curves over $\mathbb{F}_q(t)$, after first taking a large q limit. Our methods suggest a heuristic for the distributions of Selmer groups: the moments are the number of orbits of certain orthogonal group actions. (Received September 24, 2018)

1145-11-1601 **Edray Herber Goins*** (ehgoins@mac.com). *Fuchsian Differential Equations with Prescribed Monodromy: An Introduction to Solving a Quintic Without Using Radicals.* Preliminary report.

We all learn at an early age how to find the roots of a quadratic polynomial using square roots via the Quadratic Formula. In the 1540's, Gerolamo Cardano published a method of finding the roots of both cubic and quartic polynomials using both square roots and cube roots. In 1823, Niels Henrik Abel gave a proof which showed that the roots of quintic polynomials cannot be expressed in terms of radicals. But in 1858, Charles Hermite showed that such roots can be expressed in terms of hypergeometric functions!

In this talk, we explain how to express such roots in terms of these functions by reducing the problem to inverting rational functions by using solutions to certain differential equations. This is a report on work done as part of the Research Experiences for Undergraduate Faculty (REUF) with Torina Lewis (Clark Atlanta University), Katie Quertermous (James Madison University), Chris Seaton (Rhodes College), and Alfredo Villanueva (Savannah State University). (Received September 23, 2018)

1145-11-1606 **Hannah Larson** and **Ian Wagner*** (iwagner@emory.edu). *Hyperbolicity of the partition Jensen polynomials.*

A sequence $a(n)$ is log-concave if $a(n) \geq a(n-1)a(n+1)$ for all n. Despite the extensive study of the partition function it wasn't until 2013 that Desalvo and Pak established the log-concavity of $p(n)$ for all $n > 25$. Log-concavity is just the first of an infinite family of inequalities known as the higher Turan inequalities. A recent result of Griffin, Ono, Rolen, and Zagier on hyperbolicity of Jensen polynomials implies that the partition function will eventually satisfy every degree Turan inequality. In joint work, Hannah Larson and I make this statement effective by showing the degree 3, 4, and 5 Turan inequalities are satisfied by $p(n)$ for $n \geq 96, 206$, and 381 respectively. We also give an upper bound of $(3d)^{24d}(50d)^{3d^2}$ on what n must be in order for $p(n)$ to satisfy the degree d Turan inequality. (Received September 23, 2018)

1145-11-1609 **James A Sellers*** (jxs23@psu.edu). *Congruences related to an eighth order mock theta function of Gordon and McIntosh.*

In recent years, congruences for a number of partition functions related to mock theta functions have been proven by various authors. In this work, we consider arithmetic properties of a partition function related to an eighth order mock theta function of Gordon and McIntosh. Via elementary generating function manipulations, a complete characterization of the parity of this function, as well as several additional divisibility properties, will be presented. (Received September 23, 2018)

1145-11-1640 **Lori D. Watson*** (ldwatson@uga.edu) and **Pete L. Clark**. *Hasse Principle Violations of Quadratic Twists of Hyperelliptic Curves.*

A curve $C/\mathbb{Q}$ is said to violate the Hasse Principle if C has points over every completion of $\mathbb{Q}$, but not over $\mathbb{Q}$ itself. Conditionally on the *abc* conjecture, we show that if a hyperelliptic curve $C/\mathbb{Q}$ is given by an affine model $y^2 = f(x)$ where f is a polynomial of even degree > 6 with integer coefficients and no rational roots, then there are many quadratic twists of C violating the Hasse Principle. (Received September 23, 2018)

1145-11-1651 **Paul Pollack*** (pollack@uga.edu). *Popular values and popular subsets of Euler's φ-function.*

Let $N(m)$ denote the number of preimages of m under Euler's function. The number of integers that φ maps into $[1, N]$ can be shown to be $O(N)$, and so the function $N(m)$ is bounded on average. So it is maybe surprising that, as shown by Erdős in 1935, the individual values of $N(m)$ can be as large as m^c (for a constant $c > 0$) for infinitely many m. Erdős conjectured that c could be taken arbitrarily close to 1. In fact, under plausible conjectures on the distribution of smooth shifted primes, Pomerance showed in 1981 that $N(m) \geq m/L(m)^{1+o(1)}$ on an infinite sequence of m, where $L(x) = \exp(\log x \cdot \log_3 x/\log_2 x)$. Unconditionally, he proved that $N(m) \leq m/L(m)^{1+o(1)}$, whenever $m \to \infty$, so that $m/L(m)^{1+o(1)}$ describes the true "maximal order" of $N(m)$.

We discuss recent work counting preimages of subsets of $[1, N]$ (so that $N(m)$ tells the story for singleton sets). Two corollaries of this work are a conjecturally sharp upper bound for the second moment of $N(m)$, and a conjecturally sharp upper bound for the count of n with $\varphi(n)$ a square. (Received September 23, 2018)

1145-11-1659 **Jan Reimann*** (jan.reimann@psu.edu), Department of Mathematics, Pennsylvania State University, University Park, PA 16802. *Kolmogorov Complexity and Diophantine Approximation.*

The Kolmogorov complexity of an object is the length of shortest description of the object with respect to a universal computational device (for example, a universal Turing machine). It is possible to define Kolmogorov complexity also with respect to weaker computational frameworks, such as polynomial-time bounded Turing machines. To a certain extent, Diophantine approximation of real numbers can be seen as a version of complexity with extremely limited computational power. This viewpoint lets us see some core concepts and results in Diophantine approximation in an information theoretic light. For example, the irrationality exponent of a real equals its lower asymptotic information density. This opens the door to computability theoretic methods. I will illustrate this with the help of the Jarnik-Besicovitch theorem in metric Diophantine approximation and Thue's theorem on approximation of algebraic numbers. (Received September 23, 2018)

1145-11-1664 **Robert J Lemke Oliver** and **Jiuya Wang*** (jiuya.wang@duke.edu), 120 Science, 117 Physics Building, Durham, NC 27708, and **Melanie Matchett Wood**. *Inductive Methods for Counting Number Fields.*

We propose a general framework to inductively prove new results for counting number fields. By using this method, we prove the asymptotic distribution for extensions with Galois groups in the form of $T \wr B$ where $T = S_3$ or abelian groups and B is an arbitrary group with the associated counting function not growing too fast. The key ingredient is a uniform estimate on the number of relative extensions with dependency on the base field. This is a joint work with Robert J.Lemke Oliver and Melanie Matchett Wood. (Received September 23, 2018)

1145-11-1667 **Nathan H. Fox*** (nfox@wooster.edu). *An Extension of Tree-Based Methods for Hofstadter-Like Recurrences.* Preliminary report.

The most famous and most enigmatic integer sequence defined by a nested recurrence relation is Douglas Hofstadter's Q-sequence. Despite some apparent patterns, the long-term behavior of this sequence is poorly understood. There are similar sequences with much nicer behavior, though. One example is Conolly's sequence, defined by the recurrence $C(n) = C(n-C(n-1))+C(n-1-C(n-2))$ and the initial conditions $C(1) = C(2) = 1$, which has a property known in the literature as *slow*. This and several other slow sequences generated by nested recurrences are known to have combinatorial interpretations in terms of enumerating leaves in trees. For the Conolly sequence, the tree-based interpratation proves an intimate connection with the powers of two. In fact, it has an alternate, purely number-theoretic construction based on powers of two. Replacing powers of two with Fibonacci numbers in the construction yields a different slow sequence. In this talk, we discuss the properties of this new sequence and show that it also satisfies a nested recurrence. In particular, the recurrence it satisfies has higher nesting depth than the Conolly recurrence. We also explain how this sequence has a tree-based interpretation. (Received September 23, 2018)

1145-11-1684 **Joseph A. Vandehey*** (vandehey.1@osu.edu) and **Anton Lukyanenko**. *Iwasawa continued fractions and higher-dimensional hyperbolic spaces.*

We explore the classical connection between real continued fractions and geodesics on the hyperbolic upper-half plane, and how this connection may be extended to higher dimensions. We obtain an explicit connection, via a cross-section for geodesic flow, for many new systems. This includes a connection between complex continued fractions and three-dimensional real hyperbolic space, as well as quaternionic continued fractions and five-dimensional real hyperbolic space, among many others. (Received September 23, 2018)

1145-11-1705 **Jack Klys*** (jacek.klys@ucalgary.ca), University of Calgary, 2500 University Dr. NW, Calgary, Alberta T2N 1N4, Canada. *Moments of unramified 2-group extensions of quadratic fields.*

We discuss the Cohen-Lenstra heuristics from the point of view of counting unramified number field extensions of quadratic fields. We will focus on the specific case 2-group extensions of quadratic fields which has proven to be more tractable in recent years. We will put forth a conjecture about asymptotics and distributions of such extensions (beyond those considered by Cohen and Lenstra) and discuss our recent progress on this in the case of extensions with Galois groups which are central extensions of $\mathbb{F}_2^n$ by $\mathbb{F}_2$. (Received September 24, 2018)

1145-11-1731 **Nicolas Allen Smoot*** (nicolas.smoot@risc.jku.at), Julius Raab Strasse 10/5/2523, 4040 Linz, Austria. *A Family of Congruences for Rogers–Ramanujan Subpartitions.* Preliminary report.

In 2015 Choi, Kim, and Lovejoy studied a weighted partition function, $A_1(n)$, which counted subpartitions with a structure related to the Rogers–Ramanujan identities. They conjectured the existence of an infinite class of congruences for $A_1(n)$, modulo powers of 5. We give an explicit form of this conjecture, and prove it for all powers of 5. (Received September 24, 2018)

1145-11-1764 **Jesse Kass** and **Frank Thorne*** (thorne@math.sc.edu). *What is the height of two points in the plane?* Preliminary report.

The Hilbert scheme $\mathrm{Hilb}^2(\mathbb{P}^2)$ is the parameter space counting pairs of points in the projective plane. Its rational points are in bijection with pairs of rational points in $\mathbb{P}^2$, provided you count the 'schemey points' too. For example, a Galois-conjugate pair of points, defined over a quadratic field, counts.

We define height functions corresponding to a large portion of the ample cone, and verify Manin's conjecture in these cases. I will explain how the algebraic geometry leaves us with a geometry of numbers question, and then how we addressed the geometry of numbers question.

I will also discuss, in a much more speculative manner, how we hope to connect questions like this to number field counting questions. (Received September 24, 2018)

1145-11-1788 **Zhiwei Yun***, 9 Westlund Rd, Belmont, MA 02478, and **Wei Zhang**. *On the classes of Heegner-Drinfeld cycles.*

In previous joint work with Wei Zhang, we have defined Heegner-Drinfeld cycles on the moduli of rank two Shtukas, and proved that their self-intersection numbers are related to higher derivatives of automorphic L-functions. In this talk, I will describe the cycle classes of the Heegner-Drinfeld cycles and draw some arithmetic consequences. Joint work with Wei Zhang. (Received September 24, 2018)

1145-11-1827 **Michael Cerchia*** (cercm17@wfu.edu). *Classifying the image of the Arboreal Galois representation.*

Suppose $E/\mathbb{Q}$ is an elliptic curve and $\alpha \in E(\mathbb{Q})$ is a point of infinite order. How often is it the case that α has odd order when we reduce E mod p? If we let S be the set of primes $p \leq x$ for which $E/\mathbb{F}_p$ is non-singular and $\alpha \in \mathbb{F}_p$ has odd order, then our general goal is to determine

$$\lim_{x\to\infty} \frac{\pi_S(x)}{\pi(x)}$$

where $\pi_S(x)$ is the number of primes p with $p \in S$ and $p \leq x$, and $\pi(x)$ is the total number of primes $p \leq x$. It turns out that the answer to this question is contingent upon determining all possible images of a particular Galois representation – the Arboreal Galois representation. This talk will explore this connection. (Received September 24, 2018)

1145-11-1832 **Hannah E Burson*** (hburso2@illinois.edu). *Combinatorics of some second-order mock theta functions.*

In 2007, Richard McIntosh found identities uniting two families of second order mock theta functions. In this talk, we introduce new partition theoretic interpretations of $A(q)$ and $B(q)$, two of the mock theta functions studied by McIntosh. By considering refinements of the partition functions in these interpretations, we provide a bijective proof of a new 4-variable generalized second order mock theta function identity. This generalized identity contains known identities involving $A(q)$ and $B(q)$ as special cases. (Received September 24, 2018)

1145-11-1852 **Dmitry Kleinbock*** (kleinboc@brandeis.edu), Department of Mathematics, Waltham, MA 02454. *Is one-dimensional Diophantine approximation all about continued fractions?*

Our experience seems to suggest an affirmative answer to the question in the title. In the first half of the talk I will describe recent work with Nick Wadleigh where we, capitalizing on results of Davenport and Schmidt, define ψ-Dirichlet real numbers α (those which satisfy an improvement of Dirichlet's theorem with ψ in the right hand side) and express this property via the continued fraction expansion of α. This implies a precise condition for the set of ψ-Dirichlet numbers to have zero or full measure.

In the second part however I will describe a simple modification of the ψ-Dirichlet property which does not reduce to continued fractions – yet it still can be understood using dynamics of the geodesic flow on the unit tangent bundle to the modular surface. A corresponding zero-one law can be deduced from a dynamical Borel-Cantelli lemma due to Maucourant. This is work in progress joint with Anurag Rao. (Received September 24, 2018)

1145-11-1903 **Jeremiah Bartz***, University of North Dakota, 101 Cornell Street Stop 8376, Witmer Hall Room 313, Grand Forks, ND 58202, and **Bruce Dearden** and **Joel Iiams**. *Almost gap balancing numbers.*

Almost balancing numbers were introduced by Panda and Panda as a certain generalization of balancing numbers. We extend this notion to gap balancing numbers and establish a balancer duality theorem which generalizes the relationship between balancing and cobalancing numbers. (Received September 24, 2018)

1145-11-1907 **Yuan Liu*** (yliu@math.wisc.edu) and **Melanie Matchett Wood**. *A non-abelian version of Cohen-Lenstra heuristics.*

We construct a model of random groups that is a non-abelian version of the random groups that feature in the Cohen-Lenstra heuristics. This random group is obtained from, as n goes to infinity, the free group on n generators modulo $n + u$ random relations. In this talk, we will use this model to define a probability measure on the space of profinite groups and discuss known results about the distribution of non-abelian analogs of class groups that motivate our work. Then we will assign a Γ-action to the free group, consider the random Γ-group obtained by this construction, and discuss how this model has moments matching those we see in the function fields results. This is a joint work with Melanie Matchett Wood. (Received September 24, 2018)

1145-11-1939 **Alexander Smith***, adsmith@math.harvard.edu. *2^k-Selmer groups and Goldfeld's conjecture.*

Take E to be an elliptic curve over a number field whose four torsion obeys certain technical conditions. In this talk, we will outline a proof that 100% of the quadratic twists of E have rank at most one. To do this, we will find the distribution of 2^k-Selmer ranks in this family for every $k > 1$. (Received September 24, 2018)

1145-11-1943 **Alexander Smith***, adsmith@math.harvard.edu. *2^k-class groups of imaginary quadratic fields.*

For any $n > 2$, the Cohen-Lenstra heuristic predicts how the n-torsion of the class group of K is distributed as K varies in the family of imaginary quadratic fields. These predictions have been partially verified for 3-torsion and fully verified for 4-torsion but were previously unverified for all higher torsion groups. In this talk, we will give a new approach to verifying the heuristic for 4-torsion that allows us to also verify it for 8-torsion, 16-torsion, etc. (Received September 24, 2018)

1145-11-1964 **Kirsti Biggs*** (kirsti.biggs@bristol.ac.uk). *Efficient congruencing in ellipsephic sets.*

An ellipsephic set is a subset of the natural numbers whose elements have digital restrictions in some fixed base. We bound the number of solutions to a Vinogradov system of equations in which our variables are drawn from certain sparse ellipsephic sets—a key example is those integers whose digits in a given base are squares—using a version of Wooley's efficient congruencing method. In this talk, I will outline the key ideas from the proof and discuss potential applications and generalisations. (Received September 24, 2018)

1145-11-1966 **Thomas Garrity*** (tgarrity@williams.edu), Department of Mathematics and Statistics, Williams College, Williamstown, MA 01267. *Families of Division Algorithms: Structure for Multidimensional Continued Fraction Algorithms.* Preliminary report.

There are many reasonable methods for dividing two or more numbers into another number. Each of these methods give rise to a different type of multi-dimensional continued fraction algorithm.

There is way to put almost all known multi-dimensional continued fraction algorithms into a unified family. The method involves systematically subdividing a simplex. This family includes the well-known Mönkemeyer algorithm, the triangle algorithm, the Brun algorithm, the Parry-Daniels algorithm and the Güting algorithm (which in turn is linked to the Jacobi-Perron algorithm).

We will discuss this family and some of its implications, such as their corresponding transfer operators, which in turn have various dynamical systems implications. In particular, when reduced to lower dimensional analogs, we will see how to generate some seemingly new generalizations of traditional continued fractions. (Received September 24, 2018)

1145-11-1968 **Ali K Uncu*** (akuncu@risc.jku.at), Altenbergerstrasse 69, 4040 Linz, Austria, and **Alexander Berkovich**, 1400 Stadium Rd, Gainesville, FL 32601. *Polynomial Identities Implying Capparelli's Partition Theorems.*

We will present and prove new polynomial identities that imply Capparelli's partition theorems. We will then move onto the implications of this work. This will include Slater type q-series identities, other identities involving q-trinomials, etc. (Received September 24, 2018)

1145-11-1986 **Kathryn Haymaker**, **Beth Malmskog*** (beth.malmskog@gmail.com) and **Gretchen Matthews**. *Locally Recoverable Codes with Many Recovery Sets from Fiber Products of Curves.*

A locally recoverable code is an error correcting code in which each position (coefficient) of a given codeword can be recovered with access to only r other positions. These were developed to meet needs in distributed data storage, where information may be stored on large banks of servers. It is desirable that any given codeword be distributed over many servers so that the information can be recovered if a single server fails. However, if many servers fail, it might be necessary to have multiple recovery sets for each position in order to recover it. In this talk, I briefly present a construction based on fiber products for which each coefficient has several disjoint recovery sets. This is joint work with Kathryn Haymaker and Gretchen Matthews. (Received September 24, 2018)

1145-11-1990 **Alejandra Alvarado**, **Angelos Koutsianas**, **Beth Malmskog*** (beth.malmskog@gmail.com), **Christopher Rasmussen**, **Christelle Vincent** and **Mckenzie West**. *Solving the S-Unit Equation in Sage and Applications.*

Many finiteness and enumerative problems in number theory rely on the finiteness/enumeration of the set of solutions to the equation x+y=1 over the group of S-units in a number field, where Sis a finite set of primes.

In 1995, Nigel Smart solved certain S-unit equations to enumerate all genus 2 curves defined over the rationals with good reduction away from p=2. Smart's work build on that of of Baker, de Weger, Evertse, Yu, and many others. In 2016, following Smart's methods, Malmskog and Rasmussen found all Picard curves over Q with good reduction away from p=3, and Angelos Koutsianas described methods for enumerating, and in some cases explicitly describes, all elliptic curves defined over a number field with good reduction outside S. Both projects involved Sage implementation of special cases of Smart's general method. In January 2017, Alejandra Alvarado, Angelos Koutsianas, Beth Malmskog, Christopher Rasmussen, Christelle Vincent, and Mckenzie West combined these implementations and created new functions to solve the equation x+y=1 over the S-units of a general number field K for any finite set S of primes in K. This talk will give an overview of the methods, the capabilities of the implementation, and some motivating problems and applications in algebraic curves. (Received September 24, 2018)

1145-11-2021 **Larry Ericksen*** (larryericksen@gmail.com), P.O. Box 172, Millville, NJ 08332-0172, and **Karl Dilcher**. *Continued fractions from b-ary Stern polynomials.*

Lucas sequences, like those of Fibonacci and Pell, are identified within generalized Stern number sequences. Each Stern polynomial analogue in b variables is obtained from recursions and generating functions. Then the associated continued fractions are developed as ratios of consecutive polynomials which involve single terms in their partial numerators. (Received September 24, 2018)

1145-11-2026 **Olivia Beckwith*** (obeckwith@gmail.com), Howard House, Queen's Ave, Bristol, BS8 1SD, United Kingdom. *Indivisibility and divisibility of class numbers of imaginary quadratic fields.*

Questions about the structure of ideal class groups are notoriously difficult and arise in the study of elliptic curves and L-functions. For any prime $\ell > 3$, the strongest lower bounds for the number of negative square-free D down to $-X$ for which the class group of $\mathbb{Q}(\sqrt{D})$ has trivial (or non-trivial) ℓ-torsion are due to Kohnen and Ono (Soundararajan). I will discuss recent refinements of these classic results in which we consider the negative square-free values D such that a finite set of rational primes factor (i.e. split, remain inert, or ramify) in $\mathbb{Q}(\sqrt{D})$ in a given prescribed way. We prove a lower bound for the number of such D down to $-X$ for which the class number of $\mathbb{Q}(\sqrt{D})$ is indivisible (or divisible) by ℓ. This bound is of the same order of magnitude as Kohnen and Ono's (Soundararajan's) results. For the indivisibility case, we rely on a result of Wiles establishing the existence of imaginary quadratic fields with trivial ℓ-torsion in their class groups satisfying almost a given finite set of local conditions, and a result of Zagier which says that class numbers of imaginary quadratic fields are the Fourier coefficients of a harmonic Maass form. (Received September 24, 2018)

1145-11-2048 **Katie Lynn McKeon*** (katie.mckeon@rutgers.edu). *Low-lying geodesics in a hyperbolic 3-manifold.*

We'll examine closed geodesics in the quotient of hyperbolic three space by the discrete group of isometries SL(2,Z[i]). There is a correspondence between closed geodesics in the manifold, the complex continued fractions originally studied by Hurwitz, and binary quadratic forms over the Gaussian integers. According to this correspondence, a geodesic is called fundamental if the associated binary quadratic form is. Using techniques from sieve theory, symbolic dynamics, and the theory of expander graphs, we show the existence of a compact set in the manifold containing infinitely many fundamental geodesics. (Received September 24, 2018)

1145-11-2080 **Levent Hasan Ali Alpöge*** (lalpoge@math.princeton.edu) and **Wei Ho** (weiho@umich.edu). *The second moment of the number of integral points on elliptic curves is bounded.*

We show that, when elliptic curves $E/\mathbb{Q}$ are ordered by height, the variance of the number of integral points $\#|E(\mathbb{Z})|$ is bounded. (Received September 24, 2018)

1145-11-2082 **Levent Hasan Ali Alpöge*** (lalpoge@math.princeton.edu). *The average number of rational points on genus two curves is bounded.*

We show that, when genus two (thus hyperelliptic) curves $C/\mathbb{Q}$ are ordered by height, the average number of rational points $\#|C(\mathbb{Q})|$ is bounded. (Received September 24, 2018)

1145-11-2083 **Frank Garvan*** (fgarvan@ufl.edu). *Hecke-Rogers series for Ramanujan's mock theta functions.* Preliminary report.

We describe a method for finding Hecke-Rogers indefinite binary theta series identities for Ramanujan's mock theta functions. We present a number of identities and conjectures. We study the relations between the coefficients of mock theta functions. (Received September 24, 2018)

1145-11-2100 **Stephanie Chan*** (stephanie.chan.16@ucl.ac.uk), Department of Mathematics, University College London, Gower Street, London, WC1E 6BT, United Kingdom. *Ranks, 2-Selmer groups, and Tamagawa numbers of elliptic curves with $\mathbb{Z}/2\mathbb{Z} \times \mathbb{Z}/8\mathbb{Z}$-torsion.*

In 2016, Balakrishnan–Ho–Kaplan–Spicer–Stein–Weigandt produced a database of elliptic curves over $\mathbb{Q}$ ordered by height in which they computed the rank, the size of the 2-Selmer group, and other arithmetic invariants. They observed that after a certain point, the average rank seemed to decrease as the height increased. Here we consider the family of elliptic curves over $\mathbb{Q}$ whose rational torsion subgroup is isomorphic to $\mathbb{Z}/2\mathbb{Z} \times \mathbb{Z}/8\mathbb{Z}$. Conditional on GRH and BSD, we compute the rank of 92% of the 202,461 curves with parameter height less than 10^3. We also compute the size of the 2-Selmer group and the Tamagawa product, and prove that their averages tend to infinity for this family. This talk is on joint work with Jeroen Hanselman and Wanlin Li. (Received September 24, 2018)

1145-11-2112 **Lauren Rose*** (rose@bard.edu), Bard College, Department of Mathematics, Campus Road PO Box 5000, Annandale on Hudson, NY 12504, and **Jeff Suzuki**. *Triangular Bases for Modules of Generalized Splines on Arbitrary Graphs.*

Let R be a commutative ring, and $G = (V, E, A)$ be an edge labeled graph with vertex set V, edge set E and edge weights A. A vertex labeling $(g_1, g_2, \ldots, g_{|V|}) \in R^{|V|}$ is called a **generalized spline** if for any pair of vertices i, j joined by edge e with weight a, $g_i - g_j$ is an element of the ideal generated by a (equivalently, if R is the ring of integers, $g_i \equiv g_j \bmod a$). We designate the set of all such splines R_G.

In (2016), Gilbert, Tymoczko, and Viel asked for a characterization of R_G as an R module. We show that if R is a Euclidean domain, R_G is a free module with a triangular basis, and we provide an explicit construction for this basis. This generalizes work done by and with undergraduates at Smith College and Bard College. (Received September 24, 2018)

1145-11-2154 **Özlem Ejder*** (ejder@math.colostate.edu), Department of Mathematics, Louis R. Weber Building, 841 Oval Drive, Fort Collins, CO 80523. *Modular Symbols for Fermat Curves.*

Let F_n denote the Fermat curve given by $x^n + y^n = z^n$ and let μ_n denote the Galois module of nth roots of unity. It is known that the integral homology group $H_1(F_n, \mathbb{Z})$ is a cyclic $\mathbb{Z}[\mu_n \times \mu_n]$ module. In this talk, we will see that this result can also be described using modular symbols and the modular description of Fermat curves. We will also talk about how these computations can be used in understanding the action of the Galois group of $\mathbb{Q}(\zeta_n)$ on the certain homology groups of F_n. (Received September 24, 2018)

1145-11-2183 **Alexander J Barrios***, Carleton College, Department of Mathematics and Statistics, One North College Street, Northfield, MN 55057. *Good Elliptic Curves with Specified Torsion Subgroup.*

Let E be a rational elliptic curve and define its modified Szpiro ratio to be $\sigma_m(E) = \frac{\max\{|c_4^3|, c_6^2\}}{N_E^6}$ where c_4 and c_6 are the invariants associated to a minimal model of E and N_E is its conductor. We say that a rational elliptic curve is good if $\sigma_m(E) > 6$. By Mazur's Torsion Theorem, there are 15 possible groups T satisfying $E(\mathbb{Q})_{\text{tors}} \cong T$. In this talk we show that for each of these possible T, there are infinitely many good elliptic curves E with $T \hookrightarrow E(\mathbb{Q})$. In addition, we will use this result to attain computational data that parallels the work done by the ABC@Home project for the modified Szpiro conjecture. (Received September 25, 2018)

1145-11-2189 **Michael R. Bush*** (bushm@wlu.edu), Department of Mathematics, Washington and Lee University, 204 W. Washington Street, Lexington, VA 24450, **Nigel Boston** (boston@math.wisc.edu), Department of Mathematics, University of Wisconsin, Madison, and **Farshid Hajir** (hajir@math.umass.edu), Department of Mathematics and Statistics, University of Massachusetts, Amherst. *Non-abelian generalizations of the Cohen-Lenstra heuristics.*

Formulated in the 1980s, the Cohen-Lenstra heuristics make precise predictions about the distribution of class groups in various families of number fields. While still largely unproven, there is much numerical evidence and a number of extensions have been made beyond the original setting. In order to formulate a non-abelian generalization, we replace the p-part of the class group (for p an odd prime) with the Galois group of the maximal unramified p-extension of the base field. In this talk, we describe our conjectures regarding the distribution of such Galois groups for both real and imaginary quadratic fields along with some more recent developments. (Received September 25, 2018)

1145-11-2197 **Travis William Morrison*** (travis.morrison@uwaterloo.ca), IQC-QNC, University of Waterloo, 200 University Ave W, Waterloo, Ontario N2. *Local-global principles and diophantine definability.*

Diophantine definability and decidability are closely related. Because it is not known if Hilbert's tenth problem over $\mathbb{Q}$ is undecidable, we are motivated to study which sets are diophantine over $\mathbb{Q}$, or more generally, over a global field. Koenigsmann proved that $\mathbb{Q} \setminus \mathbb{Z}$ is diophantine over $\mathbb{Q}$, and Park generalized this to number fields. In joint work with Eisentraeger, we proved that the complement of a ring of S-integers in a global function field is diophantine. In this talk, I will discuss how local-global principles and class field theory are used to produce these diophantine definitions. Additionally, I will discuss how to generalize these ideas to prove that the non-norms of some cyclic extensions are diophantine. (Received September 25, 2018)

1145-11-2224 **Piper H*** (paharron@math.hawaii.edu) and **Christelle Vincent** (christelle.vincent@uvm.edu). *Joint Shapes of Quartic Fields and Their Cubic Resolvents.*

In studying the (equi)distribution of shapes of quartic number fields, one relies heavily on Bhargava's parametrizations which brings with it a notion of resolvent ring. Maximal rings have unique resolvent rings so it is possible to live a long and healthy life without understanding what they are. The authors have decided, however, to forsake such bliss and look into what ever are these rings and what happens if we consider their shapes along with our initial number fields. What indeed! Please stay tuned. (Received September 25, 2018)

1145-11-2233 **Melvyn B. Nathanson*** (melvyn.nathanson@lehman.cuny.edu), Department of Mathematics, Lehman College (CUNY), Bronx, NY 10468. *Matrix scaling and a problem in number theory.*

Recently, there has been renewed interest in alternate minimization algorithms to generate doubly stochastic matrices, and their generalization to operator scaling. This talk will describe a problem in diophantine approximation that these algorithms suggest. (Received September 25, 2018)

1145-11-2273 **Jackson Salvatore Morrow*** (jmorrow4692@gmail.com), 400 Dowman Drive, Atlanta, GA 30022. *Composite level images of Galois and Entanglement fields.*

Let E be an elliptic curve defined over $\mathbf{Q}$ without complex multiplication. For each prime ℓ, there is a representation $\rho_{E,\ell}\colon \mathrm{Gal}(\overline{\mathbf{Q}}/\mathbf{Q}) \to \mathrm{GL}_2(\mathbf{Z}/\ell\mathbf{Z})$ that describes the Galois action on the ℓ-torsion points of E. This representation is called the mod ℓ image of Galois.

In this talk, I will discuss what happens when one considers composite level images of Galois. In particular, I will introduce composite level modular curves whose rational points classify elliptic curves over $\mathbf{Q}$ with simultaneously non-surjective, composite image of Galois. I will also describe techniques used to provably find the rational points on these curves, which yield results concerning when composite level images of Galois occur.

Finally, I will give an application of our results to the study of entanglement fields and present non-CM elliptic curves with peculiar division fields. Some of the results I will talk about are joint work with Catalina Camacho, Wanlin Li, Jack Petok, and David Zureick-Brown. (Received September 25, 2018)

1145-11-2279 **Chatchawan Panraksa*** (chatchawan.pan@mahidol.edu), Mahidol University International College, 999 Phutthamonthon 4 Road, Salaya, Nakhonpath 73170, Thailand. *Arithmetic Dynamics of $f(x) = x^d + c$.*

Arithmetic dynamics is a combination of dynamical systems and number theory. In this talk, we discuss the rational periodic points of polynomials in the form $f(x) = x^d + c$. We also discuss Morton and Silverman's uniform boundedness conjecture. It states that the number of periodic points of any rational function with rational coefficients is bounded by a constant depending only on the degree of the function. The conjecture is still unsolved even for quadratic polynomials. (Received September 25, 2018)

1145-11-2286 **Lubjana Beshaj*** (lubjana.beshaj@usma.edu). *Isogenous components of 2-dimensional reducible Jacobians.*

Isogeny based cryptography is a promising scheme in the post quantum world. In this talk we will cover the mathematical background needed for supersingular isogeny based cryptography and some current research on isogenous components of 2-dimensional reducible Jacobians. (Received September 25, 2018)

1145-11-2288 **Jennifer Berg*** (jb93@rice.edu) and **Anthony Várilly-Alvarado**. *Odd order obstructions to rational points on general K3 surfaces.*

K3 surfaces are 2-dimensional analogues of elliptic curves, but lack a group structure. They need not have rational points. However, in 2009 Skorobogatov conjectured that the Brauer group should account for all failures of the local-to-global principle for rational points on K3 surfaces. In this talk I will briefly describe the geometric origin of certain 3-torsion classes in the Brauer group of a K3 surface. We utilize this geometric description to show that these classes can in fact obstruct the existence of rational points. This is joint work with Anthony Várilly-Alvarado. (Received September 25, 2018)

1145-11-2330 **Abbey Bourdon*** (bourdoam@wfu.edu) and **Pete L. Clark**. *Torsion Points and Isogenies on CM Elliptic Curves.*

We say an elliptic curve E defined over a number field F has complex multiplication (CM) if $\mathrm{End}_{\overline{F}}(E) \cong \mathcal{O}$, an order in an imaginary quadratic field K. For any positive integer N, we determine the least d in which there exists a number field F of degree d and an $\mathcal{O}$-CM elliptic curve E/F with an F-rational point of order N. This relies on several new results concerning rational cyclic isogenies on CM elliptic curves, extending work of Kwon (1999). (Received September 25, 2018)

1145-11-2331 **Sandie Han** (shan@citytech.cuny.edu), **Ariane M Masuda** (amasuda@citytech.cuny.edu), **Satyanand Singh** (ssingh@citytech.cuny.edu) and **Johann Thiel*** (jthiel@citytech.cuny.edu), 300 Jay St., Brooklyn, NY 11201. *Maximal and Average Behavior of Elements in (u, v)-Calkin-Wilf Trees.* Preliminary report.

The Calkin-Wilf tree is an infinite binary tree enumerating the positive rationals that has many interesting properties. In particular, one can compute the maximal and average values of elements of a fixed depth in the tree. In this talk we will extend these results to a generalization, due to Nathanson, of the Calkin-Wilf tree referred to as the (u, v)-Calkin-Wilf tree for positive integers u and v. (Received September 25, 2018)

1145-11-2397 **Daniel Garbin*** (dgarbin@qcc.cuny.edu), Queensborough Community College CUNY, Mathematics and Computer Science, 222-05 56th Avenue, Bayside, NY 11364. *Effective bounds for Fourier coefficients of certain weakly holomorphic modular forms.*

In Jorgenson et. al., Exp. Math. 25 (2016) 295–319, the authors derived generators for the function fields associated to certain low genus arithmetic surfaces realized through the action of the discrete Fuchsian group $\Gamma_0(N)^+/\{\pm 1\}$ on the upper half plane. In particular, they constructed modular forms which are analogs to the modular discriminant and the Klein j-invariant of the full modular group $\mathrm{PSL}(2, \mathbb{Z})$. In this presentation, we show how to produce effective and practical bounds for the Fourier coefficients in the q-expansion of such generators, thus allowing for rigorous numerical inspection of the generators. (Received September 25, 2018)

1145-11-2418 **Robert J.S. McDonald*** (robert.j.mcdonald@uconn.edu), 48C Mount Vernon Drive, Vernon, CT 06066. *Torsion Subgroups of Elliptic Curves over Function Fields.*

Let $\mathbb{F}_q$ be a finite field of characteristic p, and $C/\mathbb{F}_q$ be a smooth, projective, absolutely irreducible curve. Let $K = \mathbb{F}_q(C)$ be the function field of C. When the genus of C is 0, and $p \neq 2, 3$, Cox and Parry provide a minimal list of prime-to-p torsion subgroups that can appear for an elliptic curve E/K. In this talk, we extend this result by determining the complete list of full torsion subgroups possible for an elliptic curve E/K for any prime p when the genus of C is 0 or 1. (Received September 25, 2018)

1145-11-2449 **Angelica Babei***, angelica.babei.gr@dartmouth.edu. *Class and Type Numbers of Orders in Central Simple Algebras.*

Given any two orders in a central simple algebra, their completions will be equal almost everywhere. In case their completions are isomorphic everywhere, the question arises: do these local isomorphisms lift to global isomorphisms? The answer is that generally, they do not, and the number of such global isomorphism classes is given by the type number of the order. In this talk, we examine idelic methods and use strong approximation to find class and type numbers of some classes of orders in central simple algebras of arbitrary dimension $n^2, n \geq 3$. (Received September 25, 2018)

1145-11-2469 **Michael James Musty*** (michaelmusty@gmail.com), Kemeny Hall, 27 North Main Street, Hanover, NH 03779. *2-Group Belyi Maps.*

In this talk we discuss the computation of 2-group Belyi maps. First we will explain the process to produce a database of all such maps (up to degree 256). Then we will discuss some interesting features of their associated Jacobians and 2-torsion fields. (Received September 25, 2018)

1145-11-2525 **Alison Beth Miller*** (abmiller@math.harvard.edu). *Asymptotic counting of $\mathrm{Sp}_{2g}(\mathbb{Z})$-orbits on quadratic forms.*

We use the geometry of numbers to give a weighted asymptotic count for the number of orbits of the symmetric square of the standard representation of $\mathrm{Sp}_{2g}(\mathbb{Z})$-. That is, we count binary $2g$-ic forms up to $\mathrm{Sp}_{2g}(\mathbb{Z})$–equvalence.

Our results generalize the classical results of Gauss-Mertens-Siegel on binary quadratic forms, and they can also be generalized further to count integral orbits of the adjoint representation of any semisimple algebraic group.

We show that the number of positive definite orbits with invariants $\leq X$ is asymptotic to $X^{g(2g+1)}$, and give the analogous result weighted by regulators in the indefinite case. (Received September 25, 2018)

1145-11-2532 **Chris Hall*** (chall69@uwo.ca) and **Alexandra Shlapentokh**. *Defining Subgroups of Mordell-Weil Groups.*

Let K be a finitely generated extension of $\mathbb{Q}$ and E be an elliptic curve over K whose j-invariant is not an algebraic number. Given a point P in the Mordell-Weil group $E(K)$, we consider the problem of giving a Diophantine definition for the cyclic subgroup $\langle P\rangle$. We explain the problem and a solution using results of Barroero and Capuana from unlikely intersection theory. (Received September 25, 2018)

1145-11-2544 **Sam Schiavone*** (sam.schiavone@gmail.com), 27 N Main St, Hanover, NH 03755. *Computing A Database of Belyi Maps.*

In the paper Numerical calculation of three-point branched covers of the projective line, we presented a method for computing equations of Belyi maps based on the correspondence described by Grothendieck in his celebrated work Esquisse d'un Programme. In this talk, we discuss the progress we have made in exhaustively computing all Belyi maps of low degree using this method. We also present some initial analysis of the data we have computed. Joint work with Michael Musty, Jeroen Sijsling, and John Voight. (Received September 25, 2018)

1145-11-2594 **Eric M Jovinelly*** (ejovinel@nd.edu). *Primes and Perfect Powers in the Catalan Triangle.*

The Catalan triangle is an infinite lower-triangular matrix that generalizes the Catalan numbers. The entries of the Catalan triangle, denoted by $c_{n,k}$, count the number of shortest lattice paths from $(0,0)$ to (n,k) that do not go above the main diagonal. This talk concerns the occurrence of primes and perfect powers in the Catalan triangle. We prove that no prime powers except 2, 5, 9, and 27 appear in the Catalan triangle when $k \geq 2$. We further prove that $c_{n,k}$ are not perfect semiprime powers when $k \geq 3$. Finally, we prove that aside from perfect squares when $k = 2$, there are at most finitely many perfect powers among $c_{n,k}$ when $k \geq 2$. Part of the last result depends on the *abc* conjecture. (Received September 25, 2018)

1145-11-2630 **Adriana Salerno***, 3 Andrews Rd, Lewiston, ME 04240, and **Charles F Doran**, **Tyler L Kelly**, **Steven Sperber**, **John Voight** and **Ursula Whitcher**. *Hypergeometric decomposition of symmetric K3 quartic pencils.*

In this talk, we will show the hypergeometric functions associated to five one-parameter deformations of Delsarte K3 quartic hypersurfaces in projective space. We compute all of their Picard–Fuchs differential equations; we count points using Gauss sums and rewrite this in terms of finite field hypergeometric sums; then we match up each differential equation to a factor of the zeta function, and we write this in terms of global L-functions. This computation gives a complete, explicit description of the motives for these pencils in terms of hypergeometric motives. (Received September 25, 2018)

1145-11-2633 **Holley Friedlander*** (friedlah@dickinson.edu), **Elena Fuchs**, **Piper H**, **Catherine Hsu**, **Katherine Sanden**, **Damaris Schindler** and **Katherine Stange**. *Almost Prime Components in Apollonian Circle Packings.* Preliminary report.

Apollonian circle packings (ACPs) are obtained by repeatedly inscribing circles into the triangular interstices of a configuration of four mutually tangent circles. If the four initial circles have integer curvature, then so will all of the circles in the packing; in this case we say that the packing is integral. Sarnak showed that any primitive, integral ACP has infinitely many circles of prime curvature, and there are a number of interesting results on prime components of ACPs. In this talk, we discuss problems and partial results concerning the almost prime components. This project was initiated at the Women in Numbers 4 workshop. (Received September 25, 2018)

1145-11-2648 **Aly Deines***, aly.deines@gmail.com. *Elliptic Curves of Prime Conductor.* Preliminary report.

The torsion elliptic curves over $\mathbb{Q}$ with prime conductor has been well studied. In particular, we know that for an elliptic curve $E/\mathbb{Q}$ with conductor p a prime, if $p > 37$, then E has either no torsion, or is a Neumann-Setzer curve and has torsion order 2. In this talk we examine similar behavior for elliptic curves of prime conductor defined over totally real number fields. (Received September 25, 2018)

1145-11-2655 **Craig S Franze*** (franze.3@osu.edu) and **Pin Hung Kao**. *Products of polynomials at prime arguments.* Preliminary report.

We adopt A. J. Irving's double-sieve method to study the almost-prime values produced by products of irreducible polynomials evaluated at prime arguments. This generalizes the previous results of Irving and Kao, who separately examined the almost-prime values of a single irreducible polynomial evaluated at prime arguments. We also show that the double-sieve method, combined with the estimates involving the upper and lower sifting functions, improve upon the results cited in Diamond–Halberstam for both small and large values of g, where g is the number of irreducible components of the polynomial in question. (Received September 25, 2018)

1145-11-2679 **Stephan Ramon Garcia** and **George Todd*** (toddg@union.edu). *Supercharacters, Elliptic Curves, and the Sixth Moment of Kloosterman Sums.*

We employ supercharacter theory to realize Kloosterman sums as eigenvalues of a certain matrix. We then realize the sixth Kloosterman power moment in terms of the sum of Frobenius traces of a one-parameter family of elliptic curves. As an application, we provide a simple proof that Kloosterman sums K_u with $p \nmid u$ are $O(p^{2/3})$, breaking the naive $O(p^{3/4})$ barrier. (Received September 25, 2018)

1145-11-2696 **Sara Chari*** (sara.chari.gr@dartmouth.edu), Department of Mathematics, 102 Kemeny Hall, 27 North Main St., Hanover, NH 03755. *Metacommutation of Primes in Central Simple Algebras.*

In a quaternion order of class number one, an element can be factored in multiple ways depending on the order of the factorization of its reduced norm. The fact that multiplication is not commutative causes an element to induce a permutation on the set of primes of a given reduced norm. We discuss this permutation and previously known results about the cycle structure, sign, and number of fixed points for quaternion orders. We generalize these results to other orders in central simple algebras over global fields. (Received September 25, 2018)

1145-11-2697 **Benjamin Breen***, Department of Mathematics: Dartmouth College, 6188 Kemeny Hall, 27 North Main Street, Hanover, NH 03755, and **John Voight** and **Ila Varma**. *Heuristics for cyclic fields: totally positive units and narrow class groups.*

We describe heuristics in the style of Cohen-Lenstra for the narrow class group of cyclic extensions of odd degree. The narrow class group differs from the ordinary class group only in its 2-part. We model this discrepancy using the 2-Selmer group of a number field as a representation of its Galois group equipped with a bilinear form. Along the way, we discuss the connection to the signature ranks of units and classical results on the relation between the class group and narrow class group. (Received September 25, 2018)

1145-11-2705 **Benjamin Linowitz**, **D. B. McReynolds**, **Paul Pollack** and **Lola Thompson*** (lola.thompson@oberlin.edu). *Bounded gaps between primes and the length spectra of arithmetic hyperbolic 3-orbifolds.*

In 1992, Reid posed the question of whether hyperbolic 3-manifolds with the same geodesic length spectra are necessarily commensurable. While this is known to be true for arithmetic hyperbolic 3-manifolds, the non-arithmetic case is still open. Building towards a negative answer to Reid's question, Futer and Millichap have recently constructed infinitely many pairs of non-commensurable, non-arithmetic hyperbolic 3-manifolds which have the same volume and whose length spectra begin with the same first n geodesic lengths. In the present talk, we show that this phenomenon is surprisingly common in the arithmetic setting. In particular, given any arithmetic hyperbolic 3-orbifold derived from a quaternion algebra and any finite subset S of its geodesic length spectrum, we produce, for any $k \geq 2$, infinitely many k-tuples of arithmetic hyperbolic 3-orbifolds which are pairwise non-commensurable, have geodesic length spectra containing S, and have volumes lying in an interval of (universally) bounded length. The main technical ingredient in our proof is a bounded gaps result for prime ideals in number fields lying in Chebotarev sets. This colloquium-style talk is based on a series of papers with B. Linowitz, D. B. McReynolds, and P. Pollack. (Received September 25, 2018)

1145-11-2722 **Irene Bouw**, **Ozlem Ejder*** (ejder@math.colostate.edu) and **Valentijn Karemaker**. *Arboreal Galois Representations of Dynamical Belyi Maps.* Preliminary report.

A dynamical Belyi map is a finite morphism $f : \mathbb{P}^1_{\mathbb{C}} \to \mathbb{P}^1_{\mathbb{C}}$ defined over $\mathbb{C}$ which is branched exactly at the three ordered points $0, 1, \infty$ such that $f(\{0, 1, \infty\}) \subseteq \{0, 1, \infty\}$. All iterates f^n are also Belyi maps. Given a dynamical Belyi map defined over a field K and a non-preperiodic point $\alpha \in K$, one can construct a tree of preimages of α. This construction leads to the phenomena: one has a tower of fields $K = K_0 \subseteq K_1 \subseteq K_2 \subseteq \cdots$ where $K_n := K\left(\phi^{-n}(\alpha)\right)$. One also has a natural Galois representation on the tree of preimages, the so-called Arboreal Galois representation of the function f. In this talk, we describe the Arboreal Galois representations and the monodromy groups of iterations of a large class of dynamical Belyi maps. Studying these Galois groups has applications in the study of the density of prime divisors of elements of dynamical sequences. If time allows, we will mention some applications as well. (Received September 25, 2018)

1145-11-2728 **Benjamin Linowitz**, **D. B. McReynolds**, **Paul Pollack** and **Lola Thompson*** (lola.thompson@oberlin.edu). *Counting quaternion algebras.*

We discuss how classical techniques from analytic number theory can be used to count quaternion algebras over number fields subject to various constraints. In particular, we will show how to construct Dirichlet series whose coefficients give us these counts. Because of the correspondence between maximal subfields of quaternion algebras and geodesics on arithmetic hyperbolic manifolds, these counts have interesting applications to the field of spectral geometry. (Received September 25, 2018)

1145-11-2774 **Joseph Gunther*** (jgunther7@gmail.com). *Irrational points on hyperelliptic curves.*

We consider genus g hyperelliptic curves with a marked rational Weierstrass point. If $d < g$ is odd, we prove there exists B_d such that a positive proportion of these curves have at most B_d points of degree d. If $d < g$ is even, we similarly bound degree d points not pulled back from points of degree $\frac{d}{2}$ on the projective line. The proof uses tropical geometry work of Park as well as work of Bhargava and Gross on Selmer groups of odd hyperelliptic curves. This is joint work with Jackson Morrow. (Received September 25, 2018)

1145-11-2847 **Peter Floodstrand Blanchard*** (peter-blanchard@uiowa.edu), University of Iowa Department of Mathematics, 14 MacLean Hall, Iowa City, IA 52246. *Difference Divisible Sets in Hurwitz Quaternions.* Preliminary report.

A set A in a ring is said to be *difference-divisible* if every subset of A (of cardinality at least 2) has a difference which divides every other difference in that subset. We report on the problem of describing up to equivalence all such sets in the Hurwitz Quaternions. The classification begins with the unit-connected sets, that is, the difference-divisible sets in which every two elements are connected by some sequence of unit differences. We give a description of the unit-connected sets, and discuss the general classification of difference-divisible sets in the Hurwitz Quaternions. (Received September 25, 2018)

1145-11-2867 **Edgar Costa*** (edgarc@mit.edu). *Upper bounds for the endomorphism algebra of an abelian variety.*

We describe how to compute tight upper bounds for the structure of the endomorphism algebra of an abelian variety over a number field. (Received September 25, 2018)

1145-11-2892 **Ricardo Conceição*** (rconceic@gettysburg.edu), 300 N Washington st, Department of Mathematics, Gettysburg, PA 17325, and **Rodrigo Gondim** (rodrigo.gondim@ufrpe.br). *On a Frobenius problem for integral domains.* Preliminary report.

Given a set of co-prime positive integers $a_1, \ldots, a_n$, the Diophantine Frobenius Problem is the following classical problem in number theory – Find the largest positive integer g for which the equation

$$x_1 a_1 + \cdots + x_n a_n = g,$$

has no solution with $x_i \geq 0$.

In this talk we will present a generalization of the Frobenius problem to integral domains, paying particular attention to those domains that are natural extensions of $\mathbb{Z}$, such as ordered Archimedean integral domains and the ring of p-adic integers. (Received September 25, 2018)

1145-11-2908 **Robert J Lemke Oliver*** (robert.lemke_oliver@tufts.edu), Department of Mathematics, Tufts University, 503 Boston Ave, Medford, MA 02155. *Number fields and arithmetic.* Preliminary report.

The speaker will report on recent work of his and coauthors' on counting problems for number fields, with an eye toward arithmetic applications. (Received September 25, 2018)

1145-11-2910 **Alexis Suki Dasher*** (adasher@smith.edu), Smith College, Department of Mathematics and Statistics, 44 College Lane, Northampton, MA 01063, and **Arianne Hermida** (ahermida@smith.edu), Smith College, Department of Mathematics and Statistics, 44 College Lane, Northampton, MA 01063. *Generalizing the Three Gap Theorem.*

Place the tip of a knife at the center of a circular cake and score the cake from center to edge. Rotate the cake under the knife and score it again after every rotation by angle θ until you have marks at $\theta, 2\theta, \ldots, N\theta$ for some fixed number N. After marking the cake this way, slice it up along those marks. No matter your N and even if θ is irrational, you'll end up with slices of at most three different sizes! This surprising result is known as the Three Gap Theorem.

If we let our cake have unit circumference and angle θ has associated arc length a, then the above process is like travelling along a 1-periodic sawtooth wave making marks at $a, 2a, \ldots, Na$. In our research, we study generalizations of the Three Gap Theorem to other periodic functions. We investigate the distinct gap sizes created by evaluating periodic functions at uniformly spaced inputs, marking these values, and studying the distinct gap sizes between nearest marks in the image. In particular, we study periodic piecewise linear and trigonometric functions. (Received September 25, 2018)

1145-11-2922 **Robert Harron** and **Erik Holmes*** (eholmes@math.hawaii.edu), Department of Mathematics, University of Hawai at Manoa, 2565 McCarthy Mall (Keller Hall 401A), Honolulu, HI 96821. *Shapes of sextic $C_3 \wr C_2$-fields: equidistribution, Malle's conjecture, and detection of log terms in Klüners; counterexample.*

In this talk, we'll discuss the shapes of sextic extensions of $\mathbb{Q}$ containing a fixed quadratic subfield. Specifically, those sextic extensions appearing as subfields of $C_3 \wr C_2$-fields. In 2004 Klüners gave a counterexample to Malle's conjecture, which predicts asymptotic behavior of number fields with specified invariants, by studying the asymptotics of C_3 extensions of $\mathbb{Q}(\sqrt{d})$: he finds that, when $d = -3$, the fields contribute to showing the conjecture is false as it fails to detect the $\log(X)$ term in the asymptotics. We'll introduce the notion of relative shape, show equidistribution results, and also show how the shape allows us to detect this additional term in the asymptotics. (Received September 25, 2018)

1145-11-2949 **Terrence Richard Blackman*** (tblackman@mec.cuny.edu), 1638 Bedford Ave., Brooklyn, NY 11225. *Spectral correspondences for Maass waveforms on quaternion groups.*

We prove that in most cases the Jacquet-Langlands correspondence between newforms for Hecke congruence groups and newforms for quaternion orders is a bijection. Our proof covers almost all cases where the Hecke congruence group is of cocompact type, i.e., when a bijection is possible. The proof uses the Selberg trace formula. (Received September 25, 2018)

1145-11-2975 **Patrick Allen*** (pballen@illinois) and **James Newton**. *Monodromy for some rank two Galois representations over CM fields.*

In the automorphic-to-Galois direction of Langlands reciprocity, one aims to construct a Galois representation whose Frobenius eigenvalues are determined by the Satake parameters of the automorphic representation at all but finitely many places. For cohomological cuspidal automorphic representations of GL_n over CM fields, these Galois representations were constructed by Harris–Lan–Taylor–Thorne. It is natural to ask what happens at the ramified places, and conjecturally the answer is given by the local Langlands correspondence. Up to semisimplification, this was proved by Varma for the Galois representations constructed by Harris–Lan–Taylor–Thorne. These methods, however, do not prove the existence of the monodromy operator in cases it should exist, because they rely on p-adic interpolation, which can only keep track of characteristic polynomials. Using recently developed automorphy lifting theorems and a strategy of Luu, we prove the existence of the monodromy operators for some rank two Galois representations over CM fields. This is joint work with James Newton. (Received September 25, 2018)

13 ▶ *Commutative rings and algebras*

1145-13-25 **Trung Vu*** (vu2@stolaf.edu), St. Olaf College, 1500 St. Olaf Avenue, Northfield, MN 55057, and **Kosmas Diveris** (diveris@stolaf.edu), St. Olaf College, Mathematics, Statistics and Computer Science Department, Northfield, MN 55057. *Matrix square roots of polynomials.*

In this research, we consider matrix factorizations of a polynomial where the two matrices appearing in the factorization are the same, which we call "matrix square roots." The main result is that any polynomial in $\mathbb{R}[x_1, ..., x_n]$ admits a matrix square root. Our proof is constructive and provides an algorithm for constructing these matrices. (Received August 09, 2018)

1145-13-262 **Daniel Erman***, Department of Mathematics, 480 Lincoln Dr, Madison, WI 53706, and **Steven V Sam** and **Andrew Snowden**. *Big polynomial rings and Stillman's Conjecture.*

I'll discuss how certain limits of polynomial rings are themselves polynomial rings (in an uncountable number of variables) and how this leads to two new proofs of Stillman's conjecture. This is joint work with Steven Sam and Andrew Snowden. (Received August 26, 2018)

1145-13-299 **Adam Boocher*** (aboocher@sandiego.edu). *Betti Numbers: Large and Small.*
Given a system of homogeneous polynomials, the Betti numbers of this system offer a measure of its complexity. In this talk I'll discuss some upper and lower bounds for these numbers and share how recent work by undergraduates has helped us understand when these bounds are achieved. There will be ideals generated by monomials, binomials, and some connections to graph theory. We'll see this story has more questions than answers! (Received August 29, 2018)

1145-13-357 **Kevin Bombardier*** (kevin-bombardier@uiowa.edu) and **D. D. Anderson**. *Atoms in Quasilocal Integral Domains.*
Let (R, M) be a quasilocal integral domain. We investigate the set of irreducible elements (atoms) of R. Special attention is given to the set of atoms in $M\backslash M^2$ and to the existence of atoms in M^2. While our main interest is in local Cohen-Kaplansky (CK) domains (atomic integral domains with only finitely many nonassociate atoms), we present results in the greatest generality possible. In contradiction to a statement of Cohen and Kaplansky, we construct a local CK domain with precisely eight nonassociate atoms having an atom in M^2. (Received September 03, 2018)

1145-13-422 **Manuel González-Sarabia*** (mgonzalezsa@ipn.mx), Instituto Politécnico Nacional, UPIITA, Av. IPN 2580, Barrio La Laguna, Ticomán, Delegación Gustavo A. Madero, 07340 Ciudad de México, Mexico, and **José Martínez-Bernal**, **Rafael H. Villarreal** and **Carlos E. Vivares**. *Generalized Minimum Distance Functions.*
Using commutative algebra methods we study the generalized minimum distance function (gmd function) and the corresponding generalized footprint function of a graded ideal in a polynomial ring over a field. The number of solutions that a system of homogeneous polynomials has in any given finite set of projective points is expressed as the degree of a graded ideal. If $\mathbb{X}$ is a set of projective points over a finite field and I is its vanishing ideal, we show that the gmd function and the Vasconcelos function of I are equal to the r-th generalized Hamming weight of the corresponding Reed-Muller-type code $C_{\mathbb{X}}(d)$ of degree d. We show that the generalized footprint function of I is a lower bound for the r-th generalized Hamming weight of $C_{\mathbb{X}}(d)$. To give applications of our lower bound to algebraic coding theory, we show an interesting integer inequality. Then we show an explicit formula and a combinatorial formula for the second generalized Hamming weight of an affine cartesian code. (Received September 05, 2018)

1145-13-463 **Nicholas Switala*** (nswitala@uic.edu) and **Wenliang Zhang**. *On completion of graded D-modules.*
Let k be a field of characteristic zero, R a polynomial ring in finitely many variables with coefficients in k, and $\widehat{R}$ the formal power series ring in the same variables. If M is a left $D(R, k)$-module, then $\widehat{R} \otimes_R M$ is naturally a left $D(\widehat{R}, k)$-module. Hartshorne and Polini gave an example showing that the de Rham cohomology of M and $\widehat{R} \otimes_R M$ need not be the same, even when M is holonomic. They asked whether the de Rham cohomology is the same in the case where M is not just holonomic but *graded*, that is, M is a graded R-module and the partial derivatives in $D(R, k)$ act as operators of degree -1. We prove that the answer is yes. In fact, we need only assume that M is graded and has finite-dimensional de Rham cohomology. (Received September 06, 2018)

1145-13-497 **Anya Michaelsen***, 39 Chapin Hall Dr, 1841 Paresky, Williamstown, MA 01267. *Noetherian Rings with Unusual Prime Ideal Structures.* Preliminary report.
For a ring R, the set of prime ideals of R, called the spectrum of R, is a partially ordered set with respect to inclusion. Given a partially ordered set X, M. Hochster showed exactly when X can be realized as the spectrum of a commutative ring. It is unknown, however, when a partially ordered set can be realized as the spectrum of a commutative *Noetherian* ring. In 2016, C. Colbert showed that there exists an uncountable Noetherian commutative ring with Krull dimension at least 2 and a countable spectrum. We extend this result in two ways. First, we consider a spectrum with a countable and uncountable branch and discuss progress toward constructing a Noetherian ring with this spectrum. Second, we construct a 2-dimensional uncountable excellent ring with a countable spectrum. We will outline both constructions as well as future work to extend these results. (Received September 07, 2018)

1145-13-585 **Lokendra P Paudel*** (lpaudel1@uakron.edu), The University of Akron, Akron, OH 44325. *The group of t-invertible t-ideals of Prüfer v multiplication domains.* Preliminary report.
Let D be a Prüfer v-multiplication domain (PVMD). The group of t-invertible t-ideals $\mathfrak{I}_t(D)$ is a lattice-ordered group (ℓ-group) with respect to the ordering defined by $A \leq B$ if and only if $B \subseteq A$, and coincides with the

group of invertible ideals of D in the case when D is Prufer domain. In this talk, we'll discuss about the ℓ-groups that occur as a group of t-invertible t-ideals of PVMD. (Received September 10, 2018)

1145-13-639 **Christopher ONeill***, 5500 Campanile Dr, San Diego, CA 92182. *Numerical semigroup invariants and eventually quasipolynomial behavior.*

A numerical semigroup S is a subset of the natural numbers that is closed under addition, and a factorization of $n \in S$ is an expression of n as a sum of generators of S. In this talk, we examine several factorization invariants, which are arithmetic quantities assigned to each semigroup element n, such as the maximum factorization length of n or number of distinct factorization lengths of n. A surprisingly large collection of factorization invariants coincide with a quasipolynomial (that is, a polynomial with periodic coefficients) for sufficiently large semigroup elements; we survey several such results (spanning numerous undergraduate research projects), and explore structural reasons for this phenomenon. (Received September 12, 2018)

1145-13-653 **Matthew C. Enlow*** (mce87290@ucmo.edu). *Multiplicative factorization in numerical semigroups.* Preliminary report.

Numerical semigroups are complement-finite additive subsemigroups of $\mathbb{N}_0$; that is, they are the sets of sums of whole-number multiples of its whole-number generators. While their additive factorization theory has been widely studied, their multiplicative structure has not. The elasticity $\rho(S) = \sup\{m/n\colon a_1 \cdots a_m = b_1 \cdots b_n\colon a_i, b_j$ irreducible elements$\}$ of a multiplicative semigroup S provides a measure of how nonunique its factorization can be. The multiplicative elasticity of a numerical semigroup is always finite, and is larger than 1 unless $S = \mathbb{N}$. By relating numerical semigroups to an easier-to-understand additive structure we can characterize the irreducible elements and provide tighter bounds for $\rho(S)$. (Received September 12, 2018)

1145-13-690 **Rebin A Muhammad*** (rm775311@ohio.edu), 24 home street apt 104, athens, OH 45701. *Infinite-Dimensional Algebras Without Simple Bases.* Preliminary report.

An amenable basis B is called simple if it is not properly congenial to any other amenable basis. The fundamental question whether all algebras have simple bases has been raised by Al-Essa, López-Permouth and Muthana in 2017. In this work, using a construction inspired by the work of Oates-Williams (1984), we introduce a family of algebras granting us examples of algebras without simple bases and of one-sided simple bases. The same construction also provides examples which shows that the notion of amenability is not left-right symmetric. Among other results, we also prove that there is no infinite-dimensional algebra such that every basis is amenable. This is a joint work with Pınar Aydoğdu and Sergio R. López-Permouth. (Received September 25, 2018)

1145-13-757 **Whitney I Liske*** (liske.2@nd.edu). *Defining equations of the Rees algebra for a family of ideals.* Preliminary report.

Let $R = k[x_1, \ldots, x_d]$ be a polynomial ring in d variables over a field k. Let $m = (x_1, \ldots, x_d)$ be the maximal homogenous ideal of R. Let I be a Gorenstein ideal generated by all the generators of m^2 except for one. For each fixed d these ideals are all equivalent, up to change of coordinates. The goal is to compute the defining equations of the special fiber ring and the Rees ring of these ideals. To compute the Rees ring, we study the Jacobian dual and the defining equations of the special fiber ring of m^2. (Received September 14, 2018)

1145-13-782 **Sema Gunturkun*** (gunturku@umich.edu) and **Mel Hochster**. *A Case of Eisenbud-Green-Harris Conjecture.* Preliminary report.

The Eisenbud-Green-Harris (EGH) conjecture states that a homogeneous ideal in a polynomial ring $K[x_1, \ldots, x_n]$ over a field K that contains a regular sequence with given degrees $a_1, \ldots, a_n$ has the same Hilbert function as a lex-plus-powers ideal containing the powers of the variables x_i with the degrees a_i. In this talk, we discuss a case of the EGH conjecture for homogeneous ideals generated by $n + 2$ quadrics containing a regular sequence of full length and show that EGH is true when $n = 5$ and $a_1 = \ldots = a_5 = 2$. This is a joint work with Mel Hochster . (Received September 14, 2018)

1145-13-817 **Roger A Wiegand*** (rwiegand1@unl.edu), Department of Mathematics, University of Nebraska, Lincoln, NE 68588-0130. *Semigroups of Modules.*

Let R be a commutative, Noetherian, local ring. We consider the semigroup of isomorphism classes of finitely generated R-modules, with the semigroup operation induced by the direct sum. This approach yields some "nice" properties that hold for all decompositions. For example, one *cannot* have indecomposable modules A and B such that $A \oplus A \oplus A \cong B \oplus B$. It also allows one to construct many "silly" examples. For instance, one can have four pairwise non-isomorphic indecomposable R-modules A, B, C, D such that $A \oplus B \oplus C \cong D^{(217)}$ (the direct sum of 217 copies of C).

In this talk I will describe how one obtains such silly examples and also consider the following question: Given a module M and a positive integer n, how many indecomposable modules occur as direct summands of $M^{(n)}$? This will lead to some open problems that are accessible to advanced undergraduates. (Received September 15, 2018)

1145-13-868 **Akeel Omairi*** (aomairi2015@fau.edu), 6019 Boca Colony Dr. Apt 215, Boca Raton, FL 3443, and **Lee Klingler**. *Unique Decomposition of Direct Sums of Ideals.*

Let R be a commutative Noetherian ring. We say that R has the unique decomposition into ideals (UDI) property if each finite direct sum of ideals of R is uniquely decomposable as a direct sum of indecomposable R- ideal. For integral domain R, Goeters and Olbering showed that R has UDI if and only if R has at most one nonprincipal maximal ideal and has UDI locally at that nonprincipal maximal ideal (if it exists). For local domain R, they gave necessary and sufficient condition that R has UDI in terms of its integral closure. Their results were extended to reduced (commutative Noetherian) rings by Ay and Klingler. We show that if R is any commutative Noetherian ring, then R has UDI if and only if R has at most one nonprincipal maximal ideal and has UDI locally at that nonprincipal maximal ideal (if it exists). We also give an example of a ring without UDI but which has UDI modulo its nilradical, so that the UDI property does not lift modulo the nilradical. (Received September 16, 2018)

1145-13-877 **András C Lőrincz*** (alorincz@purdue.edu), Department of Mathematics, Purdue University, W Lafayette, IN 47907, and **Claudiu Raicu**. *Iterated local cohomology groups and Lyubeznik numbers for determinantal rings.*

We present a recipe for determining iterated local cohomology groups with support in ideals of minors of a generic matrix in characteristic zero, expressing them as direct sums of indecomposable $\mathcal{D}$-modules. For non-square matrices these indecomposables are simple, but this is no longer true for square matrices where the relevant indecomposables arise from the pole order filtration associated with the determinant hypersurface. Specializing our results to a single iteration, we determine the Lyubeznik numbers for all generic determinantal rings, thus answering a question of Hochster. (Received September 16, 2018)

1145-13-922 **Radoslav Dimitric*** (raddimitric@netscape.net). *Slenderness Program.*

An object S in a category C is *slender* if, for every family of objects $A_n, n \in N$, and every morphism $f : \prod_{n\in N} A_n \longrightarrow S$ in C, one has $f|A_n = 0$, for all but possibly finitely many $n \in N$. In this note, I will outline a number of research directions in pursuing the constructions generated by the notion of slenderness. (Received September 17, 2018)

1145-13-938 **Matthew F Menture*** (30menture@cua.edu), Matthew Menture, Department of Mathematics, 620 Michigan Avenue NE, Washington, D.C., DC 20064. *Gröbner bases with respect to several monomial orderings and computation of Hilbert-type dimension polynomials.*

Let $R = K[x_1, \dots, x_n]$ be a ring of polynomials over a field K of characteristic zero, and let a partition of the set of variables into p disjoint subsets be fixed ($1 \le p \le n$). Treating R as a filtered ring with the natural p-dimensional filtration, we consider a special type of reduction in a free R-module and develop the corresponding Gröbner-type basis technique that allows one to prove that the p-variable Hilbert function of a finitely generated filtered R-module is polynomial. We also present a method of computation of this function based on a generalization of the Buchberger algorithm to the case of several monomial orderings. (Received September 17, 2018)

1145-13-958 **Sean Sather-Wagstaff**, **Tony Se*** (ttse@olemiss.edu) and **Sandra Spiroff**. *Some properties of ladder determinantal rings.* Preliminary report.

Let X be a matrix of indeterminates. We form a ladder Y from X by removing certain indeterminates, and we form a ladder determinantal ring from Y, which is similar to the more familiar determinantal rings defined for X. Ladder determinantal rings are known to be Cohen-Macaulay ("nice rings"). We would like to, in some sense, measure how far a ladder determinantal ring is from being Gorenstein (a "nicer ring"). This is done by finding the number of isomorphism classes of semidualizing modules of the ring. We will show how to determine this number from the shape of the ladder Y and display many examples. This is joint work with Sean Sather-Wagstaff and Sandra Spiroff. (Received September 17, 2018)

1145-13-966 **Courtney R Gibbons*** (crgibbon@hamilton.edu), Math Department, Hamilton College, 198 College Hill Road, Clinton, NY 13323. *Boij-Soederberg theory as an introduction to research in commutative algebra.* Preliminary report.

Commutative algebra is ripe with topics for undergraduate research, and I will discuss one such topic: Boij-Soederberg theory. I will focus on specific results from two undergraduate research projects I mentored in this context, including how I developed the projects to dovetail with my own research agenda. I will also (briefly!) describe my experience as a mentor to undergraduates and a few things I wish I'd known ahead of time. (Received September 17, 2018)

1145-13-1004 **Susan Morey*** (morey@txstate.edu), Department of Mathematics, Texas State University, 601 University Dr., San Marcos, TX 78666. *Depths of Powers of Ideals and the Power of Depth of Understanding Algebra.*

There are many ways to measure the size of objects in Commutative Algebra. One such measure for an ideal I of a ring R is the depth of R/I. This talk will focus on joint work with various groups of undergraduate or early graduate students studying this key invariant, particularly when applied to powers of ideals in polynomial rings. Early results will focus primarily on monomial ideals, with a discussion of how to make research in this area accessible to students in a way that deepens their understanding of algebraic concepts as well as builds connections between different areas of mathematics, particularly algebra and graph theory, thereby increasing depth of understanding of both fields. The talk will incorporate some new results on how to use concretely constructed initially regular sequences to realize effective depth bounds, with a discussion of open problems that show promise for being approachable by motivated students. (Received September 18, 2018)

1145-13-1060 **Joe A. Stickles, Jr.*** (jstickles@millikin.edu). *Graphs and Commutative Rings.*

Nearly twenty years ago Anderson and Livingston published their paper on zero-divisor graphs of commutative rings. Since then hundreds of papers concerning graphical structures associated with algebraic objects have been published, and many of the results were produced by undergraduates. In this talk, we will focus on three specific structures: zero-divisor graphs, ideal-divisor graphs, and irreducible divisor graphs. Student results and avenues for future research will be discussed. (Received September 18, 2018)

1145-13-1078 **Jennifer Kenkel*** (kenkel@math.utah.edu). *Local Cohomology of Thickenings.* Preliminary report.

Let R be a standard graded polynomial ring that is finitely generated over a field, and let I be a homogenous prime ideal of R. Bhatt, Blickle, Lyubeznik, Singh, and Zhang examined the local cohomology of R/I^t, as t goes to infinity, which led to the development of an asymptotic invariant by Dao and Montaño. I will discuss their results and give concrete examples of the calculation of this new invariant in the case of determinantal rings. (Received September 18, 2018)

1145-13-1145 **Samuel H Chamberlin*** (samuel.chamberlin@park.edu), 8700 NW River Park Dr. Box 30, Parkville, MO 64152, and **Azadeh Rafizadeh**. *A generalization of the Newton Girard formula to the monomial symmetric polynomials.*

The Newton-Girard Formula allows one to write any elementary symmetric polynomial as a sum of products of power sum symmetric polynomials and elementary symmetric polynomials of lesser degree. It has numerous applications. We have generalized this identity by replacing the elementary symmetric polynomials with monomial symmetric polynomials. We will also discuss an application of this formula to representations of Lie algebras. (Received September 19, 2018)

1145-13-1146 **Jackson Autry*** (jautry@sdsu.edu). *Membership and Elasticity in Certain Affine Monoids.*

For affine monoids of dimension 2 with embedding dimension 2 or 3, we study the problem of determining when a vector is an element of the monoid, and the problem of determining the elasticity of a monoid element. (Received September 19, 2018)

1145-13-1268 **Adam Boocher** and **James Seiner***, james.seiner@stonybrook.edu. *Lower Bounds on Betti Numbers.*

Let R be a polynomial ring and I an ideal of R of height c. The *Betti numbers* $\beta_i(R/I)$ of R/I are the ranks of the modules in a minimal free resolution of R/I. Intuitively, these give some measure of the complexity of relations on the generators of I, and therefore we expect that there should be "at least as many relations as there are trivial ones," an expectation which motivates a conjecture due to Buchsbaum-Eisenbud and Horrocks that $\beta_i(R/I) \geq \binom{c}{i}$. This conjecture however, has been open since 1977. In this talk I will discuss some variants of the conjecture– various weakenings and special cases, including our recent result that if I is a monomial ideal that is not a complete intersection then $\sum \beta_i(R/I) \geq 2^c + 2^{c-1}$. (Received September 20, 2018)

1145-13-1424 **Irena Swanson** (iswanson@reed.edu), 3203 SE Woodstock Boulevard, Portland, OR 97202, and **Robert Marshawn Walker*** (robmarsw@umich.edu), 530 East Church Street, 2070 East Hall, Ann Arbor, MI 48109. *Tensor-Multinomial Sums of Ideals and Applications.*

This is joint work with Irena Swanson found on arXiv:1806.03545. Given a polynomial ring C over a field and proper ideals I and J whose generating sets involve disjoint variables, we determine how to embed the associated primes of each power of $I + J$ into a collection of primes described in terms of the associated primes of select powers of I and of J. We discuss applications to constructing primary decompositions for powers of $I + J$, and to attacking the persistence problem for associated primes of powers of an ideal. (Received September 21, 2018)

1145-13-1446 **Alessandra Costantini*** (costanta@purdue.edu). *Cohen-Macaulayness of Rees algebras of modules.* Preliminary report.

Rees algebras of ideals and modules arise in Algebraic Geometry as homogeneous coordinate rings of blow up or as graphs of rational maps. The Cohen-Macaulayness of the Rees algebra of an ideal I is well-understood in connection with the Cohen-Macaulayness of the associated graded ring of I, thanks to results of Huneke, Trung and Ikeda. However, there is no module analogue for the associated graded ring, so the study of Cohen-Macaulayness of Rees algebras of modules is in general more complicated. In this talk we will present the technique of generic Bourbaki ideals introduced by Simis, Ulrich and Vasconcelos, and use it to provide sufficient conditions for the Rees algebra of a module to be Cohen-Macaulay. Our results generalize results of Johnson and Ulrich, and of Goto, Nakamura and Nishida. (Received September 21, 2018)

1145-13-1482 **Tim C McEldowney*** (tmcel001@ucr.edu). *Jacobson and Hilbert Module Equivalence.* Preliminary report.

It has been known for half a century that for commutative rings being Hilbert is equivalent to being Jacobson. Recently, Hilbert modules were created by D. Rush and Jacobson modules were created by M. Maani Shirazi1 and H. Sharif. We will show that if M is a finitely generated module then M is a Hilbert module if and only if it is a Jacobson module. We will also show the relationship between Hilbert modules and Hilbert rings. (Received September 22, 2018)

1145-13-1504 **Robert Huben*** (rhuben@huskers.unl.edu). *A Recursive Technique for finding Betti Decompositions of Complete Intersections.*

Certain algebraic objects known as Betti diagrams can be decomposed into a linear combinations of "pure diagrams" through a greedy algorithm. In this talk, I will discuss my research experience as an undergraduate overseen by Dr. Gibbons, and the recursive method we found that provides an alternative decomposition algorithm in certain circumstances. (Received September 22, 2018)

1145-13-1517 **Simplice Tchamna*** (simplice.tchamna@gcsu.edu), Department of Mathematics, Georgia College, Campus Box: 017, Milledgeville, GA 31061. *A study of m-canonical ideals.*

We study properties of multiplicative canonical (or m-canonical) ideals of ring extensions. Let $R \subseteq S$ be a ring extension. A nonzero S-regular ideal I of R is called an *m-canonical ideal* of the extension $R \subseteq S$ if $(I :_S (I :_S J)) = J$ for all S-regular ideal J of R. We study multiplicative canonical ideals for pullback diagrams, and we use the notion of multiplicative canonical ideal to characterize Prüfer extensions. (Received September 22, 2018)

1145-13-1525 **Babak Jabbar Nezhad*** (bjabbarn@uark.edu), 1 University of Arkansas, Dpartment of Mathematical Sciences, Fayetteville, AR 72701. *Gröbner bases and equations of the multi-Rees algebras.*

In this talk we describe the equations defining the multi-Rees algebra $R[I_1^{a_1}t_1, \ldots, I_r^{a_r}t_r]$, where R is a Noetherian ring containing a field and the ideals are generated by a subset of a fixed regular sequence. (Received September 22, 2018)

1145-13-1594 **Benjamin J Drabkin*** (benjamin.drabkin@huskers.unl.edu), 1535 F Street, Apt 10, Lincoln, NE 68508. *The containment problem for symbolic powers and hyperplane arrangements.*

Given an ideal I in a commutative Noetherian ring R, the m-th symbolic power of I is defined to be $I^{(m)} = \bigcap_{p \in \mathrm{Ass}(I)} I_p^m \cap R$. It is well known, due to the works of Ein-Lazarsfelt-Smith, Hochster-Huneke, and Ma-Schwede, that every ideal I of codimension e in a regular ring satisfies the containment $I^{(er)} \subseteq I^r$ for all $r \geq 1$. In many cases, this containment can be improved upon, however, in recent years a number of ideals have been found for which the containment is tight.

Ideals exhibiting tight containments have been the object of a great deal of study over the last few years, and there has been a concerted effort to find new containment-tight ideals. All known ideals exhibiting tight containments arise from certain hyperplane arrangements. This talk will demonstrate a technique by which containment-tight ideals arising from the singular locus of a hyperplane arrangement can be used to find containment-tight ideals in higher-dimensional hyperplane arrangements. This has applications to providing novel examples of containment-tight ideals. (Received September 23, 2018)

1145-13-1622 **Corey Brooke*** (cbrooke@uoregon.edu), Department of Mathematics, 202 Fenton Hall, University of Oregon, Eugene, OR 97403-1222. *Associated Primes of h-Wheels and Other Graphs.*

In this talk, I will present the main result of the 2016 Fairfield REU in algebra: a family of graphs whose cover ideals have high indices of stability, called h-wheels. Necessarily, I will need to approach this result from both purely algebraic and relatively combinatorial perspectives, but the most satisfying insights will marry the two, exposing how changing a graph affects the algebraic properties of its cover ideal. Along the way, I will share my experiences as an REU student terrified of graph theory and will offer some ideas for future research. (Received September 23, 2018)

1145-13-1670 **Janet Striuli***, **Corey Brooke**, **Molly Hoch**, **Sabrina Lato** and **Bryan Wang**. *The index of stability: a project for undergraduate students.*

Given an ideal I in a Noetherian ring, Brodmann proved that there exists an integer k such that $Ass(I^k) = Ass(I^{k+n})$ for all $n \geq 0$. The index k is called index of stability. In this talk we will survey what is known about the value of k and we will present the project that was carried out in the Fairfield REU 2016. (Received September 23, 2018)

1145-13-1759 **Joseph W Skelton*** (jskelton@tulane.edu), 2220 Cleary Ave., Apt 123, Metairie, LA 70001. *Algebraic Invariants and Symbolic Powers of Edge Ideals.*

I will introduce important invariants invariants, such as the Wald- schmidt constant, resurgence number, and regularity, that have broad applications in commutative algebra and other areas of research. Examples will be given to illustrate each topic. A number of recent results will also be discussed. (Received September 24, 2018)

1145-13-1849 **H Lindo***, 64 Meacham St, Williamstown, MA 01267, and **N Pande**. *Trace Ideals and the Gorenstein Property.*

The trace ideal of an R-module M is the ideal generated by all the homomorphic images of M in R. Recent work with undergrads has successfully used trace ideals to characterize zero-dimensional Gorenstein rings. In this talk I will discuss how trace ideals can capture the homological properties of a commutative ring and several resulting open questions. (Received September 24, 2018)

1145-13-2142 **Amal Mattoo*** (amattoo@college.harvard.edu), 6809 Persimmon Tree Rd., Bethesda, MD 20817, and **Jiyang Gao**, **Yutong Li** and **Michael C. Loper**. *Virtual Complete Intersections in $\mathbb{P}^1 \times \mathbb{P}^1$.*

We study homological invariants of a finite set of points in $\mathbb{P}_1 \times \mathbb{P}_1$. We give examples where the size of a minimal free resolution for the vanishing ideal of the points depends on interactions between the cross ratios of the points in each copy of $\mathbb{P}_1$. We then examine virtual resolutions in the sense of Berkesch, Erman and Smith, which for points in $\mathbb{P}_1 \times \mathbb{P}_1$ are complexes that resolve the vanishing ideal only up to saturation by the irrelevant ideal. We show that virtual resolutions, though not a combinatorial invariant, nevertheless convey more condensed geometric structure. We show that set-theoretically every finite set of points forms a complete intersection, meaning that there is an ideal whose vanishing set is exactly the set of points and the ideal admits a virtual resolution taking the form of a Koszul complex. In the richer case of reduced points, we use tools including Generalized Bézout's Theorem, degree analysis, and number-theoretic techniques, to give various sufficient conditions and necessary conditions for a virtual complete intersection. In particular, we completely classify the case where the points form a Ferrers diagram on a ruling of $\mathbb{P}_1 \times \mathbb{P}_1$. (Received September 24, 2018)

1145-13-2151 **Thomas M. Ales*** (tales@masonlive.gmu.edu), 210 Marcum Ct, Sterling, VA 20164. *Invariants of closure operators in Stanley-Reisner rings.*

Let $R = k[x_1, \ldots, x_n]/I_\Delta$ where I_Δ is an ideal of $k[x_1, \ldots, x_n]$ generated by square free monomials and k is an infinite field of characteristic $p \geq 0$. If I is an ideal of R with $I^* = J$, the tight closure of I, I is called a $*$-reduction of J. Further, the intersection of all minimally generated $*$-reductions of J is called the $*$-core of J.

Let $J = (x_1, \ldots, x_n)$. Then we examine all $*$-reductions of J and bounds and special cases of $*$-core of J. We expand this work to the integral closure operator and the analogous integral closure ideas of reductions and core of J. (Received September 24, 2018)

1145-13-2214 **Erin Bela*** (bela@juniata.edu). *Numerical Maculification in Arbitrary Codimension.*
An ideal $J \subset k[x_0, \cdots, x_n]$ is said to be *Numerically ACM* (NACM) if R/J has the Hilbert function of some codimension c ACM subscheme of $\mathbb{P}^n$. In this talk, I describe an algorithm which takes an arbitrary ideal and produces, via a finite sequence of basic double links, an ideal which is NACM. An immediate consequence of this result is that every even liaison class of codimension c subschemes of $\mathbb{P}^n$ contains elements which are NACM. This was first proved for the codimension two case by Migliore and Nagel, and I demonstrate that these results can be extended to higher codimension.

Let $\mathcal{L}$ denote the even liaison class of three skew lines in $\mathbb{P}^4$, and let $\mathcal{L}_S$ denote the even liaison class of three skew lines on a smooth hypersurface $S \subset P^4$ of degree $d \geq 2$. It is possible to give a complete description of the sequences of basic double links which (in S) produce curves which are NACM. I conclude by using this to show that the subset of $\mathcal{L}_S$ consisting of NACM subschemes, denoted by $\mathcal{M}_S$, fails to have the Lazarsfeld-Rao property. (Received September 25, 2018)

1145-13-2314 **Eliseo Sarmiento*** (esarmiento@ipn.mx), Secretaría de Investigación y Posgrado, 07738 Mexico City, Mexico, Mexico, and **Eduardo Camps**, **Rafael Villarreal** and **Manuel Gonzalez**. *The second generalized hamming weight of some evaluation codes arising from a projective torus.*
Let K be a finite field and let X be a subset of a projective space, over the field K, which is parameterized by the square-free monomials.

It is shown that $I(X)$ is a complete intersection if and only if X is a projective torus. In this case we determine a formula for the second generalized Hamming weight of evaluation codes arising from a projective torus. This allows us to compute the corresponding weights of the codes parameterized by the edges of a complete bipartite graph. We determine some of the generalized Hamming weights of non-degenerate evaluation codes arising from a complete intersection in terms of the minimum distance, the degree and the regularity. (Received September 25, 2018)

1145-13-2340 **Hailong Dao** (hdao@ku.edu), **Joseph Doolittle** (jdoolitt@ku.edu), **Ken Duna**, **Bennet Goeckner** (goeckner@uw.edu), **Brent Holmes*** (brentholmes@ku.edu) and **Justin Lyle** (justin.lyle@ku.edu). *Higher Nerves of Simplicial Complexes.*
We investigate generalized notions of the nerve complex for the facets of a simplicial complex. We show that the homologies of these higher nerve complexes determine the depth of the Stanley-Reisner ring $k[\Delta]$ as well as the f-vector and h-vector of Δ. We present, as an application, a formula for computing regularity of monomial ideals. (Received September 25, 2018)

1145-13-2607 **Ashleigh Thomas*** (athomas@math.duke.edu). *Summary statistics for persistent homology.*
Persistent homology is a multiscale geometric and topological data analysis technique that has output in the form of a module. These modules can be too unwieldy to work with, so statistical analysis is done on summary statistics for the modules instead of on the modules themselves. I will discuss the interplay of algebra and stochastic analysis while I describe some desirable properties of persistence module summary statistics and give a novel example. (Received September 25, 2018)

1145-13-2711 **Kevin Tucker*** (kftucker@uic.edu), **Karl Schwede**, **Thomas Polstra** and **Linquan Ma**. *The Behavior of the F-signature under Small Birational Modifications.*
The F-signature is a local numerical invariant of commutative rings in positive characteristic, defined in terms of the number of splittings of the iterates of the Frobenius endomorphism. It can be viewed as a measure of singularity, as it is one if and only if the ring is regular, and positive only when the ring is strongly F-regular. While the behavior of the F-signature under arbitrary blowups is not well understood, we show that the F-signature increases under a small birational modification. In particular, this shows that the F-signature is subtle enough to detect the improvement in the singularities under such a morphism. (Received September 25, 2018)

1145-13-2861 **Ranthony A.C. Edmonds***, edmonds.110@osu.edu. *Factorization in Polynomial Rings with Zero Divisors.* Preliminary report.
It is well known that if R is a unique factorization domain, then $R[X]$ is a unique factorization domain and vice versa. However, if R satisfies the unique factorization property but is not an integral domain, $R[X]$ does

not have to be a unique factorization ring. This example highlights the general bad behavior of factorization properties with respect to the polynomial ring extension $R[X]$ when R is an arbitrary commutative ring with zero divisors.

In this talk we discuss how factorization in an arbitrary commutative ring R with zero divisors differs from when R is an integral domain, and frame that conversation in the context of polynomial rings. Along the way we focus on some of the challenges in factorization that arise when working with zero divisors, and give a characterization of when a polynomial ring over an arbitrary commutative ring has unique factorization. (Received September 25, 2018)

1145-13-2887 **Davis Deaton*** (davis.deaton@pop.belmont.edu) and **Jordan Sawdy** (jordan.sawdy@pop.belmont.edu). *Unstacking Tortoise Shells with Math: Factoring Multivariate Polynomials in the Tropical Semiring.* Preliminary report.

The real numbers endowed with the operations of min and + form an idempotent semiring referred to as the Tropical Semiring. Factorizations of the multivariate polynomials over this semiring are not unique. Our goal is to provide an algorithm to produce all the factorizations of any given multivariate tropical polynomial. To do so, we associate each polynomial with a polyhedral complex such that multiplication of the polynomials corresponds to Minkowski addition of the complexes. We use a dual complex to describe each factor as a polyhedral complex satisfying a certain zero tension condition. This condition allows us to frame the irreducible factors as the Hilbert basis of a system of Diophantine linear equalities, which can be computed using known algorithms. These irreducible factors are then easily stitched together to form all possible factorizations. (Received September 25, 2018)

14 ► *Algebraic geometry*

1145-14-236 **Robert Lazarsfeld***, Department of Mathematics, Stony Brook University, Stony Brook, NY 11794. *Tangent Developable Surfaces and the Equations Defining Algebraic Curves.*

In the early 1980's, Mark Green made a very influential conjecture about the defining equations and higher syzygies of canonically embedded projective algebraic curves. While the conjecture remains open in general, Voisin settled the generic case in two breakthrough papers appearing about fifteen years ago. Very recently, Aprodu, Farkas, Papadima, Raicu and Weyman gave a simple new proof of Voisin's theorem. Their work revolves around the analysis of a very classical geometric object, namely the tangent developable surface of a rational normal curve. In this talk aimed at non-experts, I will survey this circle of ideas. (Received August 23, 2018)

1145-14-303 **Juliette Bruce*** (juliette.bruce@math.wisc.edu), Van Vleck Hall, 480 Lincoln Dr, Madison, WI 53706. *Asymptotic Syzygies for Products of Projective Space.*

I will discuss results describing the asymptotic syzygies of products of projective space, in the vein of the explicit methods of Ein, Erman, and Lazarsfeld's non-vanishing results on $\mathbb{P}^n$. (Received August 29, 2018)

1145-14-331 **Dmitrii Kubrak*** (dmkubrak@mit.edu). *The growth of the number of semistable G-bundles on curves over finite fields.*

Let $\{X_i\}$ be a sequence of smooth complete curves over $\mathbb{F}_q$ such that the genus g_{X_i} grows with i. Then one can ask how fast the class number $h_{X_i} = |\mathrm{Pic}^0_{X_i}(\mathbb{F}_q)|$ grows when $i \to \infty$. Weil's conjectures give bounds from above and below: $2\log_q(\sqrt{q}-1) \leq \frac{\log h_{X_i}}{g_{X_i}} \leq 2\log_q(\sqrt{q}+1)$. In 1990's Tsfasman and Vlăduts proved that if the sequence $\{X_i\}$ satisfies some additional asymptotic properties (e.g. if $\{X_i\}$ is a tower of curves) there is a precise formula for $\lim_{i\to\infty} \frac{\log h_{X_i}}{g_{X_i}}$ in terms of some invariants $\beta_n(\{X_i\})$. Given a split reductive group G we prove an analogous formula for the (stacky) number of points on the stack Bun^0_{G,X_i} of G-bundles on X_i. Studying the geometry of Bun_G we also prove that the asymptotic formula does not change if we restrict the count to the semistable locus Bun^{ss}_G . We also expect that one can replace the stacky count with the actual number of semistable G-bundles, but can prove this only for $G = \mathrm{GL}_n$ at the moment. (Received September 01, 2018)

1145-14-332 **Borys Kadets*** (bkadets@mit.edu). *Sectional monodromy groups of projective curves and Galois groups of generic trinomials.*

Fix a degree d projective curve $X \subset \mathbb{P}^r$ over a field K. The talk is concerned with the Galois group G_X of the field extension defined by the intersection of X with the hyperplane $x_0 + t_1x_1 + ... + t_rx_r = 0$ over $K(t_1, ..., t_r)$. It is well-known that G_X is related to the Hilbert polynomial of X. When K has characteristic zero $G_X = S_d$. The failure of the equality $S_d = G_X$ in characteristic p forces some classical results to have a characteristic zero assumption, e.g. Harris' extension of Castelnuovo's inequality. Even in the special case of the plane curve $x^n = y^m$, when G_X is the Galois group of the trinomial $x^n + ax^m + b$ over $K(a,b)$, determining the possibilities for G_X is an open problem. As an unusual example, the Galois group of $x^{23} + ax^3 + b$ over $\mathbb{F}_2(a,b)$ is the Mathieu group M_{23}. We study the group G_X for curves over fields of positive characteristic. When $r \geq 3$ we can list all nonstrange nondegenerate projective curves with $A_d \not\subset G_X$. All of them turn out to be smooth and rational. We also classify the Galois groups of generic trinomials, the possible groups are $AGL_1(\mathbb{F}_{p^d}), PGL_d(\mathbb{F}_{p^k}), PSL_2(\mathbb{F}_5), M_{11}, M_{23}, M_{24}, A_n$ and S_n. (Received September 01, 2018)

1145-14-603 **Brian Collier***, bcollie2@math.umd.edu. *Higher Teichmuller components for SO(p,q).*

In this talk we will use Higgs bundles to describe new connected components of the SO(p,q) character variety of a closed surface. Moreover we will explain how these components are deformation spaces of certain Fuchsian representations. (Received September 11, 2018)

1145-14-855 **Bhargav Bhatt***, 2074 East Hall, 530 Church Street, Ann Arbor, MI 48105. *Perfectoid geometry and its applications.*

There is a strong and classical analogy, linking number theory and algebraic geometry, between the field of rational numbers and the field of rational functions in one variable. Perfectoid geometry animates this analogy by providing a context where one can treat a (fixed) prime number like a variable. The resulting notion has helped solve long-standing problems in diverse areas of mathematics—not just in number theory and algebraic geometry, but also commutative algebra and algebraic topology. In this talk, I will explain the definition of a perfectoid ring and discuss some applications. (Received September 16, 2018)

1145-14-1138 **Charlotte Ure*** (urecharl@msu.edu). *An Algorithm to Determine the Three Torsion of the Brauer Group of an Elliptic Curve.* Preliminary report.

Let k be a field of characteristic different from 2 or 3 containing a primitive third root of unity and let E be an elliptic curve over k. An implication of the Merkurjev-Suslin theorem is that every element in the Brauer group of E of exponent 3 can be described as a tensor product of symbol algebras over the function field of E. I give an algorithm to calculate the generators and relations of the three torsion of the Brauer group of E in terms of these tensor products. This is work in progress. (Received September 25, 2018)

1145-14-1159 **Ravi Jagadeesan*** (ravi.jagadeesan@gmail.com). *Crepant resolutions of $\mathbb{Q}$-factorial threefolds with compound Du Val singularities.*

We study the set of crepant resolutions of $\mathbb{Q}$-factorial threefolds with compound Du Val singularities. We derive sufficient conditions for the Kawamata–Kollár–Mori–Reid decomposition of the relative movable cone into relative ample cones to be the decomposition of a cone into chambers for a hyperplane arrangement. Under our sufficient conditions, the hyperplane arrangement can be determined by computing intersection products between exceptional curves and divisors on any single crepant resolution. We illustrate our results by considering the Weierstrass models of elliptic fibrations arising from Miranda collisions with non-Kodaira fibers. Many of our results extend to the set of crepant partial resolutions with $\mathbb{Q}$-factorial terminal singularities. (Received September 19, 2018)

1145-14-1348 **Yuwei Zhu*** (yuwei_zhu@brown.edu), Math department, 151 Thayer Street, Brown University, Providence, RI 029012. *Shioda's fourfold and CM Mumford's fourfold.*

It was proved by Shioda in 1981 that the Jacobian of the curve $y^2 = x^9 - 1$ has extra Hodge cycles of codimension 2 that is not generated by divisors. Shioda noted that this phenomenon is similar to the family of abelian fourfold constructed by Mumford in 1969, which naturally leads to the question of whether one can realize Shioda's Jacobian as a special case of Mumford's construction. In this talk we will use the Mumford-Tate group to show that Shioda's fourfold cannot be realized as a special Mumford's fourfold, but it is derived equivalent to one. (Received September 21, 2018)

1145-14-1409 **Edoardo Persichetti*** (epersichetti@fau.edu). *Reproducible Codes and Cryptographic Applications.* Preliminary report.

In this talk I will present a work on structured linear block codes. The investigation starts from well-known examples and generalizes them to a wide class of codes that we call reproducible codes. These codes have the property that they can be entirely generated from a small number of signature vectors, and consequently admit matrices that can be described in a very compact way. I will show some cryptographic applications of this class of codes and explain why the general framework introduced may pave the way for future developments of code-based cryptography. (Received September 21, 2018)

1145-14-1696 **Dan Bates*** (dbates@usna.edu). *Geolocation via polynomial systems.* Preliminary report.
Given a radio frequency emitter and multiple receivers, there are various formulations of polynomial systems that can be used to recover the emitter location from received measurements. This goes for planar and scalar scenarios and a variety of types of measurements (time, frequency, etc.). Some of these formulations been available and used in practice for years, others are just beginning to draw attention now.

In this talk, we describe some recent advances in approaching the RF emitter geolocation problem with various techniques from numerical algebraic geometry, a set of methods for solving polynomial systems. (Received September 24, 2018)

1145-14-1744 **Jeb Collins*** (jbcolli2@gmail.com), **Matt Welz**, **Jessie Lenarz** and **Kristine Pelatt**. *θ-Twisted Involution Graphs of S_n with non-standard generating sets.* Preliminary report.
Twisted involutions are important in the study of reductive symmetric spaces and symmetric k-varieties. In many cases, the twisted involutions of an algebraic group classify particular orbits of that group. It is possible to determine the θ-twisted involutions algorithmically. This algorithm depends on a particular generating set. This algorithm has been proved to generate all twisted involutions for a group given the standard generating set. In this work, we focus particularly on S_n and show that any generating set of S_n can be used to generate all twisted involutions. (Received September 24, 2018)

1145-14-1829 **Carlos A. Florentino*** (caflorentino@fc.ul.pt), Dep. Matematica, Fac. Ciencias, Univ. de Lisboa, Edf. C6, Campo Grande, 1749-016 Lisboa, Portugal. *Topology and Arithmetic of $GL(n,\mathbb{C})$-Character Varieties.* Preliminary report.
Given a finitely generated group F and a complex reductive Lie group G, the G-character variety of F, $X_F G = Hom(F,G)//G$, is typically a singular algebraic variety, defined over the integers, and some of its geometric, topological and arithmetic properties can be encoded in a polynomial generalization of the Euler-Poincaré characteristic: the E-polynomial. The most interesting cases are when F is the fundamental group of a Kähler manifold M, since then $X_F G$ is homeomorphic to a space of G-Higgs bundles over M. In this seminar, concentrating in the case of the general linear group $G = GL(n,\mathbb{C})$, we present a remarkable relation between the E-polynomials of $X_F G$ and those of $X_F^{irr} G$, the locus of *irreducible representations* of F into G. We will also give an overview of known explicit computations of E-polynomials, as well as some conjectures and open problems. (Received September 24, 2018)

1145-14-2267 **Sean Ballentine*** (seanbal@math.umd.edu), 9200 Edwards Way, Unit 108, Hyattsville, MD 20783. *Codes With Hierarchical Locality from Maps Between Algebraic Curves.*
In applications of coding to distributed storage systems it is important to consider the efficiency of the repair of erasures. Locally recoverable codes provide a way to repair simple erasures without having to access every storage node. When constructing locally recoverable codes we fix an erasure threshold under which the recovering can be done locally. In 2015, Sasidharan et al. introduced codes with hierarchical locality, a natural extension of locally recoverable codes in which there are tiers of recoverability handling different amounts of erasures. The main goal of this talk will be to examine constructions of such codes from towers of projective curves. (Received September 25, 2018)

1145-14-2287 **Vance Blankers*** (blankers@math.colostate.edu), 2700 Stanford Rd #33, Fort Collins, CO 80525. *The Witten Conjecture for κ-classes on the Moduli Space of Curves.*
κ-classes were introduced by Mumford, as a tool to explore the intersection theory of the moduli space of curves $\mathcal{M}_g$. Iterated use of the projection formula shows there is a close connection between the intersection theory of κ-classes on the moduli space of unpointed curves, and the intersection theory of ψ-classes on all moduli spaces. We show that the generating function for κ-class intersections is related to the Gromov-Witten potential of a point via a change of variables given by complete symmetric polynomials, rediscovering a theorem of Manin and Zokgraf from '99. Surprisingly, the starting point of our story is a combinatorial formula that relates intersections of κ-classes and ψ-classes via a graph theoretic algorithm (the relevant graphs being dual graphs to stable curves). Further, this story is part of a large wall-crossing picture for the intersection theory of Hassett spaces, a family of birational models of $\mathcal{M}_g$. (Received September 25, 2018)

1145-14-2326 **Bill F Trok*** (william.trok@uky.edu). *Points and Differential Forms.* Preliminary report.
Given a finite collection of points Z in projective space $\mathbb{P}^n$, we say Z admits unexpected hypersurfaces if the intersection of the ideal I(Z) and I(mQ) where Q is a generic linear subspace is larger than expected. We show that this problem can be studied by looking at the bundle of logarithmic differential forms of the hyperplane arrangement, A(Z), which is dual to the sets of points Z. In particular, a differential form defines either a rational

map through the points or a polynomial vanishing on these points. This perspective allows us to reinterpret old results in a new context, and study these differential forms from a new perspective. (Received September 25, 2018)

1145-14-2387 **Ben Thompson*** (blt@bu.edu) and **Emma Previato**. *A New Poncelet Porism.*
A new construction for a Poncelet-type porism is presented. The set of planes tangent to a family of quadrics in 3-dimensional space is of a curve of genus one, just as the incidence correspondence of a plane conic and its dual in the classical case. In this new construction the translation on the curve is a suitably defined reflection of a tangent plane to another. We will sketch a proof of this inspired by the proof of the classical theorem given by P. Griffiths and J. Harris. Finally, we will highlight the fundamental differences between the constructions. (Received September 25, 2018)

1145-14-2391 **Sarah Frei*** (sfrei@uoregon.edu). *Galois representations of moduli spaces of sheaves.*
We will study moduli spaces of stable sheaves on K3 surfaces defined over an arbitrary field. While these varieties have been studied extensively over the complex numbers, they have only recently been studied more thoroughly over other fields and were used by Charles to prove the Tate conjecture for K3 surfaces over finite fields. In this talk, we will discuss the cohomology groups of the moduli spaces as Galois representations. Our main result is that for any two K3 surfaces, a Galois equivariant isomorphism between their etale cohomology groups implies an isomorphism as Galois representations between the cohomology groups of moduli spaces of stable sheaves on each of equal dimension. In particular, when the K3 surfaces are defined over a finite field, this implies that the moduli spaces have the same zeta functions. (Received September 25, 2018)

1145-14-2577 **Suzanna Stephenson***, Department of Mathematics, Brigham Young University, Provo, UT 84602, and **Natalie Larsen**, **Erik Parkinson**, **Hayden Ringer**, **Tyler Moncur** and **Tyler Jarvis** (jarvis@math.byu.edu). *Fast, stable multivariate numerical rootfinding in a compact region.*
We present a multivariate numerical rootfinding algorithm that finds all real zeros in a given compact region in $\mathbb{C}^n$ of a system of functions. Our method builds on the ideas of Nakatsukasa, Noferini and Townsend of subdividing the original search interval and approximating the functions with Chebyshev polynomials. We then use a variant of the method of Telen and van Barel, finding the roots in each subdomain by computing eigenvectors of the Chebyshev form of certain Möller-Stetter matrices constructed with a well-chosen basis. We compare our algorithm, in terms of accuracy and speed, to other popular numerical rootfinding algorithms. In many instances, this algorithm outperforms all known competitors. (Received September 25, 2018)

1145-14-2777 **James Parson*** (parson@hood.edu), 401 Rosemont Avenue, Frederick, MD 21701. *Computing the regular locus of a finitely presented scheme over $\mathbb{Z}$.*
The regular locus of a variety over an algebraically closed field (its nonsingular part) can be computed using a Jacobian criterion. Nagata has analyzed regular loci of Noetherian schemes, where the Jacobian criterion no longer applies. His analysis shows, in particular, that the regular locus of a finitely presented $\mathbb{Z}$-scheme is open. We will discuss an algorithm for computing such open sets using Groebner bases for finitely presented $\mathbb{Z}$-algebras and prime factorization in $\mathbb{Z}$. (Received September 25, 2018)

15 ► Linear and multilinear algebra; matrix theory

1145-15-150 **David Hestenes*** (hestenes@asu.edu). *Quaternions in Geometric Algebra and Physics.*
Geometric Algebra and Calculus has emerged as a unified mathematical language for the whole of physics —- a language that simplifies formulation and solution of all fundamental equations while providing new insights into the geometric structure of physics [1]. In this talk I discuss how quaternions fit into Geometric Algebra with emphasis on rotational dynamics, spinors and Hopf fibrations in electrodynamics.

[1] Geometric Calculus website: <http://geocalc.clas.asu.edu>. Most papers and books on GC can be accessed or traced from here and links to other websites, especially one at Cambridge University. (Received August 09, 2018)

1145-15-374 **Jon Lee*** (jonxlee@umich.edu). *On sparse (reflexive) generalized inverses.*
We study sparse generalized inverses H of a rank-r real matrix A. We give a "block construction" for reflexive generalized inverses having at most r^2 nonzeros. When $r = 1$, we demonstrate how minimizing the (vector) 1-norm of H among generalized inverses can be achieved by a particular reflexive generalized inverse following our block construction. When $r = 2$ and A is equivalent to a nonnegative matrix by signing rows and columns,

we again demonstrate how minimizing the (vector) 1-norm of H among generalized inverses can be achieved by a particular reflexive generalized inverse following our block construction. Finally, for general r, we demonstrate how to efficiently find a reflexive generalized inverse following our block construction that is within approximately a factor of r^2 of the (vector) 1-norm of the generalized inverse having minimum (vector) 1-norm. This is joint work with Marcia Fampa (UFRJ). (Received September 04, 2018)

1145-15-669 **Stephan Ramon Garcia*** (stephan.garcia@pomona.edu), 610 N College Ave, Claremont, CA 91711. *Nonvanishing minors and uncertainty principles.*

Fourier uncertainty principles play a major role in harmonic analysis, mathematical physics, and number theory. In 2005, Tao used a nonvanishing minors result for the DFT matrix to establish the best possible Fourier uncertainty principle for fields of prime order, a result independently discovered by Biró and Meshulam. We prove an optimal generalization of the BMT principle for functions that enjoy certain symmetries. The discrete cosine matrix and its generalizations play a central role. This is joint work with D. Katz and G. Karaali. (Received September 12, 2018)

1145-15-674 **Shaun M. Fallat** and **Xavier Martinez-Rivera*** (xaviermr@auburn.edu). *The almost-principal minors and ap-rank of symmetric matrices.*

An *almost-principal* minor of a given matrix is the determinant of a (square) submatrix whose row and column indices differ in exactly one index. The *almost-principal rank characteristic sequence* (*apr-sequence*) of a symmetric matrix $B \in F^{n\times n}$ is $a_1a_2\cdots a_{n-1}$, where a_k is $\mathtt{A}$ (respectively, $\mathtt{N}$) if all of (respectively, none of) the almost-principal minors of order k are nonzero; if some but not all are nonzero, then $a_k = \mathtt{S}$. The *almost-principal rank* of a symmetric matrix B, denoted by ap-rank(B), is the size of a largest nonsingular almost-principal submatrix of B. Results regarding apr-sequences will be presented, and particular attention will be given to the relationship between the rank and ap-rank of a symmetric matrix. (Received September 12, 2018)

1145-15-703 **Christino Tamon*** (tino@clarkson.edu), Department of Computer Science, Clarkson University, 8 Clarkson Avenue, Potsdam, NY 13699-5815. *Is quantum state transfer monogamous?*

Given a graph with adjacency matrix A, if a continuous-time quantum walk matrix exp(-itA) sends the characteristic vector of a vertex to the characteristic vector of another vertex, we say perfect state transfer occurs between the two vertices. We consider the possibility for a vertex to be involved in perfect state transfer with two other distinct vertices. In this talk, we survey what is known about this question and describe some recent observations. (Received September 13, 2018)

1145-15-773 **Wasin So*** (wasin.so@sjsu.edu). *On the Spectral Radius of an Equitable Quotient Matrix.* Preliminary report.

Let M be a partitioned matrix with blocks M_{ij} whose rows have a constant sum b_{ij}. Then the smaller matrix $B = [b_{ij}]$ is called the equitable quotient matrix of M. It is known in literature that the spectrum of B is contained in the spectrum of M (including algebraic multiplicity). In this talk, we investigate the equality of the spectral radii of M and B, and the structure of the associated eigenvectors under the additional assumption that M is nonnegative. (Received September 14, 2018)

1145-15-1090 **Gi-Sang Cheon*** (gscheon@skku.edu), , South Korea. *A new aspect of Riordan arrays.*

A Riordan array denoted as (g, f) is an infinite lower triangular matrix constructed out of two formal power series $g, f \in \mathbb{F}[[z]]$ with $f(0) = 0$ in such a way that its kth column generating function is gf^k for $j \geq 0$. In many contexts, we see that the Riordan arrays are used as a machine to generate new approaches in enumerative combinatorics, graph theory, matrix theory, orthogonal polynomials, umbral calculus, analytic number theory, etc. Particularly, this talk will be devoted to discussing a new aspect of Riordan arrays in connection with a poset and semigroup algebra $\mathcal{A}[S]$ of S of the form:

$$\mathcal{A}[S] = \left\{ \sum_{\alpha\in S} c_\alpha \alpha | c_\alpha \in \mathbb{F} \right\}$$

where $(S, \star)$ is a commutative semigroup such that for each $\alpha \in S$ there are only finitely many (β, γ) such that $\beta \star \gamma = \alpha$. (Received September 18, 2018)

1145-15-1204 **Derek D Young*** (ddyoung@iastate.edu). *Determining the maximum nullity and minimum rank field independence for some graphs.*

In 2008, it was shown that the maximum nullity of a graph could be bounded above by the zero forcing number of the graph. We study techniques for determining the value of the maximum nullity for some graphs such as the extended cube graphs and Circulant graphs. One technique consists of determining the Colin de Verdiére number of the graph. It is known that the Colin de Verdiére number is a lower bound for the maximum nullity but the value is not easily determined. We also use equitable partitions of the graph's vertex set to determine the nullity of the adjacency matrix. Lastly, equitable decompositions on the adjacency matrix is used determine minimum rank field independence for some graphs. (Received September 20, 2018)

1145-15-1771 **Misha E Kilmer*** (misha.kilmer@tufts.edu), Mathematics Department, 503 Boston Ave, Medford, MA 02155, and **Elizabeth Newman** (e.newman@tufts.edu), Department of Mathematics, 503 Boston Ave., Medford, MA 02155. *Tensor Dictionaries for Applications in Imaging.*

Most problems in imaging science involve operators or data that are inherently multidimensional, yet often traditional approaches to modeling, analysis and dimensionality reduction involve matricized data. In this talk, we discuss ways in which multiway array (aka tensor) dictionaries can be leveraged for tasks such as image compression and reconstruction, recognition, and classification. The unifying mathematical construct in our approaches is the t-product (Kilmer and Martin, LAA, 2011) and associated algebraic framework which permits extension of linear algebraic concepts and matrix algorithms to tensors. Dictionaries from training data can be generated via an Eckart-Young result or, in the cases requiring constraints such as sparsity or non-negativity, learned in an optimization framework. As we demonstrate on examples, these dictionaries are a powerful tool we can leverage in matrix-mimetic algorithms for the tasks noted above. (Received September 24, 2018)

1145-15-2036 **Jillian L Glassett*** (jillian.glassett@wsu.edu) and **Judith J McDonald**. *Spectrally arbitrary patterns over rings with unity.*

A zero-nonzero pattern $\mathcal{A}$ is a matrix with entries from the set $\{0, *\}$. A square pattern $\mathcal{A}$ is spectrally arbitrary over R, a commutative ring with unity, if for each n-th degree monic polynomial $f(x) \in R[x]$, there exists a matrix A over R with pattern $\mathcal{A}$ such that characteristic polynomial of A, $p_A(x)$, is $f(x)$. $\mathcal{A}$ is relaxed spectrally arbitrary over R if for each n-th degree monic polynomial $f(x) \in R[x]$, there exists a matrix A over R with either pattern $\mathcal{A}$ or a subpattern of $\mathcal{A}$ such that $p_A(x) = f(x)$. We evaluate how the structure of rings affects how we determine if a pattern is spectrally arbitrary. We consider whether a pattern that is spectrally arbitrary over R is spectrally arbitrary or relaxed spectrally arbitrary over another commutative ring S with unity. We establish that a pattern that is spectrally arbitrary over $\mathbb{Z}$ is relaxed spectrally arbitrary over $\mathbb{Z}_m$ for all $m \in \mathbb{Z}_+$ and spectrally arbitrary over $\mathbb{Q}$. Similarly, a pattern that is spectrally arbitrary over the p-adic integers is spectrally arbitrary over the p-adic numbers. (Received September 24, 2018)

1145-15-2086 **Edinah K. Gnang***, Whitehead Hall, 3400 North Charles Street, Baltimore, MD 21218. *Theory and applications of algebraic and combinatorial constructs.* Preliminary report.

We describe a theory of constructs as a framework for unifying the multiple variants of the algebra of matrices while at the same time broadening the scope of classical linear algebra algorithms and concepts. (Received September 24, 2018)

1145-15-2352 **Nancy Matar*** (matar1n@cmich.edu), Department of Mathematics, Central Michigan University, Mount Pleasant, MI 48859, and **Sivaram Narayan**. *On Signed Graphs Whose Minimum semidefinite Rank Is Equal To Two.*

For a simple graph G, the minimum rank among all symmetric positive semidefinite matrices associated to G by their zero-nonzero pattern is called the minimum semidefinite rank of G. The patterns $(+, -, 0)$ of real symmetric positive semidefinite matrices are used to study the minimum semidefinite rank of signed graphs (G, f), where f is a function that associates to every edge in G a sign from the set $\{+, -\}$. In this talk, a characterization of the signed graphs with minimum semidefinite rank equal to two will be presented. (Received September 25, 2018)

1145-15-2552 **Sima Ahsani*** (sza0043@auburn.edu). *Extension of some* log-*majorization inequalities to Lie groups.* Preliminary report.

The topic log-majorization of matrices have been studied extensively in matrix theory. Bertram Kostant in 1973 generalized the concept of log-majorization for matrices to Lie groups. In fact, he defined a preorder on noncompact connected semisimple Lie groups. We will look at some recent results on log-majorization inequalities including the geometric mean of two positive definite matrices and show their extension to the context of Lie groups using Kostant preorder. (Received September 25, 2018)

1145-15-2629 **Samuel J Ivy*** (samuel.ivy@usma.edu). *Classifying the Fine Structures of Involutions Acting on Root Systems.* Preliminary report.

We consider real reductive symmetric spaces produced by Lie groups with an involution and the orbits of parabolic subgroups acting on these symmetric spaces. This characterization involves the action of both the symmetric space involution θ on maximal $\mathbb{R}$-split tori and their associated root systems along with the action of the opposing involution $-\theta$. The classification of the fine structures of root systems by an involution help to better understand the action of both θ and $-\theta$. (Received September 25, 2018)

1145-15-2681 **Aritra Dutta** and **Xin Li*** (xin.li@ucf.edu), 4000 Central Florida BLVD, Orlando, FL 32816. *A fast weighted singular value thresholding method.* Preliminary report.

Singular value thresholding (SVT) plays an important role in many low rank matrix approximation algorithms that have many applications in machine learning, pattern recognition, and computer vision. In this talk, we propose a new fast algorithm to solve a weighted version of the singular value thresholding problem (WSVT) which uses a combination of the nuclear norm and a weighted Frobenius norm. We will also give a survey on the various version of generalized or weighted variants of SVT in the current literature. (Received September 25, 2018)

1145-15-2787 **Zhuo-Heng He** and **Jianzhen Liu*** (lj445@medaille.edu), 18 Agassiz Cir, Buffalo, NY 14214, and **Tin-Yau Tam** and **Qing-Wen Wang**. *A system coupled Sylvester-type tensor equations over quaternion and its applications.*

We consider the system of coupled Sylvester-type tensor equations $\mathcal{A}_i *_N \mathcal{X}_i - \mathcal{X}_{i+1} *_M \mathcal{B}_i = \mathcal{C}_i,\ (i = 1, 2, 3, 4)$ over the quaternion algebra, where the operation $*_N$ is the Einstein product, $\mathcal{A}_i, \mathcal{B}_i$, and $\mathcal{C}_i$ are given quaternion tensors with suitable order. We derive some necessary and sufficient conditions for the solvability of this system in terms of Moore-Penrose inverses of quaternion tensors, and provide an expression of the general solution to this system when it is solvable. As an application, we provide some necessary and sufficient conditions for the solvability and the expression of the general solution to the system of mixed pairs of Sylvester quaternion tensor equations $\mathcal{A}_1 *_N \mathcal{X} - \mathcal{Y} *_N \mathcal{B}_1 = \mathcal{C}_1,\ \mathcal{A}_2 *_N \mathcal{Y} - \mathcal{Z} *_N \mathcal{B}_2 = \mathcal{C}_2$, where $\mathcal{Z}$ is Hermitian. Some algorithms and numerical examples are presented to illustrate the results. (Received September 25, 2018)

1145-15-2846 **Troy V Banks*** (tvbanks@salisbury.edu), Department of Math and Computer Science, 1101 Camden Ave, Salisbury, MD 21801. *On the structure of a class of Hankel-like Positive Definite Kernels.*

We investigate a certain class of Hankel-like positive definite kernels using their associated orthogonal polynomials. We focus on the connection between the moments of the kernel and its Jacobi coefficients. (Received September 25, 2018)

16 ► *Associative rings and algebras*

1145-16-250 **Garri Davydyan*** (garri.davydyan@gmail.com), 213-224 Viewmount Drive, Nepean, Ontario K2E 0B4, Canada. *Split-quaternion representation of a functional hierarchy of a biologic system.* Preliminary report.

Previously it was proposed that three regulatory patterns (negative feedback, positive feedback and reciprocal links) determine a functional cor of biologic systems. As a math structure each pattern is represented by a second order matrix over R, M(2,R). Evolution of biologic systems occurs through the formation of more complex, organized in hierarchy, steady functional structures. It is assumed that R, C, H entries on M(2,*) module represent a sequence of hierarchical levels obtained by a functional splitting of characters during biologic development. (Received August 24, 2018)

1145-16-455 **Cris Negron***, Department of Mathematics, Massachusetts Institute of Technology, Cambridge, MA 02142. *Modular quantum groups at even roots of 1.* Preliminary report.

I will discuss recent work on constructing small quantum groups–also known as Frobenius-Lusztig kernels–at even roots of unity. In particular, for any simple Lie algebra $\mathfrak{g}$ and even root of unity q, we would like to associate a corresponding finite-dimensional, factorizable, ribbon (i.e. modular) quasi-Hopf algebra. The main issue here is that, for $\mathfrak{g} = \mathfrak{sl}_2$ at any even root of unity, for example, naive construction of such quantum groups produce finite tensor categories which admit no braiding, by a result of Kondo and Saito. Our investigation is motivated by conjectural relations between triplet vertex algebras and such modular quantum groups, and intersects with works of Gainutdinov, Runkel, and coauthors. (Received September 06, 2018)

1145-16-637 **Elizabeth Wicks*** (lizwicks@uw.edu). *Frobenius-Perron Theory of Modified ADE Bound Quiver Algebras.*

The Frobenius-Perron dimension for an abelian category was recently introduced. We apply this theory to the category of representations of the finite-dimensional radical square zero algebras associated to certain modified ADE graphs. In particular, we take an ADE quiver with arrows in a certain orientation and an arbitrary number of loops at each vertex. We show that the Frobenius-Perron dimension of this category is equal to the maximum number of loops at a vertex. Along the way, we introduce a result which can be applied in general to calculate the Frobenius-Perron dimension of a radical square zero bound quiver algebra. We use this result to introduce a family of abelian categories which produce arbitrarily large irrational Frobenius-Perron dimensions. (Received September 12, 2018)

1145-16-795 **Meric Augat*** (mlaugat@ufl.edu). *The Free Grothendieck Theorem.*

A remarkable pair of theorems of Grothendieck say if $p : \mathbb{C}^g \to \mathbb{C}^g$ is an injective polynomial, then p is bijective and its inverse is a polynomial. We prove a free analog of this. Recall that a free polynomial mapping in g freely non-commuting variables sends g-tuples of matrices (of the same size) to g-tuples of matrices (of the same size).

Our result is as follows; if p is a free polynomial mapping that is injective, then it has a free polynomial inverse. We will make use of a free version of the Jacobian Conjecture as well as results from free analysis, formal power series and skew fields. If there is enough time we will discuss the generalization of the theorem to free rational mappings.

The Free Grothendieck Theorem is related to free analysis, automorphisms of the free algebra and tame vs. wild automorphism of the free algebra. (Received September 14, 2018)

1145-16-969 **Jacob Laubacher*** (jacob.laubacher@snc.edu). *A Deformation Theory Controlled by* $H^{\bullet}_{S^d}(A, A)$. Preliminary report.

In this talk we explore how the higher order Hochschild cohomology of a commutative algebra A with coefficients in A controls a deformation theory when the simplicial set is taken as the d-sphere for any $d \geq 1$. (Received September 17, 2018)

1145-16-1059 **Daniel P. Bossaller*** (dbossaller@jcu.edu) and **Sergio R. López-Permouth** (lopez@ohio.edu). *The Toeplitz-Jacobson Algebra is not Spanned by Strongly Regular Elements.*

The algebra $\mathcal{T} = K\langle x, y \,|\, xy = 1\rangle$ was introduced by Jacobson in during his investigation of elements which are one-sided invertible. Since then, the so-called "Toeplitz-Jacbson" algebra has been widely studied because it fails to be directly finite, in other words, $\mathcal{T} \simeq \mathcal{T} \oplus B$ as left $\mathcal{T}$-modules for some nonzero module B. A recent paper by López-Permouth and Pilewski showed that $\mathcal{T}$ does not have a basis consisting solely of invertible elements. Moore, López-Permouth, Pliewski, and Szabo called algebras which have a basis of units "invertible." In this talk, we will generalize this result by first outlining Jacobson's embedding of $\mathcal{T}$ into the ring of row and column finite matrices, then show that in general, an element $a \in A$ is strongly regular if and only if there exists a unique idempotent element e such that a is invertible in the corner algebra eAe. Finally we will show that $y \in \mathcal{T}$ cannot be written as the span of strongly regular elements. This is joint work with Sergio R. López-Permouth. (Received September 18, 2018)

1145-16-2043 **Ellen E Kirkman*** (kirkman@wfu.edu), Box 7388 Wake Forest University, Winston-Salem, NC 27109, and **James J Zhang**. *The Jacobian, Reflection Arrangement, and Discriminant for Reflection Hopf Algebras.* Preliminary report.

Let $\Bbbk$ be an algebraically closed field of characteristic zero. When H is a semisimple Hopf algebra that acts inner faithfully and homogenously on an Artin-Schelter algebra A so that A^H is also Artin-Schelter regular, we call H a reflection Hopf algebra for A; when $H = \Bbbk[G]$ and $A = \Bbbk[x_1, \ldots, x_n]$ then H is a reflection Hopf algebra for A if and only if G is a reflection group. We show that there exist notions of the Jacobian, reflection arrangement, and discriminant that extend the definitions used for reflection groups actions on polynomial algebras to this noncommutative setting. (Received September 24, 2018)

1145-16-2448 **Geoffrey Thayer Glover*** (glovergt7775@uwec.edu), 5708 Curtis St, McFarland, WI 53558. *Algebras associated with the Hasse graphs of polytopes.* Preliminary report.

We can construct a graded algebra $A(\Gamma)$ associated to a directed Hasse graph, Γ, of a regular polytope by taking the quotient of the free algebra on the set of edges of the graph by the relations given by equating two directed paths having the same initial and final vertices. The automorphism group of each graph is the symmetry group of the associated polytope. For each unique symmetry, we consider the Hasse subgraph consisting of fixed k-faces of the polytope under the action. From each Hasse subgraph, we determine the graded dimension of the related subalgebras of $A(\Gamma)$ by counting the directed paths between each pair of levels in the graph. Polynomials with the graded dimensions as the coefficients allow us to describe the complete algebraic structure of $A(\Gamma)$ using representation theory. Previous work has studied the finite Coxeter groups A_n, B_n, D_n, $I_2(p)$ and their related polytopes. In my talk I will discuss the computer programs we wrote to find the fixed faces under each symmetry and count the paths in each subgraph for the icosahedron (H_3) and how they can be extended to be used on the 600-cell (H_4) and the 24-cell (F_4). (Received September 25, 2018)

1145-16-2610 **Gordon Brown**, **Nicholas Davidson*** (ndavidson@math.ou.edu) and **Jonathan Kujawa**. *Quantum Webs of type Q.* Preliminary report.

Originally introduced by Kuperberg, webs are combinatorially defined diagrams used to describe homomorphisms between certain representations of quantum groups. I will discuss joint work with Jon Kujawa and Gordon Brown which uses webs to give a combinatorial description of the homomorphisms between tensor products of representations of the type Q quantum supergroup $U_q(\mathfrak{q}_n)$. (Received September 25, 2018)

1145-16-2764 **Jory L Wagner** (mathematics@uwec.edu), Hibbard Humanities Hall 508, 124 Garfield Avenue, Eau Claire, WI 54701, and **Tyler Jules Gonzales*** (mathematics@uwec.edu), Hibbard Humanities Hall 508, 124 Garfield Avenue, Eau Claire, WI 54701. *"Z2-graded Complex Associative Algebras: Background, Deformations, and Maple v.s. SageMath" presented by Tyler Gonzales and Jory Wagner.*

In this talk, we will share the research we have completed during the summer REU mathematics program. We begin by sharing some definitions, and examples, of topics we have learned relating to the field of noncommutative geometry and deformation theory. We will open this talk with a discussion on the concepts of algebras, graded vector spaces, tensor products, and the tensor algebra. We will then move into the notion of deformation theory, including an example of how to compute the bracket of what is called a versal deformation. We will conclude this talk with a comparison of Maple and SageMath, and discuss why we hope to continue the translation of the computer software from one to the next. (Received September 25, 2018)

1145-16-2765 **Haotian Wu*** (mathematics@uwec.edu), Hibbard Humanities Hall 508, 124 Garfield Avenue, Eau Claire, WI 54701. *The moduli space of non-nilpotent complex 5-dimensional associative algebras.* Preliminary report.

We have been studying the moduli space of non-nilpotent complex associative five dimensional algebras. There are 285 strata in the space including some strata which are parametrized by either $\mathbb{P}$ or the projective orbifold $\mathbb{P}/\sum_2$. We discuss the deformation theory of these algebras. (Received September 25, 2018)

1145-16-2912 **Miodrag C Iovanov*** (miodrag-iovanov@uiowa.edu). *On the bijectivity of the antipode and serial quantum groups.* Preliminary report.

We survey a few recent results and classifications which involve Hopf algebras which are co-serial ("serial quantum groups"), and present some questions relating these to other problems. We investigate the bijectivity of the antipode of a one sided co-serial infinite dimensional Hopf algebra, and the left-right symmetry of this notion. We present some new ideas inspired by methods of representations of finite dimensional algebras as well as by those of tensor categories, and which can be of interest in other situations where the bijectivity of the antipode is an open question (such as Noetherian Hopf algebras). (Received September 25, 2018)

17 ► Nonassociative rings and algebras

1145-17-437 **Ryan Roger Moruzzi, Jr*** (rmoru001@ucr.edu). *An isomorphism of modules of type D_n.* Preliminary report.

In 2010, Hernandez and Leclerc identified a family of prime representations of the quantum affine algebra associated to a lie algebra of type A_n and D_n. In 2015, Brito, Chari, and Moura studied the classical limit of that family of prime representations of type A_n, which can be viewed as representations of the current algebra, and proved such representations specialize to stable prime Demazure modules.

Currently, I am working on proving similar results for the lie algebra of type D_n. In this setting, the prime representations specialize not to Demzaure modules as in the case of a lie algebra of type A_n, but $V(\xi)$ modules defined by Chari and Venkatesh in 2013. In this talk, I will introduce an isomorphism between representations of the current algebra of type D_n, specifically, an isomorphism of a $V(\xi)$ module and a generalized Demazure module. I will also talk about current work and further exploration of such representations. (Received September 25, 2018)

1145-17-450 **Tyler Kenefake*** (tylerkenefake@my.unt.edu). *Annihilators of Indecomposable Bounded Modules of* Vec($\mathbb{R}$).

We report on work in progress towards computing the annihilators of certain indecomposable bounded modules of Vec($\mathbb{R}$), the Lie algebra of vector fields on the line. The annihilators of the tensor density modules $\mathcal{F}_\lambda$ are known. We describe the annihilator of the extension of $\mathcal{F}_\lambda$ by $\mathcal{F}_{\lambda+2}$ in the subalgebra of lowest weight vectors of $\mathfrak{U}(\mathrm{Vec}(\mathbb{R}))$, the universal enveloping algebra of Vec($\mathbb{R}$), in the non-resonant case $\lambda \neq -\frac{1}{2}$. (Received September 06, 2018)

1145-17-803 **Prakash Ghimire*** (pghimire@lsua.edu), 920 Twin Bridges Rd Apt 3, Alexandria, LA. *Lie Triple Derivations of the Lie Algebra of Dominant Block Upper Triangular Matrices.*

Let N be the Lie algebra of all $n \times n$ dominant block upper triangular matrices over a field F. In this talk, we explicitly describe all Lie triple derivations of N when char(F) $\neq 2$. As an application, we characterize Lie derivations of N when char(F) $\neq 2$. (Received September 15, 2018)

1145-17-1249 **Rustam Gaybullaev**, **Abror Khudoyberdiyev** and **Kyla Pohl*** (pohl1@stolaf.edu). *Classification of Solvable Leibniz Algebras with Abelian Nilradical and $k-1$ Dimensional Extension.*

This talk is devoted to the classification of solvable Leibniz algebras with an abelian nilradical. We consider a $k-1$ dimensional extension of k dimensional abelian algebras and classify all $2k-1$ dimensional solvable Leibniz algebras with an abelian nilradical of dimension k. (Received September 20, 2018)

1145-17-1838 **Jude L Quintero*** (jlquintero@randolphcollege.edu) and **Michael Penn** (mpenn@randolphcollege.edu). *Finite Group Orbifolds of the Rank 2 Heisenberg Vertex Algebra.*

Finding invariant subalgebras known as orbifolds is an important technique for constructing new vertex operator algebras. We apply classical invariant theory, similar to the approach of A. Linshaw, to the Rank 2 Heisenberg Vertex Algebra, $\mathcal{H}(2)$. Using the facts that the full automorphism group of $\mathcal{H}(2)$ is the orthogonal group $\mathcal{O}(2)$, and all finite subgroups of $\mathcal{O}(2)$ are cyclic or dihedral, we classify all finite group orbifolds of $\mathcal{H}(2)$. (Received September 24, 2018)

1145-17-1962 **Elyse Suzanne Rogers*** (esrogers@ncsu.edu), Department of Mathematics, 2108 SAS Hall, Box 8205, NC State University, Raleigh, NC 27695. *The Leibniz Multiplier of Lie and Leibniz Algebras.*

The Schur multiplier is a topic of great interest and has been investigated in both group theory and Lie algberas. In this talk, I wish to explain how this theory can be applied to Leibniz algebras. Leibniz algebras are a non-commutative generalization of Lie algebras. If L is a finite dimensional Leibniz algebra over a field $\mathbb{F}$ with $char(\mathbb{F}) \neq 2$ then a pair of algebras (K, M) is called a defining pair for L if $L \cong K/M$ and if $M \subset Z(K) \cap [K, K]$. If K is of maximal dimension then it is called the cover of L and the corresponding maximum dimensional M is called the multiplier for L. We will discuss the differences in structure and dimension of the Lie and Leibniz multipliers of algebras in the lower central series. Furthermore, we can discuss the structure of the Leibniz multiplier of the Heisenberg Lie and Leibniz algebras of dimension $2n + 1$. (Received September 24, 2018)

1145-17-2028 **Olga Kharlampovich***, okharlampovich@gmail.com. *Diophantine problem in free Lie algebras.*

Using the undecidability of the Diophantine problem in integers we show that the Diophantine problem in a free Lie algebra L of rank > 2 over a field or an integral domain is undecidable.

First-order theory of a free Lie algebra over a field of characteristic 0 (even without coefficients) is undecidable.

This answers questions by Baudisch (86) and by Bokut' and Kukin (94) (also attributed to Malcev). These are joint results with A. Miasnikov. (Received September 24, 2018)

1145-17-2139 **Guy R Biyogmam*** (guy.biyogmam@gcsu.edu), 231 W. Hancock St, Arts & Sciences Room 1-29 — Campus Box 17, Milledgeville, GA 31061. *The c-nilpotent Schur Lie-multiplier of Leibniz algebras.*

In this talk, we will present the notion of c-nilpotent Schur Lie-multiplier of Leibniz algebras. We will examine a few tools useful in characterizing Lie-nilpotency and c-Lie-stem covers of Leibniz algebras. We will discuss the existence of c-Lie-stem covers for finite dimensional Leibniz algebras and the non existence of c-covering on certain Lie-nilpotent Leibniz algebras with non trivial c-nilpotent Schur Lie-multiplier. (Received September 24, 2018)

1145-17-2460 **Suzanne Elise Crifo*** (secrifo@ncsu.edu). *Some Maximal Dominant Weights and their Multiplicities for Affine Lie Algebra Representations.* Preliminary report.

Affine Lie algebras are infinite dimensional analogs of finite dimensional simple Lie algebras. It is known there are finitely many maximal dominant weights for any integrable highest weight representation of an affine Lie algebra. However, determining these maximal dominant weights is a nontrivial task. So far only the descriptions of these weights are known for affine Lie algebra $A_n^{(1)}$. In this talk we will discuss the maximal dominant weights of the integrable highest weight representation of any affine Lie algebra with highest weight $k\Lambda_0$ and give some examples of their multiplicities. (Received September 25, 2018)

1145-17-2516 **Yevgenia Kashina***, Department of Mathematical Sciences, DePaul University, Chicago, IL 60614. *On classification of semisimple Hopf algebras of dimension 2^n.*

In this talk we will discuss a family of semisimple Hopf algebras of dimension 2^n with a large abelian group of grouplike elements. All Hopf algebras in this family can be obtained as abelian extensions. We will classify these extensions up to equivalence and discuss which of them could be distinguished by categorical invariants. (Received September 25, 2018)

1145-17-2518 **Antun Milas**, **Michael Penn*** (mpenn@randolphcollege.edu) and **Joshua Wauchope**. *Permutation Orbifolds of Fermion Vertex Superalgebras.*

Invariant subalgebras of free fields vertex algebras and superalgebras are rich sources of interesting simple vertex algebras. There is already a substantial body of work on this subject, especially from the perspective of W-algebras. These approaches are primarily based on classical invariant theory. When it comes to permutation orbifolds (fixed under the *full* symmetric group S_n) very little is known except for $n = 2$, except for recent work of the first two authors describing the rank 3 Heisenberg permutation orbifold. We extend this work and describe the structure of the permutation orbifold of the rank three free fermion vertex superalgebra (of central charge $\frac{3}{2}$) and of the symplectic fermion vertex superalgebra (of central charge -6). In the case of the free fermion algebra, we prove an isomorphism between the orbifold and a subalgebra of a lattice vertex algebra. (Received September 25, 2018)

1145-17-2559 **Chad R Mangum*** (cmangum@niagara.edu). *Twisted Toroidal Lie Algebras: Present and Future.*

The theory of Lie algebras, and specifically Lie algebra representation theory, has been significant in various areas of mathematics and physics for several decades. One important class of Lie algebras with many interesting open questions is that of twisted toroidal Lie algebras, which we view as universal central extensions of twisted multiloop algebras. In this talk, we will discuss some recent advances in regards to presentations and representations of these algebras, followed by thoughts about potential future directions in this field which are of particular interest. (Received September 25, 2018)

18 ► *Category theory; homological algebra*

1145-18-1118 **Pinhas Grossman**, **Scott Morrison**, **David Penneys**, **Emily Peters** and **Noah Snyder*** (nsnyder@gmail.com). *Morita equivalence classes of small index subfactors.*

Most known fusion categories can be constructed from quantum groups and finite groups. The main exceptional examples come from the classification of small index subfactors: the Haagerup, Asaeda-Haagerup, and Extended Haagerup fusion categories. Izumi later put the Haagerup examples into a larger framework of Izumi quadratic categories, and we'd like to understand if there's anything that doesn't come from groups, quantum groups or Izumi categories. It is natural to ask what other fusion categories are Morita equivalent to the exceptionals: on the one hand we may find something new which is easier to understand showing that the original fusion category is less exceptional than we thought, and on the other hand we might find additional exceptional examples. In joint work with Grossman and Grossman-Izumi we found all categories Morita equivalent to Asaeda-Haagerup and found that some of them are Izumi categories. In joint work with Grossman, Morrison, Penneys, Peters, we also answered this question for Extended Haagerup finding two new exceptionals. In order to construct these two new examples we use a new technique of "Graph planar algebra embeddings for module categories" which Dave Penneys will talk about in his talk. (Received September 19, 2018)

1145-18-1219 **David Penneys***, 100 Math Tower, 231 West 18th Ave., Columbus, OH 43210-1174. *The module embedding theorem.*

By Cayley's theorem, a G-module X for a group G is equivalent to a homomorphism from G into the set of bijections of X. The tensor category analog is that a C-module structure on a category M is equivalent to a tensor functor from C into End(M), the endofunctors of M. We will explain the pivotal, unitary, and unitary pivotal analogs of this fact, as well as a generalization to multitensor categories. We will then explain that one such analog is the module embedding theorem for finite depth subfactor planar algebras, which was recently used to construct the Extended Haagerup fusion categories. (Received September 20, 2018)

1145-18-1349 **Alex Levin** and **Dmitri Nikshych*** (dmitri.nikshych@unh.edu), Department of Mathematics and Statistics, Kingsbury Hall, 33 Academic Way, Durham, NH 03861. *On the subcategory lattices of fusion categories.* Preliminary report.

Given a fusion category $\mathcal{C}$ we describe the lattices of fusion subcategories of its equivariantizations and graded extensions by finite groups in terms of subcategories of $\mathcal{C}$ and certain group-theoretical data. Combining these we determine the subcategory lattice of a braided fusion category obtained by gauging. As an example, we describe this lattice of an arbitrary weakly group-theoretical braided fusion category in terms of its core. This extends the previously known results about the subcategory lattice of the representation category of a twisted group double. (Received September 21, 2018)

1145-18-1376 **Michael Robinson*** (michaelr@american.edu), 4400 Massachusetts Ave NW, Washington, DC 20016. *Analyzing data with the consistency filtration of a sheaf assignment.*

Suppose that there are a number of events that have occurred, and that we have observed a subset of these events. Some of these events are related by causality, which is to say that the occurrence of some events ensures that certain others will also occur. Conversely, there may be events that could have happened, but didn't. One rarely has a complete understanding of causality among events, so the model of which events cause other events may be wrong and our observations may be faulty.

Sheaves can represent both data and modeling assumptions about causality, yet can avoid prioritizing one over the other. By incorporating geometry into "attributes" attached to events from the start, the global "fit" between local data and models can be quantified. This supports robust inferences about missing or inaccurate data.

This talk will formalize and unify these ideas using the consistency filtration associated to a sheaf of pseudometric spaces and an assignment of data. As a filtration, it has persistence properties – both functorial and geometric – and generalizes persistent cohomology. This generalization is strict, which leads to new, interesting, and robust tools for data analysis. (Received September 21, 2018)

1145-18-1403 **Jared Culbertson***, jared.culbertson@us.af.mil, and **Paul Gustafson**, **Daniel E Koditschek** and **Peter F Stiller**. *Semantics of Dynamical Systems.*

We will present ongoing work in providing a formal semantics for the composition of dynamical systems that model robotic behaviors. Using the well-known Curry–Howard–Lambek correspondence and more recent extensions (which show how to formalize computational semantics using categorical structures) as a guide, we will discuss our progress in abstracting certain kinds of dynamics for gaits in robotic legged platforms as well as dynamics in multi-agent systems. Mathematically, this requires understanding how aspects of these systems such as trapping regions or attracting and repelling sets relate to formalizations of sequential composition, coupled systems and equivalences. (Received September 21, 2018)

1145-18-1647 **Marcel Bischoff*** (bischoff@ohio.edu), **Corey Jones** (jones.6457@osu.edu), **Yuan-Ming Lu** (lu.1435@osu.edu) and **David Penneys** (penneys.2@osu.edu). *Symmetry breaking from anyon condensation.* Preliminary report.

The topological order of a topological phase of matter can be described by a unitary modular tensor category $\mathcal{C}$ where objects correspond to anyons. If an anyon A in $\mathcal{C}$ has the structure of a connected étale algebra it can be condensed and one obtains a new topological phase with topological order $\mathcal{D}$ which is described by the category of local A-modules in $\mathcal{C}$. We give a mathematical description of symmetry preservation and breaking in this context by discussing the following question. Under which conditions can a symmetry of $\mathcal{C}$ described by a finite group G be promoted to a symmetry of $\mathcal{D}$? (Received September 23, 2018)

1145-18-1652 **Kenichi Shimizu***, 307 Fukasaku, Minuma-ku, Saitama-shi, Saitama 337-8570, Japan. *A description of the relative Serre functor for comodule algebras.*

Let $\mathcal{C}$ be a finite tensor category, and let $\mathcal{M}$ be an exact left $\mathcal{C}$-module category. The relative Serre functor of $\mathcal{M}$, introduced by Fuchs, Schaumann and Schweigert, is an endofunctor S on $\mathcal{M}$ such that there is a natural isomorphism $\underline{\mathrm{Hom}}(M,N)^* \cong \underline{\mathrm{Hom}}(N,S(M))$ for $M,N \in \mathcal{M}$, where $\underline{\mathrm{Hom}}$ is the internal Hom functor. In this talk, I discuss the case where $\mathcal{C} = H$-mod and $\mathcal{M} = L$-mod for a finite-dimensional Hopf algebra H and a finite-dimensional exact left H-comodule algebra L. Such an algebra L is shown to be Frobenius by an argument using the Frobenius-Perron dimension. I give an explicit description of the relative Serre functor of L-mod and its twisted module structure $S(X \otimes M) \cong X^{**} \otimes S(M)$ ($X \in H$-mod, $M \in L$-mod) in terms of integrals of H and the Frobenius structure of L. (Received September 23, 2018)

1145-18-1785 **Robert Laugwitz*** (robert.laugwitz@rutgers.edu) and **You Qi**. *Categorification of Cyclotomic Integers.*

A basic ingredient in the approach to categorification of small quantum groups proposed by M. Khovanov is to use p-complexes to categorify the cyclotomic integers at a prime root of unity. Based on this approach, $\mathfrak{sl}_2$ quantum groups were categorified for prime roots of unity by Khovanov–Qi and Elias–Qi.

In this talk, the construction of a triangulated tensor category categorifying cyclotomic integers, which does not require the restriction on the order of the root of unity to be prime, is discussed. (Received September 24, 2018)

1145-18-1791 **Corey Jones*** (cormjones88@gmail.com). *Permutation gauging of modular categories.*

Gauging a global symmetry group G of a field theory is the process of constructing a new theory where G acts by local symmetries. When the selection sectors of your theory are described by a modular tensor category (e.g. rational 2D conformal field theory or 2D topological phases of matter), gauging can be described categorically. However, gauging is very difficult from a mathematical perspective and is not always possible. There are difficult-to-compute cohomological obstructions to performing the gauging construction. In this talk, we will explain joint work with Terry Gannon which uses the stability properties of symmetric group cohomology to show that gauging the standard action of S_n on $\mathcal{C}^{\boxtimes n}$ is always possible for any modular category $\mathcal{C}$. (Received September 24, 2018)

1145-18-1793 **Robert Laugwitz*** (robert.laugwitz@rutgers.edu) and **Johannes Flake**. *An Interpolation Approach to Untwisted Dijkgraaf–Witten Invariants.* Preliminary report.

P. Deligne introduced a remarkable tensor category interpolating the representation theory of symmetric groups, allowing for the natural number of permuted letters to be replaced by any complex number. This talk explains an approach to extending this idea to crossed modules over symmetric groups. As an application, interpolations of untwisted Dijkgraaf–Witten invariants of ribbon link are obtained. (Received September 24, 2018)

1145-18-1944 **Daniel Michael Cicala*** (cicala.daniel@gmail.com), 400 S Main St, Unit 306, Los Angeles, CA 90013. *Syntax and inductive rewriting for open networks.*

Networks exist across disciplines and so have developed idiosyncrasies local to the various fields in which it is used. A recent research program aims to use category theory to abstract away idiosyncrasies, centralize compositionality, and develop a common language. In this talk, we introduce a syntax for open networks we call structured cospans. Starting with a functor $L\colon \mathbf{A} \to \mathbf{X}$ from a category $\mathbf{A}$ of "interface types" to a category $\mathbf{X}$ of "networks", a structured cospan is a pair of morphisms of type $La \to x \leftarrow Lb$ in $\mathbf{X}$. Here x represents a network and La, Lb give x inputs and outputs, respectively. Using pushouts, we can connect two structured cospans when the input of one coincides with the outputs of the other. This models connecting compatible open networks to form a larger open network. Making several mild assumptions about L, $\mathbf{A}$, $\mathbf{X}$, we show that structured cospans admit a rewriting theory generalized from the double pushout style popular in graph theory. The main result is a categorical semantics that characterizes the rewriting of a network inductively, that is by rewriting sub-networks and connecting them together. (Received September 24, 2018)

1145-18-2027 **Cain Edie-Michell**, **Corey Jones** and **Julia Plavnik*** (juliaplavnik@gmail.com). *Fusion rules for $\mathbb{Z}/2\mathbb{Z}$ permutation gauging.*

Given a unitary modular category with a symmetry by a group G, we can construct (when certain obstructions vanish) a new unitary modular category via the gauging procedure. One interesting example is given by the tensor square of a modular tensor category $\mathcal{C}$ with the $\mathbb{Z}_2$ action induced by swapping the factors. During this talk, we will explain how to find the fusion rules for both the extension and the subsequent equivariantization (i.e the gauging) in terms of the fusion rules and modular data of the original modular category $\mathcal{C}$. (Received September 24, 2018)

1145-18-2038 **Qing Zhang*** (zhangqing@math.tamu.edu). *Classification of super-modular categories by rank.*

A super-modular category is a unitary pre-modular category with Müger center equivalent to the symmetric monoidal category of super-vector spaces. Super-modular categories are important for a variety of reasons. For example, any unitary pre-modular category is the equivariantization of a modular or super-modular category. Physically, super-modular categories are related to the study of fermionic topological phases of matter. In this talk, we will discuss the classification of super-modular categories of rank 8. This is joint work with P. Bruillard, J. Plavnik and E. Rowell. (Received September 24, 2018)

1145-18-2208 **Siu-Hung Ng*** (rng@math.lsu.edu). *On Higer Gauss Sums of Modular Categories.*

Modular tensor categories are categorical generalizations of finite abelian groups with nondegenerate quadratic forms. The notion of Gauss sum can be defined analogously for any modular tensor category. In this talk, we will discuss some interesting arithmetic properties of the higher Gauss sums, and their relations with the Frobenius-Schur indicators. This is a joint work with Andrew Schopieray and Yilong Wang. (Received September 25, 2018)

1145-18-2213 **Yilong Wang*** (yilongwang@lsu.edu). *Higher central charge and higher Gauss sum of premodular categories.*

The Gauss sum and the central charge of premodular categories are important categorical invariants. When the category is modular, these invariants provide important information of the associated Reshetikhin-Turaev TQFTs. We generalize the notions of central charge and Gauss sum, and derive interesting arithmetic properties of them under the action of the absolute Galois group. We will also discuss how these invariants change under de-equivariantization and the local module construction. This is a joint work with Siu-Hung Ng and Andrew Schopieray. (Received September 25, 2018)

1145-18-2289 **César Galindo** and **Yiby Morales***, yk.morales964@uniandes.edu.co. *Kac cohomology as relative group cohomology.* Preliminary report.

Let F and G be finite groups. The group $Opext(kF, k^G)$ of equivalence classes of abelian extensions of the Hopf algebra kF by the Hopf algebra k^G can be described using the cohomology of a double complex, which is known as Kac cohomology. We use relative group cohomology to describe this group and the five-term exact sequence associated to Kac's double complex, which we use for some computations of groups of abelian extensions of finite dimensional Hopf algebras. This is joint work with César Galindo. (Received September 25, 2018)

1145-18-2409 **Alexei Davydov*** (davydov@ohio.edu), Department of Mathematics, Ohio University, Athens, OH 45701. *Braided module categories.* Preliminary report.

The notion of a braided module category over a braided monoidal category comes naturally from the study of extensions of braided categories. The 2-category of braided module categories comes equipped with interesting structures. This is a report on the joint work with D. Nikshych. (Received September 25, 2018)

1145-18-2425 **Costel G Bontea*** (cgbontea@colby.edu) and **Dmitri Nikshych**. *Classifying pointed braided finite tensor categories.*

One of the earliest classification results in the theory of tensor categories was given by A. Joyal and R. Street who showed that the category of pointed braided fusion categories is equivalent to the category of pre-metric groups. In this talk I will present a weak generalization of this result which says that the core of the category of pointed braided finite tensor categories admitting a fiber functor is equivalent to a category of metric quadruples. This is based on joint work with Dmitri Nikshych. (Received September 25, 2018)

1145-18-2754 **Alex A Chandler*** (achandl@ncsu.edu), 2311 Stinson Dr., Raleigh, NC 27607. *Thin Posets and Homology Theories.* Preliminary report.

Inspired by Bar-Natan's description of Khovanov homology, we discuss thin posets and their capacity to support homology and cohomology theories which categorify rank-statistic generating functions. Additionally, we present two main applications. The first, a categorification of certain generalized Vandermonde determinants gotten from the Bruhat order on the symmetric group by applying a special TQFT to diagrams of torus links. The second is a broken circuit model for chromatic homology, categorifying Whitney's broken circuit theorem for the chromatic polynomial of graphs. (Received September 25, 2018)

1145-18-2763 **Marcel Bischoff** and **Henry Tucker*** (hjtucker@ucsd.edu). *Modular data for Drinfel'd centers of near-group fusion categories obtained via the modular graft construction.* Preliminary report.

The Drinfel'd centers of fusion categories are an important source of modular tensor categories. The classification program for quadratic fusion categories initiated by Izumi has produced many such examples. In particular, Evans and Gannon have shown that the modular data for the centers of near-group quadratic categories (i.e., those with one non-invertible object whose tensor square includes all of the invertibles as subobjects) are given by quadratic forms on finite groups in a way similar to the classical Weil representation for $SL_2(\mathbb{Z})$. We make this statement precise by realizing the modular data in terms of a grafting or "smashed sum" of modular data. This follows the earlier work of Evans and Gannon on the modular data for the center of the Haagerup category. (Received September 25, 2018)

1145-18-2808 **Alex A Chandler*** (achandl@ncsu.edu), **Adam Lowrance**, **Radmila Sazdanovic** and **Victor Summers**. *Torsion in Khovanov Homology of 3-Braids.* Preliminary report.

We give a partial answer to the conjecture of Przytycki and Sazdanovic that 3-braids have only 2-torsion in Khovanov homology. In particular, we present an infinite family of 3-braids, strictly containing the 3-strand torus links, which have only 2-torsion. Furthermore, we give explicit computations of the integral Khovanov homology of all links in this family. (Received September 25, 2018)

20 ► Group theory and generalizations

1145-20-93 **John Hutchens*** (hutchensjd@wssu.edu) and **Nathaniel Schwartz**. *Involutions of groups of type* G_2 *over fields.*

We define a generalized symmetric space to be the quotient G/H where G is an algebraic group and H is the fixed point group of an involution of G. Let C be an octonion algebra over a field k, then $\mathrm{Aut}(C)$ is a group of type G_2 over k. We determine the $\mathrm{Aut}(C)$-conjugacy classes of the k-involutions and their respective fixed point groups. It is shown that the classification of conjugacy classes of involutions of $\mathrm{Aut}(C)$ correspond to isomorphism classes of quaternion algebras for almost every field. (Received July 27, 2018)

1145-20-265 **Sarah Croome*** (scroome@math.kent.edu) and **Mark L. Lewis**. *Character codegrees of p-groups.* Preliminary report.

Let G be a p-group and let χ be an irreducible character of G. The codegree of χ is given by $|G : \ker(\chi)|/\chi(1)$. The set of codegrees of the irreducible characters of G is denoted $\mathrm{cod}(G)$. If $|\mathrm{cod}(G)| = 4$, then G has nilpotence class at most 4 whenever G either has coclass at most 3, largest character degree p^2, or $|G : G'| = p^2$. Similar conditions exist which guarantee the existence of p^2 as a codegree of G. If $|G| = p^{n+1}$ then $\mathrm{cod}(G)$ contains all powers of p up to p^n if and only if G satisfies one of three cases, including the case when G has maximal class and two character degrees. If G has maximal class and $|G|$ is large enough, then p^3 and p^4 are in $\mathrm{cod}(G)$. The codegrees of maximal class p-groups which are also metabelian or normally monomial are always consecutive powers of p. The question arises whether all maximal class p-groups have consecutive p-power codegrees. (Received August 27, 2018)

1145-20-296 **Joseph Kirtland*** (joe.kirtland@marist.edu), Department of Mathematics, Marist College, 3399 North Road, Poughkeepsie, NY 12601. *The Schur-Zassenhaus Theorem: Its Origin, Development, and Extension.*

The Schur-Zassenhaus Theorem states that if N is a normal subgroup of a finite group G such that $([G : N], |N|) = 1$, then G splits over N and all of its complements are conjugate in G. This talk will present the origin and development of this result and discuss some of its extensions. (Received August 29, 2018)

1145-20-424 **Hossein Shahrtash*** (h.shahrtash@ufl.edu), 358 Little Hall, 1400 Stadium Road, Gainesville, FL 32611. *Rational Class Sizes and Their Implications About The Structure of Finite Groups.*

This talks considers the problem of the implications of rational class sizes for the structure of finite groups. Ever since Itˆo introduced the notion of a conjugate type vector in 1953, the problem of unraveling the connections between the set of conjugacy class sizes and the structure of a finite group has been widely studied. There are interesting instances of recognizing structural properties of a finite group, including solvability, nilpotency, etc. based on the set of conjugacy class sizes.

In this presentation, we will consider a similar problem concerning the set \$cs_{rat}(G)\$ of the sizes of rational classes of a finite group \$G\$, and will discuss the influence of rational class sizes on the structure of finite groups. (Received September 05, 2018)

1145-20-432 **Mark L. Lewis*** (lewis@math.kent.edu), 1300 Lefton Esplanade, Kent, OH 44242. *Maximal abelian subgroups of semi-extraspecial groups and partitions by centers of centralizers.*

A p-group G is semi-extraspecial if G is a nonabelian p-group for some prime p and G/N is extraspecial for every subgroup N that is maximal in $Z(G)$. Verardi found an upper bound for the order of a maximal abelian subgroup of a semi-extraspecial group. We found a lower bound for the order of a maximal abelian subgroup of a semi-extraspecial group. We will show that semi-extraspecial groups are partitioned by the centers of the centralizers of noncentral elements. Verardi has shown that there is an upper bound on the order of these centralizers in semi-extraspecial groups. We will show that Verardi's bound can be improved in several cases. Finally, we will consider other groups that are partitioned by the centers of the centralizers of noncentral elements. (Received September 06, 2018)

1145-20-434 **William Cocke***, cocke@math.wisc.edu, and **Meng-Che Ho**. *A Characterization of Finite Nilpotent Groups Using Word Maps.*

Many classes of groups are characterized by some class of words. Recently, there has been significant interest in the probability distributions induced by word maps over a group. For example, the recently proven Ore Conjecture stated that the commutator word map was surjective on all finite simple groups. In this talk, we will show that a finite group is nilpotent if and only if every surjective word map is uniform. In doing so, we will show how to construct for any non-nilpotent finite group G a word w that is surjective but not uniform on G. (Received September 06, 2018)

1145-20-435 **William Cocke***, cocke@math.wisc.edu, and **Steve Goldstein** and **Michael Stemper**. *A Database of Finite Groups with the Same Character Tables.*

The character table of a finite group captures many of the group theoretic properties of the group. For example, from the character table of a group G, one can tell if G is abelian, nilpotent, solvable, or simple. To help identify which properties of a group are captured by the character table we have built a database for all groups in the SmallGroups Database that identifies which groups share a character table. In general, their is no canonical ordering of the rows and columns of a character table and any rearrangement of the rows and columns produces an equivalent table. Our computations utilized HTCondor to determine which of the over 430,000,000 groups share a character table. The techniques could be apply to identify any discrete structure with a large automorphism group. (Received September 06, 2018)

1145-20-468 **M R Darafsheh*** (darafsheh@ut.ac.ir), School of Mathematics, University of Tehran, 14174 Tehran, Iran. *One rational irreducible characters of finite groups.* Preliminary report.

Let χ be a complex irreducible character of a group G. The field generated by all $\chi(x)$, $x > G$, is denoted by $\mathbb{Q}(\chi)$. The character χ is rational if $\mathbb{Q}(\chi) = \mathbb{Q}$. A group G is called a rational group or a $\mathbb{Q}$-group if all irreducible complex characters of G are rational. The order and structure of $\mathbb{Q}$-groups are restricted, for example by a result of Feit and Seitz the simple $\mathbb{Q}$-groups are among the Wyle groups of the simple Lie algebras and their extensions, while by a result of Gow the order of a solvable $\mathbb{Q}$-group is divisible by numbers 2, 3, or 5. Despite these facts the complete structure of a $\mathbb{Q}$-group of order a power of 2 is not completely known. In this talk we survey recent results on classifying $\mathbb{Q}$-groups. (Received September 06, 2018)

1145-20-503 **Shuang Ming*** (sming@math.ucdavis.edu) and **Greg Kuperberg**. *On TQFT representations of mapping class groups with boundary.*

(2+1)-dimensional TQFT provide interesting examples of representations of mapping class groups. In this talk, I will discuss the images of the representations. In the joint work with Greg Kuperberg, we proved the representations is always irreducible at odd prime level. When A is a generic complex number, we prove the image is Zariski dense when genus $g = 0$. (Received September 07, 2018)

1145-20-545 **Alexander Heaton*** (aheaton@uwm.edu), 2865 N Weil St, Milwaukee, WI 53212. *Graded multiplicity in harmonic polynomials from the Vinberg setting.*

We describe the graded multiplicity of irreducible representations by counting integral points on faces of a polyhedron. This description applies to a family of examples from the following context (first considered by Vinberg): Let G be a connected reductive algebraic group over the complex numbers. A subgroup, K, of fixed points of a finite-order automorphism acts on the Lie algebra of G. Each eigenspace of the automorphism is a representation of K. The harmonic polynomials on an eigenspace are graded by homogeneous degree, giving us a graded representation of K. Given any irreducible representation of K, we will see how its multiplicity in the harmonic polynomials is distributed among the various graded components. The results are described geometrically by counting integral points on faces of a polyhedron. The multiplicity in each graded component is given by intersecting these faces with an expanding sequence of shells. (Received September 09, 2018)

1145-20-708 **Nate Iverson*** (niverson@sienaheights.edu). *The number of nontrivial orbits under the composition operation for bounded juggling patterns.*

In the 1994 paper *Juggling Drops and Descents*, Buhler, Eisenbud, Graham and Wright define a juggling pattern to be a permutation of the integers f such that $f(t) \geq t$. These patterns mathematically describe the site-swap notation that was in use by jugglers prior to the papers publication. The authors go on to count the number of n-periodic b-ball juggling patterns.

In this talk we will examine the more algebraic properties of the semigroup of juggling patterns under the composition operation. In particular we will retrace the previous authors' result that the number of non-trivial orbits (or balls) of a bounded juggling pattern is the average of the heights and sketch a proof that the number of balls is a congruence with respect to the composition operation within the bounded juggling patterns. (Received September 13, 2018)

1145-20-711 **Alimjon Eshmatov*** (alimjon.eshmatov@utoledo.edu), Department of Mathematics and Statistics, University of Toledo, Toledo, OH 43606, and **Yuri Berest** and **Farkhod Eshmatov**. *Dixmier groups.*

We describe the structure of the automorphism groups of algebras Morita equivalent to the first Weyl algebra. In particular, we give a geometric presentation for these groups in terms of amalgamated products, using the Bass-Serre theory of groups acting on graphs. A key role in our approach is played by a transitive action of the automorphism group of the free algebra on two generators on the Calogero-Moser varieties. (Received September 13, 2018)

1145-20-750 **Javad Namazi**, 285 Madison Avenue, Madison, NJ 07940, **Ali Moghani*** (amoghani@cnr.edu), The College of New Rochelle, 29 Castel Place, New Rochelle, NY 10805, and **John Najarian**. *Computational algebraic geometry theory for chemical structures.* Preliminary report.

We state a theorem for the relation between the Q-conjugacy characters, their degree and reduction by the Hermitian symmetric sequlinear form for an arbitrary finite group. The results are then checked on the symmetry of the molecule Trimethylamin-BH3 (BH3 free of rotation). (Received September 13, 2018)

1145-20-798 **Jordan Bounds***, boundsj@bgsu.edu, and **Xiangdong Xie**. *On the quasi-isometric rigidity of a class of right-angled Coxeter groups.*

Given a finite simplicial graph Γ with vertex set $V(\Gamma)$ and edge set $E(\Gamma)$, there is an associated right-angled Coxeter group (RACG) W_Γ given by the presentation

$$W_\Gamma = \langle v \in V(\Gamma) | v^2 = 1 \text{ for all } v \in V(\Gamma); v_1 v_2 = v_2 v_1 \text{ if and only if } (v_1, v_2) \in E(\Gamma) \rangle.$$

While recent results have furthered the understanding of the large scale geometry of RACGs, the quasi-isometric classification of these groups is still wide open. In this talk we establish quasi-isometric rigidity for the class of RACGs with defining graphs joins of finite generalized thick m-gons where $m \geq 3$. In particular, we show that the corresponding right-angled Coxeter groups for this particular class are quasi-isometric if and only if their defining are isomorphic. (Received September 14, 2018)

1145-20-809 **Funda Gultepe***, funda.gultepe@utoledo.edu, toledo, OH 42606. *Generating fully irreducible outer automorphisms of the free group.*

Fully irreducible outer automorphisms of the free group on n-letters are characterized by the property that no power of them fixes a conjugacy class of a free factor. These outer automorphisms exhibit many similarities to the pseudo Anosov surface homeomorphisms, as such we follow some methods from theory of mapping class group to determine ways to construct fully irreducible outer automorphisms. To this end, we refer to the *double handlebody* n–connected sum of $S^2 \times S^1$ which provides a simplicial complex on which the outer automorphism group of the free group acts. We thus use 3– dimensional topological methods to construct outer automorphisms via their action on such a simplicial complex. (Received September 15, 2018)

1145-20-849 **Luise-Charlotte Kappe*** (menger@math.binghamton.edu) and **Elizabeth Wilcox**. *A generalization of the Chermak-Delgado lattice to words in two variables.*

The Chermak-Delgado measure of a subgroup H of a finite group G is defined as the product of the order of H with the order of the centralizer of H in G, $|H||C_G(H)|$, and the set of all subgroups with maximal Chermak-Delgado measure forms a dual sublattice of the subgroup lattice of G. In this talk we step back from centralizers and consider four types of centralizer-like subgroups, defined using general words in the alphabet $\{x, y, x^{-1}, y^{-1}\}$ instead of the specific commutator word. We show that this generalization results in four sublattices of the subgroup lattice of a finite group, some of which may be equal to one another depending on the word. We consider which properties of the Chermak-Delgado lattice generalize to the new lattices, and which properties are specialized in the Chermak-Delgado lattice. (Received September 16, 2018)

1145-20-886 **Clément Jacques Etienne Guérin*** (clement.guerin@uni.lu), Mathematics Research Unit, Maison du nombre, 6 avenue de la Fonte, 2449 Esch-Sur-Alzette, Luxembourg. *Bad subgroups in complex reductive groups.*

Schur's lemma states that the centralizers of irreducible linear subgroups (or linear representations) is the group of invertible scalar matrices. Depending on the way we extend the notion of irreducibility in complex reductive groups, Schur's lemma may or may not be true anymore. Conjugacy classes of irreducible representations commuting with non-central elements generally appear to be singular points of character varieties. After discussing the different notions of irreducibility in complex reductive groups, we shall see how to construct counter-examples to Schur's lemma in complex reductive groups. We will end up by explaining some consequences for the study of the bad locus in character varieties. (Received September 17, 2018)

1145-20-934 **Lisa A DeMeyer*** (demey1la@cmich.edu), Department of Mathematics, Pearce Hall 216, Mount Pleasant, MI 48859. *Clique Homology and the Zero-Divisor graph problem.*

The zero-divisor graph associated to a commutative ring R is the graph whose vertices are labeled by the nonzero zero divisors of R and where two distinct vertices x and y are adjacent in case $xy = 0$ in R. This graph has been studied extensively since it was first introduced by Beck in 1988. The study of the zero-divisor graph has been extended to other contexts, including commutative semigroups, the set of ideals of a ring, semilattices, lattices, posets, Boolean monoids, and groupoids. A simplicial complex using cliques was introduced by F. DeMeyer and L. DeMeyer in 2005 for the zero-divisor graph of a commutative semigroup , and which can be used to study the zero divisor graph in each of the contexts above. In this talk, we will discuss the use of clique homology to study the zero-divisor graph, including applications to the zero divisor graph of a semigroup and to the zero divisor graph of a ring. (Received September 17, 2018)

1145-20-1005 **Nham Vo Ngo*** (nvngo@ung.edu), Department of Mathematics, University of North Georgia - Gainesville, Oakwood, GA 30566. *Zariski Topology of Group Cohomology Rings.*

In this talk, we give a brief survey of the group cohomology theory and its interaction with Zariski topology of commutative rings. In particular, let G be a group defined over a field of prime characteristic p. The direct sum of all the even degree cohomology spaces $\bigoplus_{n\geq 0} \mathrm{H}^{2n}(G, k)$ has a commutative ring structure under the cup product. We investigate the Zariski topology of the maximal spectrum of this ring for various types of the group G. (Received September 18, 2018)

1145-20-1008 **Jonathan Scott Brown***, 260 Fitzelle Hall, SUNY Oneonta, Oneonta, NY 13820. *Finite W-algebra invariants.* Preliminary report.

Finite W-algebras are intimately related to the geometry of nilpotent orbits and the infinite dimensional representation theory of Lie algebras. They are defined in terms of a nilpotent orbit, and they are an invariant subalgebra of a left ideal in universal enveloping algebra of a reductive Lie algebra. Outside of type A there is no known formula for calculating generators of these algebras (apart from specific examples). Recent work by Kac, De Sole, and Valeri has produced a formula which produces generators of an important subalgebra of a finite W-algebra, and in this work we extend their results. This results in a formula for generators of more classes of finite W-algebras. (Received September 18, 2018)

1145-20-1119 **Hung P Tong-Viet*** (tongviet@math.binghamton.edu), Department of Mathematical Sciences, Binghamton University, Binghamton, NY 13902. *Brauer characters and normal Sylow p-subgroups.*

The celebrated Itô-Michler theorem for Brauer characters states that if a prime p does not divide the degrees of any irreducible p-Brauer characters of a finite group G, then G has a normal Sylow p-subgroup. In this talk, I will discuss several generalizations of this theorem using various inequalities involving p-parts and p'-parts of the p-Brauer character degrees. (Received September 19, 2018)

1145-20-1501 **Amrita Acharyya***, amrita.acharyya@utoledo.edu, and **Jon M Corson** and **Bikash C Das**. *Cofinite groupoids and their profinite completions.*

Cofinite graphs and groupoids are defined in a unified way extending the notion of cofinite group introduced by Hartley. These objects have in common an underlying structure of a directed graph endowed with a certain type of uniform structure, called a cofinite uniformity. Much of the theory of cofinite directed graphs turns out to be completely analogous to that of cofinite groups. For instance, the completion of a directed graph Γ with respect to a cofinite uniformity is a profinite directed graph and the cofinite structures on Γ determine and distinguish all the profinite directed graphs that contain Γ as a dense sub-directed graph. The completion of the underlying directed graph of a cofinite graph or cofinite groupoid is observed to often admit a natural structure of a profinite graph or profinite groupoid, respectively. (Received September 22, 2018)

1145-20-1811 **Jonathan I Hall*** (`jhall@math.msu.edu`), Department of Mathematics, Michigan State University, 619 Red Cedar Road, East Lansing, MI 48840. *Configurations, groups, and algebras.*

Dating back at least to Hilbert (1900) the closure of certain geometric configurations has been linked to the existence of certain automorphisms and thereby to the classification of related algebras. The canonical example is due to Veblen and Young (1916) and relates Desargues configurations in projective space with the existence of central collineations and then to coordinatization by division rings. We explain such connections and present recent work in this spirit. (Received September 24, 2018)

1145-20-1834 **Alexander M. Heaton**, 3200 N. Cramer St., Milwaukee, WI, **Songpon Sriwongsa**, 3200 N. Cramer St., Milwaukee, WI 53211, and **Jeb F. Willenbring*** (`jw@uwm.edu`), 3200 N. Cramer St., Milwaukee, WI 53211. *Embedding $\mathfrak{sl}_k$ in $\mathfrak{sl}_n$ as a small subalgebra and the representations of the symmetric group.* Preliminary report.

In joint work with Gregg Zuckerman the notion of a *small* subalgebra was introduced. That is, given a simple Lie algebra $\mathfrak{g}$ and a simple subalgebra $\mathfrak{k}$, we say that $\mathfrak{k}$ is *small* in $\mathfrak{g}$ if there exists a positive integer b (depending only on $\mathfrak{g}$ and $\mathfrak{k}$) such that in the restriction to $\mathfrak{k}$ of each finite dimensional representation of $\mathfrak{g}$ there exists an irreducible $\mathfrak{k}$-representation of dimension at most b.

We assume the field is $\mathbb{C}$. Let $n \geq 3$. Given any subalgebra, $\mathfrak{k}$, of $\mathfrak{sl}_n$, if $\mathfrak{k} \cong \mathfrak{sl}_2$ then $\mathfrak{k}$ is small in $\mathfrak{sl}_n$. In joint work with Hassan Lhou the speaker found that n is a best possible bound b in this case.

The question of when $\mathfrak{k} \cong \mathfrak{sl}_k$ is small in $\mathfrak{sl}_n$ is related to the notion of plethysm. Using a well understood interpretation of plethysm, we relate the question of small $\mathfrak{k} \cong \mathfrak{sl}_k$ to the representation theory of the symmetric group. (Received September 24, 2018)

1145-20-1856 **Stephen M. Gagola, Jr.*** (`gagola@math.kent.edu`), Department of Mathematics, 1300 University Esplanade, Kent State University, Kent, OH 44242. *Latin Squares from Zoomorphic Images and Orthomorphisms of Groups.* Preliminary report.

The artist Peter Raedschelders has produced an example of a Latin Square of size 8×8 in which the 8 symbols used are the 4 rotations and 4 reflections of a tile obtained by deforming the edges of a square. The tiles are zoomorphic images and have no individual symmetry, but fit together snugly in the style of M. C. Escher to produce the Latin Square. The artist asks whether the tiles can be colored using 8 colors so that the resulting coloration also produces a Latin Square that is orthogonal to the original. We use an orthomorphism of the dihedral group D_8 to find this orthogonal mate, and discuss the problem of finding orthomorphisms of groups in general. (Received September 24, 2018)

1145-20-2087 **Catherine Buell**, **Aloysius Helminck**, **Vicky Klima**, **Jennifer Schaefer**, **Carmen Wright*** (`carmen.m.wright@jsums.edu`) and **Ellen Ziliak**. *On the Structure of Generalized Symmetric Spaces of $SL_n(\mathbb{F}_q)$.*

Symmetric spaces were introduced by Élie Cartan as a special class of homogeneous Riemannian manifolds. Since then a rich and deep theory has been developed. This theory plays a key role in many fields of active research such as Lie theory, number theory, differential geometry, harmonic analysis and physics. The theory of symmetric spaces has numerous generalizations including reductive symmetric spaces, symmetric varieties, and symmetric k-varieties. In this talk, the structure of the generalized and extended symmetric spaces for $\mathrm{SL}_n(k)$ where k is a finite field of odd characteristic will be presented for the inner and outer involutions of $\mathrm{SL}_n(k)$. (Received September 24, 2018)

1145-20-2121 **Risto Atanasov** (ratanasov@email.wcu.edu), **Adam Gregory*** (adgregory1@catamount.wcu.edu), **Luke Guatelli** (lrguatelli1@catamount.wcu.edu) and **Andrew Penland** (adpenland@email.wcu.edu). *The Powerful Subgroup Covering Number of Dihedral 2-Groups.* Preliminary report.

A finite p-group G is called *powerful* if either p is odd and $[G, G] \subseteq G^p$ or $p = 2$ and $[G, G] \subseteq G^4$. A *cover* for a group is a collection of subgroups whose union is equal to the entire group. We will discuss covers of p-groups by powerful subgroups. The size of the smallest cover of a p-group by powerful subgroups is called the *powerful subgroup covering number*. Our focus in this presentation is to determine the powerful subgroup covering number of the Dihedral 2-groups. (Received September 24, 2018)

1145-20-2182 **Kassie Archer** and **Humberto Bautista Serrano*** (hbautistaserrano@patriots.uttyler.edu), Department of Mathematics, University of Texas at Tyler, 3900 University Blvd., Tyler, TX 75799, and **Kayla Cook**, **Lindsey-Kay Lauderdale**, **Yansy Perez** and **Vincent Villalobos**. *Intersections of maximal subgroups of finite groups.* Preliminary report.

In a popular paper of Cohn, the concept of a covering number of a group was introduced. The *covering number* of a finite group G is the smallest number of proper subgroups of G whose set-theoretic union is G. Covering numbers are the subject of prior research by numerous authors, and in this talk we focus on a dual problem to that of covering numbers of groups, which involves maximal subgroups of finite groups. In addition, we will compare our results to some of the well-known results on covering numbers. (Received September 25, 2018)

1145-20-2368 **Arturo Magidin*** (magidin@louisiana.edu), Mathematics Department, University of Louisiana at Lafayette, P.O. Box 43568, Lafayette, LA 70504-3568. *The Chermak-Delgado lattice of a 2-nilpotent product.* Preliminary report.

If G is a finite group, $H \leq G$, the Chermak-Delgado measure of H is $m_G(H) = |H||C_G(H)|$. The collection of subgroups of G for which the Chermak-Delgado measure is as large as possible is the Chermak-Delgado lattice of G, $\mathcal{L}(G)$. It is known that the Chermak-Delgado lattice of a direct product is the direct product of the Chermak-Delgado lattice: $\mathcal{L}(G_1 \times G_2) = \mathcal{L}(G_1) \times \mathcal{L}(G_2)$. We consider the question of how $\mathcal{L}(G_1 \amalg^{\mathfrak{N}_2} G_2)$ may be related to $\mathcal{L}(G_1)$ and $\mathcal{L}(G_2)$, where $G_1 \amalg^{\mathfrak{N}_2} G_2$ is the 2-nil product of G_1 and G_2, $G_1 * G_2/([G_1, G_2] \cap (G_1 * G_2)_3$, where $G_1 * G_2$ is the free product and $(G_1 * G_2)_3$ is the third term of the lower central series of $G_1 * G_2$. (Received September 25, 2018)

1145-20-2416 **María A. Aviñó-Díaz**, **Phill Schultz** and **Marcos Zyman***, Mathematics Department, 199 Chambers Street, Room N-599, New York, NY 10007. *The upper central series of the maximal p-subgroup of a group of automorphisms.*

Let G be a bounded abelian p-group, with automorphism group $Aut(G)$. We determine the upper central series and nilpotency class of the maximal normal p-subgroup of $Aut(G)$. In this talk we impose a condition on the p-rank of the component of G of maximal exponent. We expect our techniques to eventually yield a complete solution. (Received September 25, 2018)

1145-20-2502 **Joanna B Fawcett** and **Chase P Vogeli*** (cpvogeli@mit.edu). *On the Saxl graphs of a family of permutation groups.*

There is a long tradition of constructing graphs that encode interesting properties of groups. Recently, the Saxl graph was introduced by Burness and Giudici to encode information about bases of permutation groups. A base for a permutation group G acting on a set Ω is a subset of Ω with a trivial pointwise stabilizer in G. The base size of G is the minimal cardinality of a base for G, and permutation groups with base size 2 are of particular interest. The Saxl graph of G, denoted $\Sigma(G)$, is a graph with vertices Ω in which two vertices are adjacent if they form a base for G. It is conjectured that in the Saxl graph of a primitive group with base size 2, any two vertices have a common neighbor. We consider the Saxl graphs of a family of primitive groups constructed using the natural action of the dihedral group of order $2p$ on the regular p-gon for a prime p. For this family of groups, we prove a strong form of the conjecture, namely that the Saxl graphs are strongly regular. We also determine their automorphism groups, which are related to the unique irreducible 2-dimensional representation of the dihedral group of order 8. (Received September 25, 2018)

1145-20-2522 **Alexei Miasnikov***, amiasnikov@gmail.com. *Diophantine problems in groups and algebras.*

During the last several years it was a remarkable progress in solving equations in groups and algebras. I will discuss some new general methods to reduce Diophantine problems in large classes of groups and algebras to some specific algorithmic problems in number theory. (Received September 25, 2018)

1145-20-2638 **Saikat Das*** (joysaikat@gmail.com), 13 Donald Street, Apt D, Bloomfield, NJ 07003.
Thickness of Out($A_1 * ... * A_n$).

Behrstock-Druţu-Mosher introduced algebraic thickness of finitely generated groups to decide non-relative hyperbolicity of a large collection of geometrically interesting groups, such as mapping class groups and outer automorphism groups for all but finitely many cases.

In this talk, we will study hyperbolicity, relative hyperbolicity and thickness of Out($A_1 * ... * A_n$), where each A_i is a finite group. The geometric models for these groups will be Guirardel-Levitt deformation spaces, which are generalization of Culler-Vogtmann outer spaces. We will use these geometric models to find a virtual generating set and some suitable undistorted subgroups for our investigation. (Received September 25, 2018)

1145-20-2813 **Isabella Diaz*** (idiaz16@stac.edu), 6 Stanley Street, Dumont, NJ 07628. *Swarms and Group Theory.* Preliminary report.

Group theory is used describe and predict countless events and swarms will be the next. Many of these biological groups exhibit behaviors that may be able to be connected by guidelines of algebraic group theory. These behaviors include a maximum and minimum distance between group members and a collective between them, such as direction of movement. These behaviors are currently being researched using differential equations. However, we believe that we are the first to study them using group theory. We investigate the group-like structure of swarms and seek to develop how these structures work with each other by taking advantage of the similarity to groups. The symmetrical tendencies behavioral patterns exhibit will be crucial in understanding the way swarms operate. Swarms often depend of environmental conditions and mate recognition with the largest density of individuals concentrated in the center of the swarm according to a 2009 study by Manoukis et. al. (Received September 25, 2018)

1145-20-2945 **Angela Kraft*** (akraft@math.arizona.edu). *Constructing Basic Algebras.*

To study representations of a group algebra FG, it is often beneficial to study a generally much smaller algebra whose module category is equivalent to the module category of FG. This generally much smaller algebra is known as the basic algebra. In the case where G is a finite simple group, K. Lux has developed algorithmic methods for computing the basic algebra of FG. We will discuss basic algebras and how to extend the computational methods of K. Lux to the case where G is a central extension of a finite simple group. (Received September 25, 2018)

22 ► *Topological groups, Lie groups*

1145-22-502 **Sebastian Hurtado*** (shurtados@math.uchicago.edu), Chicago, IL 60615. *Rigidity of lattices of Lie groups: Geometry and Dynamics.*

I will discuss some famous theorems about the rigidity of manifolds with a hyperbolic metric and more type geometries (associated to Lie groups). The talk will be informal and require few basic notions about Lie groups. (Received September 07, 2018)

1145-22-572 **Jacksyn Bakeberg** (jacksyn.bakeberg@mail.mcgill.ca), **Kathryn Blaine** (kb7124@bard.edu) and **Firas Hindeleh*** (hindelef@gvsu.edu), 1 Campus Dr, Allendale, MI 49401. *Classification of seven-dimensional solvable Lie algebras with five-dimensional nilradical.* Preliminary report.

Low dimensional solvable Lie Algebras were completely classified up to dimension six. A general theorem asserts that if g is a solvable Lie Algebra of dimension n, then the dimension of its nilradical is at least $\frac{n}{2}$. For the seven-dimensional algebras, the nilradical‘s dimension could be 4, 5, 6 or 7. We give an update on this project and share our contribution to the five-dimensional nilradical case. This research was conducted as part of the 2018 REU program at Grand Valley State University. (Received September 10, 2018)

1145-22-675 **Alfred G Noel*** (alfred.noel@umb.edu), 100 Morrissey Blvd, Boston, MA 02125, and **Steven Glenn Jackson**, **Todor Milev** and **Thomas Folz-Donahue**. *Algorithms for Computing Tau Signatures.*

Let $\mathfrak{g}$ be a complex reductive Lie algebra with Weyl group W. We describe algorithms by which one can read off the complex nilpotent orbit associated with a cell representation of W. Given any representation V of W we define the *sign signature* of V *signSignatureV* to be the set of all parabolic subgroups $P \subseteq W$ (relative to a fixed simple basis) such that $V_{|P}$ contains a copy of the sign representation of P. The sign signature depends only on the conjugacy class of P.

For W of classical type, we show that the irreducible representations of W are determined by their sign signatures, and we give a simple algorithm by which one can use the sign signature to find the partition or partition-pair indexing a given irreducible representation. The parametrization of irreducible representations using sign signatures fails for the exceptional Weyl groups. But we show that the extended sign signature determines uniquely the irreducible representations of W in general.

Finally, we obtain a simple method which computes the nilpotent orbit associated with the cell representation of W directly from its τ-invariants. These algorithms are being implemented in the Atlas of Lie Groups and Representations international project. (Received September 12, 2018)

1145-22-1346 **Manuel A. Morón*** (mamoron@mat.ucm.es), Depto. Algebra, Geometria y Topologia, Facultad de Ciencias Matemáticas., Universidad Complutense de Madrid, 28040 Madrid, Madrid, Spain. *Characteristic curves for a family of linear PDEs and the exponential map in the Lie group of Riordan matrices.*

In this talk, using [2], I am going to analyze the following consequence of Corollary 24 in [1].

If we are able to solve the associated linear problem (for example by the characteristic method) then we obtain the exponential matrix of the generator. On the opposite if we are able to compute the corresponding one-parameter group (and then the exponential) we will find the characteristic curves of the corresponding linear first order partial differential equation.

[1] G.-S. Cheon, A. Luzon, M. A. Moron, L. F. Prieto-Martinez and M. Song *Finite and infinite dimensional Lie group structures on Riordan groups.* Adv. Math. 319 (2017) 522-566.

[2] F. John. *Partial Differential Equations.* Applied Mathematical Sciences 1. Third Edition. Springer-Verlag. (1980.) (Received September 21, 2018)

1145-22-1916 **Manoj Lamichhane*** (manoj.lamichhane@uwc.edu), 1500 N University Dr, Waukesha, WI 53188. *Minimal representations of Lie algebras with non-trivial Levi decomposition.* Preliminary report.

We found simple subalgebras of $gl(5, R)$ together with their representations comprising seventeen in all. The semi-simple subalgebras of $gl(5, R)$ are then found together with their representations comprising six cases in total. Each such semi-simple subalgebra acts by commutator on $gl(5, R)$ and the resulting representations are fully decomposed. The results are used to determine all possible solvable extensions of a given semi- simple subalgebra and hence all Levi subalgebras of $gl(5, R)$ are determined up to isomorphism allowing also for the use of companion subalgebra. In this talk, we will present how some of the above Levi Subalgebra are used to find the minimal dimension matrix representations for each of the Lie algebras of dimensions five, six, seven and eight obtained by Turkowski that have a non-trivial Levi decomposition. The key technique involves using the invariant subspaces associated to a particular representation of a semi-simple Lie algebra to help in the construction of the radical in the putative Levi decomposition. (Received September 24, 2018)

1145-22-2528 **Joseph Wells*** (joseph.wells@asu.edu), Arizona State University, WXLR Room 216, 901 S. Palm Walk, Tempe, AZ 85287-1804. *Hybrid subgroups of complex hyperbolic lattices.* Preliminary report.

In the 1980's Gromov and Piatetski-Shapiro presented a technique called "hybridization" wherein one starts with two arithmetic hyperbolic lattices and uses them to produce new hyperbolic lattices (and notably, nonarithmetic lattices). It has been asked whether there exists an analogous hybridization technique for complex hyperbolic lattices. In this talk I'll present a potential candidate hybridization technique and some recent results for both arithmetic and nonarithmetic lattices in PU(2,1). Some of this is joint work with Julien Paupert. (Received September 25, 2018)

1145-22-2724 **Paramasamy Karuppuchamy*** (paramasamy@gmail.com). *On Schubert varieties.*

In this talk we show that a Schubert variety X_w is a toric variety if and only if the Weyl group element w is a product of distinct simple reflections. Part of this result can be found (not explicitly mentioned) in Deodhar's article " On some geometric aspects of Bruhat orderings. I. A finer decomposition of Bruhat cell ". The author was unaware of this fact while writing his article. In A_n type, Masuda and Lee have different approach to get this result in their recent paper" Generic torus orbit closure in Schubert varities". (Received September 25, 2018)

1145-22-2790 **David Baraglia** (david.baraglia@adelaide.edu.au), School of Mathematical Sciences, the University of Adelaide, Adelaide, SA 5005, Australia, **Chi-Kwong Fok*** (chi-kwong.fok@adelaide.edu.au), School of Mathematical Sciences, the University of Adelaide, Adelaide, SA 5005, Australia, and **Varghese Mathai** (mathai.varghese@adelaide.edu.au), School of Mathematical Sciences, the University of Adelaide, Adelaide, SA 5005, Australia. *Twisted K-theory of compact Lie groups and extended Verlinde algebras.* Preliminary report.

In a series of recent papers, Freed, Hopkins and Teleman put forth a deep result which identifies the twisted K-theory of a compact Lie group G with the representation theory of its loop group LG. Under suitable conditions, both objects can be enhanced to the Verlinde algebra, which appears in mathematical physics as the Frobenius algebra of a certain topological quantum field theory, and in algebraic geometry as the algebra encoding information of moduli spaces of G-bundles over Riemann surfaces. In this talk, I will present partial results on an extension of the Verlinde algebra with disconnected G, with a view towards its relation to a generalisation of moduli spaces called twisted moduli spaces proposed recently by E. Meinrenken. The talk is based on work in progress joint with David Baraglia and Varghese Mathai. (Received September 25, 2018)

1145-22-2919 **Ehssan Khanmohammadi*** (khanmohe@union.edu). *Some Plancherel-type formulas for Lie groups.*

We present some Plancherel-type formulas that originate from the orbit method and our study of Kirillov's character formula for various Lie groups. Then we discuss some approaches to generalizing these formulas to larger classes of Lie groups. (Received September 25, 2018)

1145-22-2929 **Bob Palais*** (bob.palais@uvu.edu). *Computational advantages and historical insights from viewing quaternionic interpolation of three-dimensional rotations as geodesic vector interpolation on S^2.*

We compare three methods for interpolating two three-dimensional rotations: Directly in $SO(3)$ matrix form; Using the Euler transform from $S^3 \to SO(3)$; Using the analog of ordinary vector interpolation for directed geodesic arcs on S^2. We also compare the spherical triangles used by Euler and Rodrigues to locate an axis for general and composed rotations, and note an interesting consequence of the spherical triangles of Harriot and Girard. (Received September 25, 2018)

26 ► Real functions

1145-26-423 **Tessa Murthy*** (tessa.murthy@yale.edu), P.O. Box 200799, 206 Elm Street, New Haven, CT 06520. *Sequences of Ratios of 1-Periodic Functions.*

Sequences of Ratios of 1-Periodic Functions

T. Murthy, supervised by S. Steinerberger

Consider the sequence of functions $f_n = \sum_{k=1}^{n} \frac{|sin(kx\pi)|}{k}$. Steinerberger [2016] proves that this function has a strict local minimum at all rational points $x = \frac{p}{q}$ where $|q| \leq \sqrt{n}$. There is a family of closely related functions

$$F_n(x) = \sum_{k=1}^{n} \frac{G(kx)}{H(k)},$$

where G is a 1-periodic continuous function and H is convex. Among these is the well-known Takagi blancmange function, which is known to have several interesting properties and has been used in extremal combinatorics.

Regarding the Steinerberger function, we provide bounds on local maxima (in particular, they cannot be too closely approximated by rational points with denominators less than $\sqrt{n}$) and seek to determine an approximating function for the enveloping curve. We also consider various functions of the form $F(x)$ and explore the self-similarity properties of $F_\infty(x)$ when it converges. (Received September 05, 2018)

1145-26-1542 **DoYong Kwon*** (doyong@jnu.ac.kr), Department of Mathematics, Chonnam National University, Gwangju, 61186, South Korea. *A singular function from Sturmian continued fractions.*

For $\alpha \geq 1$, let $s_\alpha(n) = \lceil \alpha n \rceil - \lceil \alpha(n-1) \rceil$. A continued fraction $C(\alpha) = [0; s_\alpha(1), s_\alpha(2), \ldots]$ is considered and analyzed. Appealing to Diophantine approximation, we investigate the differentiability of $C(\alpha)$, and then show its singularity: $C'(\alpha) = 0$ for almost every α. (Received September 23, 2018)

1145-26-2274 **Javad Namazi*** (namazi@fdu.edu), Madison, NJ 07940. *For which geometric object , its shape can be heard?* Preliminary report.

There has been a wealth of research into the question of for which geometric object, its shape can be heard. We look into some recent research in this area. (Received September 25, 2018)

28 ► Measure and integration

1145-28-1718 **Michael Hinz*** (mhinz@math.uni-bielefeld.de) and **Daniel J. Kelleher**. *Differential forms on products of fractals.* Preliminary report.

During the recent years differential one-forms on fractal spaces have been studied by various authors. In this talk we consider products of fractals and explain a way to introduce higher order differential forms on them. We discuss how these forms can be approximated by antisymmetric functions on products of graphs and why this is a correct point of view. Our simple guiding example is the case of two-forms on the product of two Sierpinski gaskets. The talk is based on recent work in progress with Dan Kelleher (Mount Holyoke College). (Received September 24, 2018)

1145-28-1740 **Wei Tang** (twmath2016@163.com), College of Mathematics and Computational, Science, Hunan First Normal University, Changsha, Hunan 410205, Peoples Rep of China, and **Sze-Man Ngai*** (smngai@georgiasouthern.edu), Department of Mathematical Sciences, Georgia Southern University, Statesboro, GA 30460. *Heat equations defined by a class of fractal measures.*

We set up a framework to study one-dimensional heat equations defined by fractal Laplacians associated with self-similar measures with overlaps. We show that for a class of such self-similar measures, a heat equation can be discretized and the finite element method can be applied to yield a system of linear differential equations. We show that the numerical solutions converge to the actual solution and obtain the rate of convergence. We also study some properties of the solutions of the heat equation. (Received September 24, 2018)

1145-28-2527 **Irfan Alam*** (irfanalamisi@gmail.com), Department of Mathematics, Louisiana State University, Baton Rouge, LA 70802. *Integration on the infinite sphere.* Preliminary report.

The coordinates, along any fixed direction(s), of points on the sphere $S^{n-1}(\sqrt{n})$ (equipped with the uniform surface measure $\bar{\sigma}_n$), roughly follow a standard Gaussian distribution as n approaches infinity. We revisit this classical result from the point of view of a nonstandard analyst. Fixing a "good" real-valued function f on $\mathbb{R}^k$ (and extending it canonically to $\mathbb{R}^n$ for any $n \geq k$), the classical result says that $\lim_{n\to\infty} \int_{S^{n-1}(\sqrt{n})} f d\bar{\sigma}_n = \int_{\mathbb{R}^k} f d\mu$, where μ is the standard k-dimensional Gaussian measure. A difficulty in working with such a limit is that the measure spaces are changing with n. Nonstandard analysis allows access to the "hyperfinite-dimensional sphere" $S^{N-1}(\sqrt{N})$ (where $N > \infty$), which, when equipped with the correct "surface measure", is expected to capture the large-n behavior of $S^{n-1}(\sqrt{n})$. We define the appropriate measure on $S^{N-1}(\sqrt{N})$ and show that the above limit is equal to an integral on this sphere for all μ-integrable functions f, thereby proving the classical result for the largest class of functions possible. Some background in nonstandard analysis will be provided. (Received September 25, 2018)

30 ► Functions of a complex variable

1145-30-119 **Libby Farrell** and **Andres Zumba*** (andreszumba@fresnostate.edu). *Zero Distribution of a Sequence of Polynomials with a Higher Order Three Term Recurrence.*

We study the zero distribution of a sequence of polynomials with the recurrence $P_m(z) = -B(z)P_{m-r}(z) - A(z)P_{m-n}(z)$ where n and r are relatively prime and both not equal to 1. We have shown that in the case that $n = 4$ and $r = 3$, the zeros will lie on the curve given by $\mathrm{Im}\frac{A^r(z)}{B^n(z)} = 0$ and $\mathrm{Re}\frac{A^r(z)}{B^n(z)} \geq 0$, except for values of z which satisfy $B(z) = 0$. We also give results towards determining the zero distribution of the general recurrence. (Received August 03, 2018)

1145-30-125 **Fareeda Begum*** (fareeda.begum@pg.canterbury.ac.nz), Christchurch, New Zealand, and **Ngin-Tee Koh**, Christchurch, New Zealand. *Integral means of univalent functions on an annulus.* Preliminary report.

We discuss analogues of the Schwarz lemma for holomorphic functions on an annulus. Counterexamples reveal that a pointwise version of the Schwarz lemma for holomorphic functions on an annulus would not be possible.

We also examine an integral means version of the Schwarz lemma for holomorphic functions of an annulus. It turns out that normalization and univalence both play a key role. This is joint work with Dr. Ngin-Tee Koh. (Received August 08, 2018)

1145-30-932 **Lida Ahmadi*** (lahmadi@purdue.edu) and **Mark Daniel Ward** (mdw@purdue.edu). *Asymptotics of the number of bosonic string states.*

We analyze the precise first-order asymptotics of the number of bosonic string states, by analyzing the analogous generating function. This yields a succinct approximation for the enumeration, according to mass level. Our methodology utilizes the Mellin transform and application of the saddle point method, to obtain the first-order asymptotics of the coefficients of the analogous generating function. The method of analysis resembles the Hardy–Ramanujan (refined by Rademacher) methodology for the asymptotic analysis of the number of integer partitions. (Received September 17, 2018)

1145-30-991 **See Keong Lee*** (sklee@usm.my), School of Mathematical Sciences, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia. *The monotonicity properties of a generalized Bessel function.*

The monotonicity properties of the generalized Bessel function

$$ {}_a\mathsf{B}_{b,p,c}(x) := \sum_{k=0}^{\infty} \frac{(-c)^k}{k!\,\Gamma\Big(ak+p+\frac{b+1}{2}\Big)} \left(\frac{x}{2}\right)^{2k+p}, $$

where $a \in \mathbb{N} = \{1, 2, 3, \ldots\}$ and $b, p, c, x \in \mathbb{R}$, will be discussed for $c \leq 0$. Also for a closely related function to ${}_a\mathsf{B}_{b,p,c}$, its log-convexity and log-concavity properties in terms of the parameters d and p will be respectively investigated, which would then lead to direct and reverse Turán-type inequalities. (Received September 18, 2018)

1145-30-1022 **Khang D Tran*** (khangt@mail.fresnostate.edu), Department of mathematics, 5245 North Backer Avenue M/S PB108, Fresno, CA 93740, and **Andres Zumba**. *Zeros of polynomials with four-term recurrence and linear coefficients.*

This talk studies the zero distribution of a sequence of polynomials $\{P_m(z)\}_{m=0}^{\infty}$ generated by the reciprocal of $1+ct+B(z)t^2+A(z)t^3$ where $c \in \mathbb{R}$ and $A(z)$, $B(z)$ are real linear polynomials. We find necessary and sufficient conditions for the reality of the zeros of $P_m(z)$. Under these conditions, we find an explicit interval containing these zeros, whose union forms a dense subset of this interval. (Received September 18, 2018)

1145-30-1257 **Zair Ibragimov*** (zibragimov@fullerton.edu). *Transfinite Apollonian Metric.* Preliminary report.

I will discuss the concept of transfinite ζ-metrics. In some details I will discuss transfinite Apollonian metric in the settings of semi-metric spaces. I will discuss specific examples of domains where the transfinite Apollonian metric can be computed explicitly. (Received September 20, 2018)

1145-30-1370 **Tim Ferguson*** (tjferguson1@ua.edu). *Equivalence among variable exponent Hardy or Bergman spaces.*

We study the question of when two weighted variable exponent Bergman spaces or Hardy spaces are equivalent. As an application, we show that variable exponent Hardy spaces have a close relation to classical Hardy spaces when the exponent is log-Hölder continuous and has bounded harmonic conjugate (when extended from its boundary values to be harmonic in the disc). We use this to characterize Carleson measures for these variable exponent Hardy spaces. We also prove under certain conditions an analogue of Littlewood subordination and a result on the boundedness of composition operators. (Received September 21, 2018)

1145-30-1432 **Bonita V Saunders*** (bonita.saunders@nist.gov), 131 Goucher Terrace, Gaithersburg, MD 20877. *Complex Variables, Mesh Generation, and 3D Web Graphics: Research and Technology Behind the Dynamic Visualizations in the NIST Digital Library of Mathematical Functions.*

In 2010, the National Institute of Standards and Technology (NIST) launched the Digital Library of Mathematical Functions (DLMF) (https://dlmf.nist.gov), a free online resource containing definitions, recurrence relations, differential equations and other crucial information about mathematical functions useful to researchers working in various application areas in the mathematical and physical sciences. Although the DLMF was designed to replace the widely cited NBS Handbook of Mathematical Functions (Abramowitz & Stegun), the goal was to go far beyond a book on the web, incorporating web tools and technologies for accessing, rendering and searching math and graphics content [1]. This talk will focus on the research and implementation challenges in developing the graphs and surface visualizations for the DLMF and take a brief look at ongoing and future research.

Reference
[1] B. Schneider, B. Miller, B. Saunders. NIST's Digital Library of Mathematical Functions. Physics Today, 71(2):48-53, 2018, https://doi.org/10.1063/PT.3.3846. (Received September 21, 2018)

1145-30-2624 **Stacey Muir*** (stacey.muir@scranton.edu), Mathematics Department, The University of Scranton, Scranton, PA 18510. *Convolutions of Normalized Harmonic Mappings.* Preliminary report.

Recent results on the convolution of two planar harmonic mappings is built on the idea that when the convolution of functions from certain normalized families of mappings, such as half-plane or strip mappings, is locally univalent, then the convolution will possess certain direction-convexity properties. Thusly, much of the latest work on harmonic convolutions centers around establishing conditions on the dilatations of $f_1, f_2 : \mathbb{D} \to \mathbb{C}$ from the families above so that $f_1 * f_2$ is locally univalent. We will discuss how these results are impacted by dilatations that do not fix zero and broaden the families from which f_1 and f_2 are chosen. (Received September 25, 2018)

1145-30-2809 **Kourosh Tavakoli*** (ktavakoli@okcu.edu). *On the Limit Behavior of Iterated Function Systems of Holomorphic Maps.*

In this research, I studied the iterated function systems composed of holomorphic maps. I investigated some conditions that are related to the limit behavior of iterated function systems. I have also discussed several interesting examples. (Received September 25, 2018)

31 ► Potential theory

1145-31-1402 **Sizhen Fang**, **Dylan A. King**, **Eun Bi Lee*** (el542@cornell.edu) and **Robert S. Strichartz**. *Spectral Decimation for Families of Self-Similar Symmetric Laplacians on the Sierpinski Gasket.*

We construct a one-parameter family of Laplacians on the Sierpinski Gasket that are symmetric and self-similar for the 9-map iterated function system obtained by iterating the standard 3-map iterated function system. Our main result is the fact that all these Laplacians satisfy a version of spectral decimation that builds a precise catalog of eigenvalues and eigenfunctions for any choice of the parameter. We give a number of applications of this spectral decimation. We also prove analogous results for fractal Laplacians on the unit Interval, and this yields an analogue of the classical Sturm-Liouville theory for the eigenfunctions of these one-dimensional Laplacians. (Received September 21, 2018)

1145-31-1425 **Anders Bjorn** (anbjo@liu.se), , Sweden, **Jana Bjorn** (jabjo@liu.se), , Sweden, and **Nageswari Shanmugalingam*** (shanmun@uc.edu), Department of Mathematical Sciences, P.O. Box 210025, University of Cincinnati, Cincinnati, OH 45221-0025. *Liouville type theorems for p-harmonic functions in metric measure spaces.*

Classical Liouville theorem states that there is no bounded non-constant analytic function on the complex plane. Versions Liouville theorems were then subsequently given for harmonic functions (non-negative harmonic functions on the Euclidean space are constant, bounded harmonic functions on the Euclidean spaces are constant etc.). Given the analysis of p-harmonic functions ($1 < p < \infty$) on complete manifolds where the volume is a doubling measure supporting a p-Poincare inequality, we know the Liouville type theorem stating that "there are no non-constant positive p-harmonic functions on the manifold" holds. This theorem was extended to the setting of metric measure spaces with doubling measure supporting a p-Poincare inequality about 18 years ago. In this talk we will describe a Liouville type theorem in this general non-smooth setting for p-harmonic functions with globally finite energy. (Received September 21, 2018)

1145-31-1633 **Loredana Lanzani***, Department of Mathematics, Syracuse University, Syracuse, NY 13244, and **Malabika Pramanik**. *On the symmetrization of Cauchy-like kernels.* Preliminary report.

In this talk I will present new symmetrization identities for a family of Cauchy-like kernels in complex dimension one.

Symmetrization identities of this kind were first employed in geometric measure theory by P. Mattila, M. Melnikov, X. Tolsa, J, Verdera et al., to obtain a new proof of Lebesgue-space regularity of the Cauchy transform, which ultimately led to the a partial resolution of a long-standing open problem known as the Vitushkin's conjecture.

Here we extend this analysis to a class of kernels that are more closely related to the holomorphic reproducing kernels that arise in complex function theory.

This is joint work with Malabika Pramanik (U. British Columbia). (Received September 23, 2018)

1145-31-1719 **Daniel J Kelleher*** (dkellehe@mtholyoke.edu), South Hadley, MA 010175. *Differential forms on quantum graphs and Laakso spaces.* Preliminary report.

A general framework, in the setting of Dirichlet spaces, is developed to prove a weak form of the Bakry-Emery estimate and study its consequences. This estimate may be satisfied in situations, like metric graphs, where generalized notions of Ricci curvature lower bounds are not available. This is proven using semigroup domination, a beautiful, classical argument which relates the semigroup on differential forms to the heat semigroup. We discuss the application of this theory to fractals which are the limit of quantum graphs, such as Laakso spaces. Based on Joint work with P. Alonso-Ruiz, F. Baudoin, and A. Teplyaev. (Received September 24, 2018)

1145-31-2750 **Lucio M-G Prado*** (lprado@bmcc.cuny.edu), Department of Mathematics, BMCC, The City University of New York, 199 Chambers Street, New York - NY 10007, New York, NY 10007. *p-Capacity and p-Poisson Equation.* Preliminary report.

The aim of this talk is to present concepts and techniques from p-potential theory on Riemannian manifolds adapted to *infinite graphs.* We will give some overview of concepts related to p-potential theory and the states of the area on infinite graphs. In particular, we investigated the Z^n-lattice and its p-capacity to classify as p-hyperbolic or p-parabolic under specific condition in terms of p. With p-hyperbolicity /p-parabolicity, we examine surjectivity of the *p-Laplacian* and the type the solution in terms of *p-Dirichlet* spaces can be obtained to specific *p-Poisson* equations.

(Received September 25, 2018)

32 ► Several complex variables and analytic spaces

1145-32-628 **Alexandru Aleman**, **Michael Hartz** and **John E McCarthy***, Dept. of Math and Stat, Washington University, St. Louis, MO 63130, and **Stefan Richter**. *The Hardy H^1 space of a complete Pick space on the ball.*

We shall discuss what the Hardy space H^1 should be for complete Pick spaces on the ball, such as the Drury-Arveson space, and give a Nehari theorem. (Received September 11, 2018)

1145-32-1164 **Matvei Libine*** (mlibine@indiana.edu), Dept of Math, Rawles Hall, 831 East 3rd St., Bloomington, IN 47405. *New Developments in Quaternionic Analysis from the Point of View of Representation Theory.*

I will talk about recent development in quaternionic analysis from the point of view of representation theory of the conformal group $GL(2, \mathbb{H}) \approx O(5,1)$. In particular, I plan to talk about a new algebra structure on quaternionic functions that commutes with the action of $GL(2, \mathbb{H})$. I will not assume knowledge of quaternionic analysis from the audience.

This is a joint work with Igor Frenkel from Yale University. (Received September 19, 2018)

1145-32-2131 **Kate Brubaker*** (kbrubak@purdue.edu). *The homogeneous complex Monge-Ampère equation and uniform estimates for holomorphic maps into a complex manifold.* Preliminary report.

The study of the space of Kähler metrics on a compact Kähler manifold leads to a homogeneous complex Monge-Ampère equation. In 2002, Donaldson showed that the space of smooth solutions to this equation is open, when the domain is the product of the manifold with the unit disk in $\mathbb{C}$. His work employed a reformulation of the Monge-Ampère problem in terms of families of holomorphic disks in the manifold. We present a result about uniform estimates on holomorphic maps of the unit disk into a complex manifold, as a step towards apriori estimates on solutions to the equation. (Received September 24, 2018)

1145-32-2152 **Soledad Villar*** (soledad.villar@nyu.edu). *SUNLayer: stable denoising with generative models.* Preliminary report.

Recent developments in deep neural networks have produced impressive generative models for real world data. Such generative models can be successfully exploited to solve classical inverse problems like compressed sensing, phase retrieval and super resolution. In this work we focus on the classical signal processing problem of image denoising. We propose a theoretical setting that uses spherical harmonics to identify what mathematical properties of the activation functions will allow signal denoising with local methods. (Received September 24, 2018)

1145-32-2662 **Jerry R. Muir, Jr.***, Department of Mathematics, The University of Scranton, Scranton, PA 18510. *Convex families of holomorphic mappings related to the convex mappings of the ball in $\mathbb{C}^n$.*

We consider the closed convex hull of the family of convex mappings of the Euclidean unit ball $\mathbb{B} \subseteq \mathbb{C}^n$; i.e., the family of normalized biholomorphic mappings defined in $\mathbb{B}$ whose images are convex domains in $\mathbb{C}^n$. When $n = 1$ (and $\mathbb{B}$ is the unit disk $\mathbb{D}$) the closed convex hull can be described by using an integral representation derived from the Herglotz representation of analytic functions of $\mathbb{D}$ with positive real part and an elementary analytic property satisfied by convex mappings. As is typical, things are more complicated when $n \geq 2$. In that case, we will consider the natural generalization to $\mathbb{B}$ of an analytic condition characterizing the closed convex hull of the convex mappings of $\mathbb{D}$ and show that the (convex) family of mappings satisfying this condition is not the closed convex hull of the convex mappings of $\mathbb{B}$ by illustrating that the two convex sets do not have the same extreme points. (Received September 25, 2018)

33 ► Special functions

1145-33-56 **Harish Nagar*** (drharishngr@gmail.com), 2-A-16, Nagar Villa, Bapu Nagar, Bhilwara, 311001, India, and **Seema Kabra**. *Composition of Marichev-Saigo-Maeda fractional operators and generalized k-Struve function.*

The aim of present paper is to present certain new formulas using Caputo – type Marichev – Saigo – Maeda fractional integral and differential operators having the generalized k – Struve function $S^k_{\nu,c}(t)$ as one of the kernel factor. These fractional operators, when applied on k – Struve function yield the results in the form of generalized k-Wright function ${}_{\mathrm{p}}\Psi^{\mathrm{k}}_{\mathrm{q}}$. The corresponding assertion for the Saigo and Erdelyi – Kober fractional operators is also presented in this paper. (Received July 11, 2018)

1145-33-769 **Gaurav Bhatnagar*** (bhatnagarg@gmail.com) and **Mourad E. H. Ismail**. *Orthogonal polynomials associated with a continued fraction of Hirschhorn.*

We study orthogonal polynomials associated with a continued fraction due to Hirschhorn. Hirschhorn's continued fraction contains as special cases the famous Rogers–Ramanujan continued fraction and two of Ramanujan's generalizations. The orthogonality measure of the set of polynomials obtained has an absolutely continuous component. We find generating functions, asymptotic formulas, orthogonality relations, and the Stieltjes transform of the measure. Using standard generating function techniques, we show how to obtain formulas for the convergents of Ramanujan's continued fractions, including a formula that Ramanujan recorded himself as Entry 16 in Chapter 16 of his second notebook. (Received September 14, 2018)

1145-33-1723 **Sunita Nagar***, 2-A-16, Nagar Villa, Bapu Nagar, Bhilwara, and **Harish Nagar**. *Composition of pathway fractional integral operator on generalized k - Wright function.*

In this paper, the Pathway Fractional Integral operator is applied to the generalized K-Wright function. This fractional operator when applied to the power multiples of the generalized K-Wright function ${}_p\Psi^k_q$ yields a higher ordered generalized K-Wright function, namely ${}_{(p+1)}\Psi^k_{(q+1)}$. One special case of the main results given here is also considered to correspond with known result. (Received September 24, 2018)

34 ► Ordinary differential equations

1145-34-60 **Chris McCarthy*** (cmccarthy@bmcc.cuny.edu), BMCC CUNY, Dept. of Math, 199 Chambers Street, New York, NY 10007. *Virtual Experiments and Differential Equations Models.*

In this context, "virtual experiments" are videos or photos of an actual physical experiment, or a computer simulation, from which data can be culled, and which can be modeled using differential equations. I will discuss examples of virtual experiments, some created by students. I will discuss their production, usage, and their dissemination online on the City University of New York's (CUNY) Academic Commons, as part of an Open Educational Resources (OER) initiative funded by CUNY and the NYS Dept of Education. (Received July 15, 2018)

1145-34-260 **Rocio Marilyn Caja Rivera** (rcajariv@nd.edu), Department of Biological Sciences, 100 Galvin Life Science Center, Notre Dame, IN 46556, and **Alfredo Villanueva*** (avillanueva@sf.edu), 2701 Spring Street, Department of Chemistry, Computer Science, an, University of Saint Francis, Fort Wayne, IN 46808. *Global Stability: Vector Feeding Preference in Vector Borne Diseases.*

This paper presents a general system of ordinary differential Equations (ODE) for vector borne diseases that includes vector feeding preferences for carrier hosts and intrinsic incubation. Where we analyze Global stability of endemic equilibrium, and this is the first time here, we use a geometric approach presented by Li and Muldowney. Moreover, we have expanded their work from three ODE system to four ODE system, and demonstrate that the endemic equilibrium is globally asymptotically stable in the interior of a region accordingly to certain conditions. As illustrations of our findings on global stability, numerical simulations are included for vector borne diseases. (Received August 26, 2018)

1145-34-316 **Zhivko S. Athanassov*** (zhivko@math.bas.bg), G. Bonchev Str. 8, Sofia, 1113. *Some Asymptotic Properties of Ordinary Differential Equations.*

For the initial value problem $x' = f(t, x)$, $x(t_0) = x_0$, we discuss the relationship between the asymptotic behaviour of a solution and the "zero" of the right-hand side, where we denote the "zero" by $y(t)$. Thus, for a given domain of the definition of f, $y(t)$ is that unique function for which $f(t, y(t)) = 0$, $t \geq t_0$. For scalar differential equations some rather general general assumptions hold. The results for oscillatory solutions are more properly characterized as stability or boundedness results rather than asymptotic properties of the solution $x(t)$. For systems of differential equations we make corresponding assumptions. The stability properties of the scalar case have analogues in n-dimensions. Asymptotic properties of systems are presented as corollaries to the results on stability. (Received September 25, 2018)

1145-34-386 **Anarina L Murillo*** (amurillo@uab.edu), **Muntaser Safan**, **Devina Wadhera** and **Carlos Castillo-Chavez**. *Modeling the Diet Dynamics of Children: the Roles of Socialization and the School Environment.*

Childhood obesity is a health emergency in the U.S. and, consequently, identifying intervention models capable, of altering the dynamics of obesity at scales that make a difference remains a challenge. The fact that consumption of healthful foods among most youth has yet to meet recommended nutritional standards highlights a lack of effective policies aimed at addressing the epidemic of obesity. Mathematical models are used to evaluate the roles of socialization and school environment on the diet dynamics of children. Data suggest that standard nutrition education programs may have, at best, minimal impact in altering diet dynamics at the population-level. Inclusion of peer influence (model as contagion) reinforced by the use of culturally-sensitive school menus (environmental disruption) may prove capable of modifying obesity enhancing diet dynamics; altering the diets of a significant (critical) proportion of youngsters. A framework is introduced to explore the value of behavior-based interventions and policies that account for the sociocultural environments of at risk communities. These models account for the fact that when dealing with diet-dynamics systems, thinking additively is not enough as it cannot account for the power of nonlinear effects. (Received September 04, 2018)

1145-34-530 **Ismail Abdulrashid*** (iza0009@auburn.edu), Department of Mathematics and Statistics, 221 Parker Hall, Auburn University, Auburn, AL 36849, **Tomas Caraballo** (caraball@us.es), Dpto. Ecuaciones Diferenciales y Analisis, Numero, Apdo. de Correos 1160, Sevilla, Spain, and **Xiaoying Han** (xzh0003@auburn.edu), Department of Mathematics and Statistics, 221 Parker Hall, Auburn University, Auburn, AL 36849. *Effect of Delays in Mathematical Models of Cancer Chemotherapy.*

A Mathematical model of chemotherapy cancer treatment is studied where the chemotherapy agent and cells are assumed to follow a predator-prey type relation. In the model, constant delay parameters are introduced to incorporate the time lapsed from the instant the chemotherapy agent is injected to the moment it start to be effective. Existence and uniqueness of non-negative bounded solution is first established. Then both local and Lyapunov stability for all steady states are investigated. In particular, sufficient conditions dependent of the delay parameters under which each steady state is asymptotically stable are constructed. Numerical simulations are presented to illustrate the theoretical results. (Received September 08, 2018)

1145-34-712 **Lale Asik*** (lale.asik@ttu.edu), Department of Mathematics and Statistics, Texas Tech University, Broadway and Boston, Lubbock, TX 79409, and **Angela Peace**. *Dynamics of a Producer-Grazer Model Incorporating the Effects of Phosphorus Loading on Grazer's Growth.*

Recent work in ecological stoichiometry has indicated that consumer dynamics are not only affected by insufficient food nutrient content (low phosphorus (P): carbon (C) ratio) but also by excess food nutrient content (extremely high P: C ratio). This phenomenon is known as the "stoichiometric knife edge". While the Peace et al. (2014) model has captured this phenomenon, it does not explicitly track P loading of the aquatic environment. Here, we extend the Peace et al. (2014) model by mechanistically deriving and tracking P loading in order to investigate the growth response of the grazer to the producer of varying P:C ratios. We analyze the dynamics of the system such as boundedness and positivity of the solutions, existence and stability conditions of boundary equilibria. Bifurcation diagram and simulations show that our model behaves qualitatively similar but quantitatively different to the Peace et al. (2014) model. Furthermore, the structure of our model can easily be extended to incorporate seasonal phosphorus loading. (Received September 13, 2018)

1145-34-743 **Yunxiang Bai*** (yxb2781@louisiana.edu), Department of Mathematics, University of Louisiana at Lafayette, Lafayette, LA 70504, and **Aghalaya S Vatsala**. *Nonlinear Caputo Impulsive Fractional Differential Equations and Generalized Monotone Method.* Preliminary report.

It is known that Caputo fractional differential equations play an important role in modeling physical situation. The models represented by Caputo fractional differential equation in general are better and efficient models than its counterpart with integer derivative models. In this work, we consider nonlinear Caputo impulsive fractional differential equations with initial conditions. Further, the impulses occur in the non-homogeneous term. Initially, we have computed the solution of the linear Caputo impulsive fractional differential equation explicitly using the method of mathematical induction. We have developed comparison results in terms of coupled lower and upper solutions when the nonlinear terms are sums of an increasing and decreasing functions of the unknown function. Finally, we have developed generalized monotone method for the nonlinear Caputo impulsive fractional Differential Equations with initial conditions using coupled lower and upper solutions. This proves the existence coupled minimal and maximal solutions of the nonlinear problem. Finally, under uniqueness condition, we prove the existence of the unique solution of the nonlinear Caputo fraction impulsive differential equation with initial condition. (Received September 13, 2018)

1145-34-808 **Paul G Warne*** (warnepg@jmu.edu), Department of Mathematics and Statistics, James Madison University, and **Debra A Warne** (warneda@jmu.edu), Department of Mathematics and Statistics, James Madison University. *The Adaptive Parker-Sochacki Pade' Method For Robust Numerical Simulation.* Preliminary report.

For high-resolution numerical simulation involving systems of differential equations, an explicit adaptive procedure using a foundation of the Parker-Sochacki Method (PSM) has significant advantages over many standard adaptive algorithms that use a Runge-Kutta (RK) foundation. These advantages include decreased output data storage size relative to resolution and complexity, built-in series approximations of the state space to find states between time steps, an automatic stepwise a-priori error bound, and a simple way to increase or decrease the order of the method stepwise during the computation. PSM functions that represent the backbone of a future PSM tool for the scientific community are described. At each step across the domain, these functions efficiently and recursively generate both the Taylor polynomial and the remarkably robust Pade' rational approximants of the solution to the governing ODE system. An Adaptive PSM Pade' algorithm is described theoretically and demonstrated on several examples, including a 3 degree of freedom system. Results are compared against standard RK adaptive algorithms; it is noted in the 3 degree of freedom example that Adaptive PSM Pade' runs faster and takes roughly two orders of magnitude fewer steps for similar accuracy. (Received September 15, 2018)

1145-34-810 **Marius Beceanu*** (mbeceanu@albany.edu), **Juerg Froehlich** and **Avy Soffer**. *Nonlinear equations with random time-dependent potentials.*

In this talk I shall discuss some new results concerning nonlinear evolution equations with time-dependent potentials. (Received September 25, 2018)

1145-34-836 **Mangalagama Dewasurendra*** (dewasurendra_m@knights.ucf.edu), University of Central Florida, 4393 Andromeda Loop N., Orlando, FL 32816, and **Kuppalapalle Vajravelu** (kuppalapalle.vajravelu@ucf.edu) and **Ying Zhang** (ying.zhang@knights.ucf.edu). *Optimal semi-analytical method to solve coupled nonlinear differential equations arising in epidemiology.*

The Method of Directly Defining inverse Mapping (MDDiM) is an extension of Optimal Homotopy Analysis method (OHAM) and has been used to solve single nonlinear ordinary differential equations. We extended this novel method to solve systems of coupled nonlinear ordinary differential equations arise in science and engineering. In this talk, I will present solutions obtained for the SIR and the SIS models in epidemiology. In order to obtain accurate approximate analytical solutions, single inverse linear map considered which permit accuracy with relatively few terms. The convergence control parameters and pertinent parameters in directly define inverse map were select through the construction of an optimal control problem for the minimization of the accumulated residual errors. Further, we will present solution curves along with numerical results to validate our approximation solutions. This idea is more general and can be used to analyze complicated models arising in mathematical biology, physics and engineering. (Received September 16, 2018)

1145-34-856 **Wenying Feng*** (wfeng@trentu.ca), Peterborough, ON , Canada, and **Ankai Liu**. *Existence of Solutions for Integral Equations with Changing Sign Green's Functions.*

We will introduce a new class of cone as a generalization of the compression cone technique for fixed-point index. As a result, the traditional method is shown to be more adaptable in applications. We prove new results for semi-linear integral equations. Applications are illustrated by examples. Limitations of such new method are also discussed. (Received September 16, 2018)

1145-34-920 **Min Wang*** (min.wang@kennesaw.edu). *A fractional inventory model for bike share systems.*

In this talk, a fractional differential equation model is developed to describe the inventory at a bike share station based on preliminary data analysis on the historical bike share data. The analytic solution of the model is investigated as well. (Received September 17, 2018)

1145-34-921 **Youssef Naim Raffopul*** (yraffoul1@udayton.edu), 300 College Park, Dayton, OH 45469-2316. *New Variation of Parameters Formula that Leads to Stability in Integro-differential Equations.* Preliminary report.

In this work we introduce a function $v(t)$ to invert a given integro-differential equation and obtain a new variation of parameters formula. The new variation of parameters formula will be used, along with fixed point theory to arrive at stability results. Our work extends and improve the results in the literature.
(Received September 17, 2018)

1145-34-946 **Omomayowa Olawoyin*** (omomayowa.olawoyin@mavs.uta.edu) and **Christopher Kribs**. *Effects of Multiple Transmission Pathways on Zika Dynamics.*

Although the Zika virus is transmitted to humans primarily through the bite of infected female Aedes aegypti mosquitoes, it can also be sexually and vertically transmitted within both populations. In this study, we develop a new mathematical model of the Zika virus which incorporates sexual transmission in humans and mosquitos, vertical transmission in mosquitos, and mosquito to human transmission through bites. Analysis of this deterministic model shows that the secondary transmission routes of Zika increase the basic reproductive number (R_0) of the virus by 5%, shift the peak time of an outbreak to occur 10% sooner, increase the initial growth of an epidemic, and have important consequences for control strategies and estimates of R_0. Furthermore, sensitivity analysis show that the basic reproductive number is most sensitive to the mosquito biting rate and transmission probability parameters and reveal that the dynamics of juvenile mosquito stages greatly impact the peak time of an outbreak. These discoveries deepen our understanding of the complex transmission routes of ZIKV and the consequences that they may hold for public health officials. (Received September 17, 2018)

1145-34-951 **Sougata Dhar*** (sougata.dhar@maine.edu), 5752 Neville Hall, Department of Mathematics & Statistics, Orono, ME 04469, and **Qingkai kong**. *Fractional Lyapunov-type Inequalities with Mixed Boundary Conditions on univariate and multivariate domains.*

Lyapunov-type inequalities are established for Riemann-Liouville fractional differential equations with order $\alpha \in (2, 3]$ and certain pointwise or mixed boundary conditions. Results are first given for univariate case, and then extended to multivariate case. All the results are new and one of them extends and improves substantially the one in the literature for third-order multivariate boundary value problems. (Received September 17, 2018)

1145-34-1000 **Anthony Dean Stefan*** (stefanamp@yahoo.com), 111 Lake Hollingsworth Dr., Lakeland, FL 33801, and **Zachary David Fralish** and **Thomas Bernard Tyson**. *Using Differential Equations to Model Predator-Prey Relations as Part of SCUDEM Modeling Competition.* Preliminary report.

In the spring of 2018, for the SCUDEM modeling competition in St. Petersburg, Florida, we received outstanding distinction for designing a mathematical model to estimate how kinetic, spatial, auditory, electrical, and tensive output from a predator are accumulated to trigger a neural response in prey. Furthermore, the propagation of the resultant action potential and the physical flight of the prey from the predator were modelled through the analysis of larval zebrafish as a model organism. In our presentation, we will present how we developed our model and learned how to apply differential equations. The specific aspects of our modelling process we will discuss include our preparation methods for the competition, integrating knowledge from fields outside of mathematics, how assumptions contributed to the success of our model, and techniques we used to refine our presentation. Beyond our assumptions necessary for the models, we also discuss limitations and future directions for our work. (Received September 19, 2018)

1145-34-1003 **Gaston Mandata N'Guerekata*** (gaston.n'guerekata@morgan.edu), Morgan State University, 1700 East Cold Spring Lane, Baltimore, MD 21113. *Pseudo almost periodic solutions for a Nicholson's blowflies model with mortality term.*

This article is concerned with a discrete Nicholson's blowflies model, which involves a nonlinear density-dependent mortality term. By using fixed point theorem and Lyapunov functional method, we obtain the existence and locally exponential stability of pseudo almost periodic solutions for the addressed Nicholson's blowflies model. In addition, an example is given to illustrate our results. (Received September 18, 2018)

1145-34-1025 **Paul Eloe*** (peloe1@udayton.edu) and **Jaganmohan Jonnalagaddda**. *Quasilinearization and Boundary Value Problems for Riemann-Liouville Fractional Differential Equations.*

The quasilinearization method is applied to a Dirichlet boundary value problem and to a right focal boundary value problem for a Riemann-Liouville fractional differential equation. First, the method of upper and lower solutions is employed to obtain the uniqueness of solutions of the Dirichlet boundary value problem. Next, a suitable fixed point theorem is applied to establish the existence of solutions. The quasilinearization algorithm is then developed and sequences of approximate solutions are constructed that converge monotonically and quadratically to the unique solution of the boundary value problem. Two examples are exhibited to illustrate the main result for the Dirichlet boundary value problem. (Received September 18, 2018)

1145-34-1064 **John R Graef*** (john-graef@utc.edu), Department of Mathematics, University of Tennessee at Chattanooga, Chattanooga, TN 37403. *Boundary value problems for a fractional differential inclusion with a Hadamard type derivative.*

Sufficient conditions for the existence of solutions to boundary value problems for fractional differential inclusions involving the Hadamard type fractional derivative of order $\alpha \in (1, 2]$ in Banach spaces are established. The approach uses Mönch's fixed point theorem and the Kuratowski measure of noncompacteness. (Received September 18, 2018)

1145-34-1139 **Dat Cao***, Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409, and **Luan Hoang**, Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409. *Asymptotic expansions for solutions of non-autonomous differential equations.*

We establish the asymptotic expansions, when time goes to infinity, for decaying solutions of non-linear non-autonomous systems of ordinary differential equations. This extends the original work of Foias-Saut for Navier-Stokes equations for potential forces (which deal with a bilinear mapping). In our study, the nonlinearity is more general, and can have an expansion form of any order. We prove that any decaying solution admits an asymptotic expansion, as time tends to infinity, of the same type as the force's. We then briefly discuss the results for Navier-Stokes equations. This is a joint work with Luan Hoang (Texas Tech University). (Received September 19, 2018)

1145-34-1199 **Mahir Demir*** (mdemir@vols.utk.edu), 3100 Lake Brook blvd apt 51, Knoxville, TN 37909. *Applications of Optimal Control for Ecosystem-Based Fishery Management.*

In contrast to the traditional fishery management (TFM) focusing on one species, ecosystem based fishery management (EBFM) focusing on the whole ecosystem of the species by using the dynamics of food chain models is an useful trend in the commercial fishery to not only conserve and manage renewable food resources,

but also to have optimal and healthy ecosystems. A food chain model coupled with optimal control theory can be used to investigate harvesting strategies for maximizing the discounted net value of a fish population. Since fish do not exist in a habitat by themselves, the presence of predators and/or competing species is an important feature in harvest and conservation in a food web. Therefore, we present a food chain model for harvesting of Black Sea anchovy on the southern part of the Black Sea. The anchovy stock coupled with a prey and a predator species is modeled using a system of nonlinear differential equations. The objective for the problem is to find the ecosystem- based optimal harvesting strategy that maximizes the discounted net value of the anchovy population with seasonal harvesting. Necessary conditions for the optimal harvesting policy are established. (Received September 19, 2018)

1145-34-1289 **Hella M. Quinnett*** (hq939056@cameron.edu), 2800 W. Gore Blvd, Lawton, OK 73505, and **Narayan Thapa** (nthapa@cameron.edu), 2800 W. Gore Blvd, Lawton, OK 73505. *Numerical Solution of Beam Equation with Free Boundaries.* Preliminary report.

We consider the fourth order differential equation with suitable boundary conditions:

$$\frac{d^2}{dx^2}\left[r(x)\frac{d^2u}{dx^2}\right] = q(x)u(x) + p(x), \quad 0 \le x \le L$$
$$u(0) = a_0 \quad u(L) = a_L$$
$$u''(0) = b_0 \quad u''(L) = b_L$$

For simple data, $q(x)u(x) + p(x)$ and $r(x)$, the beam equation can be solved by using well known techniques in differential equations. However, for a complex source function and $r(x)$, numerical techniques are the vital tools to approximate solutions to the given Boundary Value Problem. In this work, we use the finite difference method to approximate the deflection of beam. We present computational algorithms and display numerical results. (Received September 20, 2018)

1145-34-1306 **Corban Harwood*** (rharwood@georgefox.edu). *Using Projects to Flip the Differential Equations Classroom.* Preliminary report.

This talk compares traditional lecture to several active learning styles of teaching before giving a personal example of transitioning to a flipped classroom using class activities and projects. Many of the projects used were developed by the SIMIODE community and include extensive comments for implementation by the Instructor. In agreement with previous studies done, student and instructor feedback through this experience has supported the use of projects to motivate and improve student learning as well as providing alternative perspectives and applications of the course material to deepen their understanding. (Received September 20, 2018)

1145-34-1340 **Shiping Cao**, **Anthony Coniglio*** (coniglio@iu.edu), **Xueyan Niu**, **Richard Rand** and **Robert Strichartz**. *The Mathieu Differential Equation and Generalizations to Infinite Fractafolds.*

One of the more well-studied equations in the theory of ODEs is the Mathieu differential equation. Because of the difficulty in finding closed-form solutions to this equation, it is often necessary to seek solutions via Fourier series by converting the equation into an infinite system of linear equations for the Fourier coefficients. In this talk we present results pertaining to the stability of this equation and convergence of solutions. We also investigate ways to modify the linear-system form of the equation in order to study a wider class of equations. Further, we provide a method in which the Mathieu differential equation can be generalized to be defined on an infinite fractafold, with our main focus being the fractal blow-up of the Sierpinski gasket. We discuss methods for studying the stability of solutions to this fractal differential equation and describe further results concerning properties and behavior of solutions. (Received September 21, 2018)

1145-34-1352 **Joseph Paullet*** (jep7@psu.edu). *Analysis of Stagnation Point Flow of an Upper-Convected Maxwell Fluid.*

Several recent papers have investigated the two-dimensional stagnation point flow of an upper-convected Maxwell fluid by employing a similarity change of variable to reduce the governing PDEs to a nonlinear third order ODE boundary value problem (BVP). In these previous works, the BVP was studied numerically and several conjectures regarding the existence and behavior of the solutions were made. The goal of this talk is to mathematically verify these conjectures. We prove the existence of a solution to the BVP for all relevant values of the elasticity parameter. We also prove that this solution has monotonically increasing first derivative, thus verifying the conjecture that no "overshoot" of the boundary condition occurs. Uniqueness results are presented for a large range of parameter space and bounds on the skin friction coefficient are calculated. (Received September 21, 2018)

1145-34-1445 **Aghalaya S. Vatsala*** (vatsala@louisiana.edu), Department of Mathematics, University of Louisiana at Lafayette, Lafayette, LA 70504, and **M Sowmya**. *Mixed Generalized Iterative Method For Nonlinear Problems.* Preliminary report.

Nonlinear problems arise naturally in the mathematical modeling of physical situation in various branches of science and engineering. Explicit computation of solutions of these nonlinear problems is rarely possible. Generalized monotone method combined with coupled lower and upper solutions provides the existence of coupled minimal and maximal solutions. The method is useful, when the nonlinear function is the sum of an increasing and decreasing functions. On the other hand, generalized quasilinearization method is applicable when the nonlinear function is the sum of a convex and concave functions. In this work, we mix the two methods together with coupled lower and upper solutions when the nonlinear function, is any combination of an increasing, decreasing, convex and concave functions. The rate of convergence is super linear. The method can be easily extended to Caputo fractional differential equation with initial condition. The mixed iterative method is useful in Volterra integro- differential equations. For example, such equations arise in Hodgkin-Huxley model, FitzHugh Nagumo equation. A numerical example will be presented. (Received September 21, 2018)

1145-34-1554 **Emre Esenturk*** (e.esenturk.1@warwick.ac.uk), Mathematics Institute, University of Warwick, Coventry, CV4 7AL, United Kingdom. *Mathematical theory of exchange-driven growth: Fundamentals and asymptotic behavior.*

Exchange-driven process (EDP) is a mechanism where clusters of (constituent elements of) a system interact with each other by exchanging single unit-element at a time. Examples include models population dynamics, wealth exchange etc. In this talk we present first rigorous results for the mean field rate equations of this process. We show two different types of behavior depending on the symmetry of K(j, k), the interaction kernel. For the non-symmetric case, we show global existence and uniqueness of solutions for kernels satisfying K(j, k) $\leq$ C j k. This result is optimal in the sense that we show for a large class of initial conditions and kernels satisfying K(j, k) $\geq$ C j^β ($\beta > 1$) the solutions cannot exist. On the other hand, for symmetric kernels solutions exist globally for K(j, k) $<$ C((j^μ) (k^ν) + (j^ν) (k^μ)) (μ, $\nu \leq 2$, $\mu + \nu \leq 3$), while existence is lost for K(j, k) $\geq$ C j^β ($\beta > 2$). In the intermediate regime $3 < \mu + \nu < 4$, we can only show local existence. We also present results on EDP with the possibility of breakages from massive clusters. We show that the classical indefinite growth trend is broken and the system approaches to an equilibrium even without the inclusion of a sink. (Received September 23, 2018)

1145-34-1584 **Arielle Gaudiello*** (arielle@ucf.edu), 4393 Andromeda Loop N, Orlando, FL 32816, and **Zhisheng Shuai**. *Impact of Asymmetric Movement on the Spatial Spread of Infectious Disease.* Preliminary report.

Spatial heterogeneity and rates of movement can have a large impact in the dynamics of an infectious disease. In this talk, we present an n-patch SIS model, incorporating both spatial heterogeneity and directed movement between populations. We assume mass action incidence, and disease-induced death rates. New global stability results are established utilizing a graph-theoretic approach and Lyapunov functions. Approximations for both the disease-free equilibrium and basic reproduction number are determined as the diffusion of human individuals are faster than the disease dynamics. Numerical simulations confirm validity of these approximations. (Received September 23, 2018)

1145-34-1714 **Yun Kang*** (yun.kang@asu.edu), Sciences and Mathematics Unit, The Levin Center, Arizona State University, AZ, and **Jun Chen**, **Marisabel Rodriguez-Messan**, **Komi Messan** and **Gloria DeGrandi-Hoffman**. *Modeling Population Dynamics of Honeybee: Parasite, Disease and Nutrition.*

Honeybees play an important role in sustaining our ecosystem. However, the rapid decline of honeybee population have sparked a great concern worldwide. Many field and theoretical studies have shown that the collapsing of honeybee colonies may be due to the infestation by the parasitic Varroa mite, the varied viruses that they carry, and the nutritional effects due to global warming. This talk, we would provide our recent modeling work combined with experimental data to explore how synergistic effects of parasite, diseases and nutrition on the health of honeybee colonies. (Received September 24, 2018)

1145-34-1722 **Saurabh Tomar*** (sauravtomar9793@gmail.com), Department of Mathematics, Indian Institute of Technology, Kharagpur, Kharagpur, 721302, India, and **R. K. Pandey** (rkp@maths.iitkgp.ernet.in), Department of Mathematics, Indian Institute of Technology, Kharagpur, Kharagpur, 721302, India. *Approximate analytical solutions for a nonlinear fourth-order differential equation with nonlinear boundary conditions.* Preliminary report.

In this talk, we will discuss a nonlinear fourth-order two-point boundary value problem with nonlinear boundary conditions involving third-order derivatives: modeling beams on elastic foundations. This kind of problem occurs naturally in the study of deformations of elastic beams on elastic bearings. Furthermore, fourth-order two-point boundary value problems are useful for material mechanics because the problems usually characterize the deflection of an elastic beam. Our objective is to solve the problem by implementing an iterative method. We notice that the existing iterative methods seem to be very slow in this case because of the nonlinearity in the third order boundary point. The numerical results emphasize the effectiveness and high performance of the iterative method and comparisons are made with the existing results and only a few numbers of iterations are required to achieve high accuracy. The results reveal the efficiency and applicability of the method. (Received September 24, 2018)

1145-34-1725 **Krishna P Pokharel*** (kpokhar@rockets.utoledo.edu). *An Isospectral Flow on Banded Matrices.*

In this talk, we discuss an isospectral flow in the space of matrices, which deforms any given real banded matrix with simple real spectrum to a symmetric matrix. The Lax flow is given by

$$\frac{dA}{dt} = [[A^T, A]_{du}, A],$$

where brackets indicate the usual matrix commutator, $[A, B] = AB-BA$, A^T is the transpose of A and the matrix $[A^T, A]_{du}$ is the matrix equal to $[A^T, A]$ along diagonal and upper triangular entries and zero below diagonal. We prove that if the initial condition A_0 is banded matrix with lower bandwidth $p = 2$ and upper bandwidth $q = 0$ with simple real spectrum and second subdiagonal elements different from zero, then $\lim_{t\to\infty} A(t)$ exists, it is a pentadiagonal symmetric matrix isospectral to A_0 and it has the same sign pattern in the second subdiagonal elements as the initial condition A_0. We provide some simulation results to highlight some aspects of this nonlinear system. (Received September 24, 2018)

1145-34-1758 **Seye E Adekanye*** (seyeadekanye@gmail.com), 902 N. Market Street, Apt 901, Wilmington, DE 19801. *Developing Non-Standard Finite Difference (NSFD) Schemes for a System of Coupled Second Order Differential Equations.*

Many real world phenomena can be modeled by dynamical systems that describe the evolution of phenomena over time. For example, the growth and decay equation models how a quantity changes over time. The transport equation with a flux term models the flow of a particle through a given medium. The Airy equation models the diffraction of light. Using the growth and decay equation, we can develop the foundation for an exact nonstandard finite difference scheme (NSFD) which can preserve properties of the dynamical system into its discretization (dynamical consistency). Some equations require the NSFD scheme to adhere to time and space step size constraints. In this talk, we will show how to construct NSFD schemes for a system of coupled second order differential equations that numerically outperform the traditional standard finite difference schemes. (Received September 24, 2018)

1145-34-1763 **Lingju Kong*** (lingju-kong@utc.edu). *Modeling online social network dynamics using fractional order differential equations.*

The use of social media has been spreading at an accelerated rate in the last decade. While the dynamics of online social network have been studied using several models formulated via the integer order differential equations, these models are local, fail to capture the memory of the system, and have some other deficiencies. The aim of this study is to better understand the adoption and abandonment of a social network by utilizing a model of fractional order differential equations. Various model properties such as existence, uniqueness, and stability will be investigated. Moreover, numerical simulations are performed to confirm the theoretical results. (Received September 24, 2018)

1145-34-1956 **Tyler Meadows*** (meadowta@mcmaster.ca), **Marion Weedermann** and **Gail S.K. Wolkowicz**. *Global analysis of a simplified model of anaerobic digestion and a new model for the chemostat.*

A. Bornhöft, R. Hanke-Rauschenbach, and K. Sundmacher, Steady-state analysis of the anaerobic digestion model no.1 (ADM1), Nonlinear Dyn., 73 (2013), pp. 535–549 introduced a qualitative simplification to the ADM1 model for anaerobic digestion. We obtain global results for this model by first analyzing the limiting system, a model of single species growth in the chemostat in which the response function is non-monotone and the species decay rate is included. Using a Lyapunov function argument and the theory of asymptotically autonomous Systems, we prove that even in the parameter regime where there is bistability, no periodic orbits exist and every solution converges to one of the equilibrium points. (Received September 24, 2018)

1145-34-2006 **Jeffrey W Lyons*** (jwlyons@hawaii.edu), 2565 McCarthy Mall, University of Hawaii at Manoa, Department of Mathematics, Honolulu, HI 96822, and **Jeffrey T Neugebauer** (jeffrey.neugebauer@eku.edu), 521 Lancaster Avenue, Eastern Kentucky University, Department of Mathematics, Richmond, KY 40475. *Two Point Fractional Boundary Value Problems with a Fractional Boundary Conditions.*

In this presentation, we employ Krasnosel'skii's Fixed Point Theorem to show the existence of positive solutions of three different two point fractional boundary value problems with fractional boundary conditions. Also, nonexistence results are given. (Received September 24, 2018)

1145-34-2105 **Becky Sanft*** (bsanft@unca.edu) and **Anne Walter**. *A Data-Driven Approach to Teaching Modeling with Differential Equations.* Preliminary report.

There is an ongoing paradigm shift in how science is practiced and taught, from a strong disciplinary focus to one of interdisciplinary approaches to address a question. One critical interface is that between mathematics and biology, where differential equations have often been used to develop mechanistic models of biological phenomena. In this talk we will describe case studies designed to actively engage students to use differential equations to model biological systems. Each case study is motivated by a biological question and then guides students through the steps of model formulation using differential equation models, parameter estimation, model validation, and analysis. A distinguishing feature of these materials is that each case study uses data to drive the model formulation and to estimate model parameters. These case studies help students see mathematical modeling as an iterative process that helps scientists understand complex systems, make predictions, generate causal explanations, and design new experiments. (Received September 24, 2018)

1145-34-2127 **Qingkai Kong** and **Thomas E St. George*** (tstgeorg@carrollu.edu). *Linear Sturm-Liouville Problems with Riemann-Stieltjes Integral Boundary Conditions.*

In this talk, we consider second-order linear Sturm-Liouville problems involving general homogeneous linear Riemann-Stieltjes integral boundary conditions. Conditions are obtained for the existence of a sequence of positive eigenvalues with consecutive zero counts of the eigenfunctions. Additionally, interlacing relationships between the eigenvalues of such Sturm-Liouville problems and those of Sturm-Liouville problems with certain two-point separated boundary conditions are obtained. (Received September 24, 2018)

1145-34-2141 **Christopher S. Goodrich*** (cgoodrich@creightonprep.org), 7400 Western Ave., Omaha, NE 68114. *Coercive Nonlocal Elements in Fractional Differential Equations.*

I will discuss the use of coercive linear functionals in deducing existence results for fractional differential equations with nonlocal boundary conditions. As a specific example of this methodology, I will consider the fractional boundary value problem

$$-\big[D_{0+}^{\nu}y\big](t) = \lambda f\big(t, y(t)\big),\ 0 < t < 1$$
$$y^{(i)}(0) = 0,\ 0 \leq i \leq n-2$$
$$\big[D_{0+}^{\alpha}y\big](1) = H\big(\varphi(y)\big),$$

where $n \in \mathbb{N}_4$, $n-1 < \nu \leq n$, $\alpha \in [1, n-2]$, and $\lambda > 0$ is a parameter. I will demonstrate that by utilizing a new order cone, one can generate existence results with minimal assumptions on the functions f and H. (Received September 24, 2018)

1145-34-2144 **Magdalena Czubak*** (czubak@math.colorado.edu). *Almost sure boundedness of iterates for semilinear wave equations.*

We study nonlinear wave equations in 2D with quadratic derivative nonlinearities with random initial data in the energy space. We obtain a uniform time interval on which the Picard iterates of all orders are almost surely bounded. This is in contrast to the deterministic results. (Received September 24, 2018)

1145-34-2146 **Christine Sample*** (samplec@emmanuel.edu), 400 Fenway, Boston, MA 02215, and **Joanna A Bieri**. *Engaging and supporting students as they explore mathematical modeling in differential equations.*

Introducing students to mathematical modeling in a first course in differential equations can be both rewarding and challenging. In this talk, we will share our thoughts on how to engage and support students as they learn modeling methodology alongside differential equations. First, we will share ideas of modeling projects that are interesting and relevant to undergraduates, such as wildlife conservation, zombie attacks, and environmental crises. We will then discuss ways of supporting students through cooperative learning, grading rubrics, and scaffolding of projects. Finally, we will stress the importance of providing opportunities for students to practice communicating the methods and results of a mathematical model to a general audience. (Received September 24, 2018)

1145-34-2149 **Vinodh kumar Chellamuthu*** (vinodh.chellamuthu@dixie.edu), 225 South University Avenue, St. George,, UT 84770, and **Jisun Otterson**. *Modeling the Effects of Wolbachia Transinfection and the Importance of Temperature in Dengue Epidemics.* Preliminary report.

Dengue is a mosquito-borne viral infection that is usually found in tropical and subtropical regions around the world. The cycle of dengue transmission can be broken by infecting mosquitoes with Wolbachia bacterium, which reduce the level of dengue virus in the mosquito and shorten the host mosquito's lifespan. Several studies have shown that infecting mosquitos with Wolbachia and releasing them (a process called Transinfection) can spread this bacterium to the local mosquito population and mitigate the impact of the disease. A mathematical model is developed to investigate how the strategy of using Wolbachia could reduce the spread of the Dengue virus in human populations. The model also incorporates the local temperature data, which can affect the procreation and growth of mosquitos. The model simulation results suggest that the Dengue fever outbreak can be diminished by releasing a small number of Wolbachia-carrying mosquitos at the right time. (Received September 24, 2018)

1145-34-2245 **Quynh Nguyen*** (nguyenqt@mail.uc.edu), 3300 Jefferson Avenue, Cincinnati, OH 45220, and **Nguyenho Ho**. *Mathematical Model of Dengue Fever with Vertical Transmission in an Age-Structured Population.* Preliminary report.

It has been known that Dengue virus is transmitted by Aedes aegypti, which causes dengue fever and dengue hemorrhagic fever. The majority of the disease outbreaks occurs in tropical and subtropical countries including those in Southeast Asia. In addition, the number of disease cases may be different depending on age groups. Here, we propose an age-structured deterministic model to include juvenile and adult individuals for human host while vertical transmission is considered for vector populations (aquatic and adult mosquitoes). The stability of disease-free equilibrium and the reproduction number are analyzed and calculated. The model is used to numerically study the data collected from the Southern Vietnam providences during the outbreak periods. (Received September 25, 2018)

1145-34-2269 **Hem Raj Joshi*** (joshi@xavier.edu), Xavier University, Department of Mathematics, 3800 Victory Parkway, Cincinnati, OH 45207-4441. *Application of SIR Model and Optimal Control.*

We develop an optimal control model of SIR type. In this model, the control is education or information given to the public to manage a disease outbreak when effective treatments or vaccines are not readily available or too costly to be widely used. We study stability analysis and use optimal control theory on the system of differential equations to achieve the goal of minimizing the infected population. We illustrate our results with some numerical simulations.

As an application of SIR model, we develop a mathematical model of HIV epidemiology to explore a possible mechanism by which mass incarceration can lead to increased HIV incidence. The results are particularly relevant for mass incarnation of under representative communities. Through mathematical analysis and numerical simulation, we demonstrate that young male shortage in the community lead to higher HIV incidence. (Received September 25, 2018)

1145-34-2317 **Bhuvaneswari Sambandham*** (buna.sambandham@dixie.edu), **Aghalaya S Vatsala** (vatsala@louisiana.edu) and **Vinodh Kumar Chellamuthu** (vinodh.chellamuthu@dixie.edu). *Numerical Results for Sequential Caputo Fractional Differential Equations with Laplace Transform Methods.* Preliminary report.

In our earlier work, we obtained the solutions of linear sequential Caputo fractional differential equations of order 2q in terms of Mittag-Leffler functions. Also, we obtained the representation form for the solution of the initial value problem of the fractional order 2q with Laplace transform method. In this work, we develop the numerical results of sequential Caputo fractional differential equations of order 2q using Laplace transform methods with a linear nonhomogeneous term. This, in turn, will be useful to develop the numerical results for nonlinear sequential Caputo fractional differential equations. All our results yield the integer order result as the special case. (Received September 25, 2018)

1145-34-2441 **Darin Orrie Brindle*** (dabri8@morgan.edu), Morgan State University Department of Mathema, 1700 East Cold Spring Lane, Baltimore, MD 21251. *Existence results of S-asymptotically ω-periodic mild solutions to some integro-differential equations with non-local conditions.*

In this talk, we are concerned with the existence of S-asymptotically ω-periodic mild solutions to the semilinear integro-differential equation $u'(t) = Au(t) + \int_0^t B(t-s)u(s)ds + f(t,u(t)),\ t \geq 0$ with nonlocal condition $u(0) = u_0 + g(u)$ in a general Banach space X. A and $B(t)$ are densely defined, closed linear operators on X. In addition A is the generator of a resolvent operator family. We use the Krasnosel'skii fixed point theorem to prove our results. An application is given to illustrate our abstract results. (Received September 25, 2018)

1145-34-2543 **Maria Teresa Hernandez*** (mariahernandez@csumb.edu), 100 Campus Center, Seaside, CA 93955, and **Judith E. Canner** (jcanner@csumb.edu), 100 Campus Center, Seaside, CA 93955. *Fitting Classical Mathematical Models to Small Data Sets from Lewis Lung and Human Breast Carcinomas.* Preliminary report.

Classical mathematical models are useful in modeling tumor volume growth, however, it is difficult to measure regular and long-term growth in a clinical or lab setting for ethical reasons. Hence, we must develop methods to fit models to small data sets to develop models for clinical use. We explored the minimum number of observations necessary to confidently fit the logistic and generalized logistic growth models for the prediction of tumor growth via computer simulations in R. We simulated data using estimated parameters from previous in vivo experiments with mice that observed the growth of Lewis lung and human breast carcinomas, adding a reasonable level of noise, and setting our time frame to one observation per day for 30 days. The models were visually assessed for fit to the observed data over specified time intervals and future growth prediction. The results showed that the predictive accuracy limit and best fit limit for data generated from the logistic model is 25 days for breast cancer and 15 days for lung cancer; for data generated from the generalized logistic model, it was 20 days for breast cancer and 10 days for lung cancer. Future simulations will be conducted by using varying levels of noise, different time frames, and more sophisticated model selection methods. (Received September 25, 2018)

1145-34-2582 **James H Liu**, **Alexander R McAllister*** (mtnmcallister@gmail.com) and **Alfred Williams**. *A Necessary Condition for Exponential Matrix Solutions of Differential Equations.*

For linear differential equations, we will show that a well known sufficient condition for having exponential matrix solution is also a necessary condition under the assumption that the leading matrix is analytic. (Received September 25, 2018)

1145-34-2623 **Ateq Alsaadi*** (ateq.alsaadi@bison.howard.edu), Mathematics Department, Howard University, Washington, DC 20059, and **Faina Berezovskaya**. *Power asymptotics of orbits of a Kolmogorov type polynomial vector field with a fixed Newton polyhendron.* Preliminary report.

Using the Newton polyhendron method we consider asymptotics of trajectories in a vicinity of isolated equilibrium $O\,(0,0,0)$ of a polynomial vector field $V\,(X_1, X_2, X_3)$ defined by the system of ordinary differential equations with the right hands: $X_1\,(\bar{x}) \equiv x_1 P\,(\bar{x})\,,\ X_2\,(x) \equiv x_2 Q\,(\bar{x})\,,\ X_3\,(\bar{x}) \equiv x_3 R\,(\bar{x})$, where $\bar{x} = (x_1, x_2, x_3)$. Newton polyhedron Γ_{000} is associated with V. **Theorem**. Any orbit of $V\,(\bar{x})$ that tends to O for $t \to \infty$ or $t \to -\infty$ in phase coordinates (x_1, x_2, x_3) has either power or trivial asymptotics

$$x_2 = k_1 x_1^{\rho_1}\,(1 + o\,(1))\,, x_3 = k_2 x_1^{\rho_2}\,(1 + \mathrm{o}\,(1))\,, \quad \rho_1,\ \rho_2 > 0,$$

where $(\rho_1,\ \rho_2)$ is a vector-index of Newton polyhedron Γ_{000} , k_1, k_2 are constants. (Received September 25, 2018)

1145-34-2634 **Sarah El Jamous*** (seljamou@asu.edu), Arizona State University, 900 S Palm Walk, Tempe, AZ 85281. *Cancer modeling using agent-based models.* Preliminary report.

In this talk, we will discuss how to model glioma cells which are responsive for brain tumor. We observe experimentally that these cells have different shapes and this might lead to different macroscopic behaviors (e.g. stream formation, diffusion coefficient). To explore how cancer cells manage to spread throughout the organism, we use an agent-based model describing the essential features of the cell (e.g. motility, cell-cell interaction). Depending on the shape of the cells, the stream formation can increase and influence the overall tumor growth. We compute a phase diagram of the dynamics as we change various parameters and characterize the emerging structures. (Received September 25, 2018)

1145-34-2651 **Rosemary C Farley*** (rosemary.farley@manhattan.edu), Manhattan College, Department of Mathematics, Riverdale, NY 10471, and **Patrice G Tiffany** (patrice.tiffany@manhattan.edu), Manhattan College, Department of Mathematics, Riverdale, NY 10471. *An Effort to Assess the Impact a Modeling First Approach has in a Traditional Differential Equations Class.*

Our differential equations course is required of every student in the School of Engineering. As a required course, there is a syllabus with topics that have to be covered in preparation for a common cumulative final. All the traditional methods of solving differential equations by hand must be covered. In the Spring 2018 semester, there were nine differential equations classes and one was being taught with the modeling first approach advocated by SIMIODE.

We will explain how we incorporated the modeling first approach into our differential equations classroom while still covering the traditional topics required. We will explain how we managed to devote one-third of our class time to the use of a modeling first approach together with the extensive use of a computer algebra system while still preparing students for a traditional common final. We will provide several examples of modeling problems from the SIMIODE scenarios that we adapted to our needs and time restrictions. We will give examples of how we created test questions that reflected ideas from our modeling first scenarios. We will report on the data gathered from the common final results and analyze how our modeling first students compared to others who followed the more traditional approach. (Received September 25, 2018)

1145-34-2998 **Blessing Emerenini*** (drblessing207@gmail.com), Department of Mathematics, Oregon State University, Corvallis, OR 97331. *Mathematical modeling and optimal control of Tick Fever.*

Presented in this work is a compartmental Mathematical model of the disease for the bird and Tick populations, this was analyzed using methods from dynamical systems theory. The disease steady state and the conditions for reaching a stable disease-free steady state were determined. The analysis by (Lyapunov method) showed both local and global stability. Further investigation involved the introduction of controls to the model; the existence and uniqueness of the optimal control were established. Finally, the effect of the controls were investigated using numerical simulations. (Received September 26, 2018)

1145-34-3016 **Vardayani Ratti***, 6188 Kemeny Hall, Hanover, NH 03755, and **Peter Kevan** and **Hermann Eberl**. *Mathematical Model of Honeybee Colonies Infested with Diseases.*

The western honeybees (*Apis mellifera*) are vanishing. Recent years have seen honeybees in distress, with up to 35% of colonies breaking down annually. There is no single cause that is believed to be responsible for the colony losses. In this talk, a mathematical model for the honeybees-varroa mites-virus complex is presented in which, based on division of labour, the bee population is divided into two categories: hive bees and forager bees. The model consists of ordinary differential equations for the dependent variables: uninfected hive bees, uninfected foragers, infected hive bees, number of mites overall, and of mites carrying the virus. In this talk, I will discuss the interplay between disease propagation and division of labour in a honeybee colony. I will also present the role of swarming in colony losses. The model focuses on Acute Bee Paralysis Virus and is studied with analytical and computational techniques. We use well established methods for autonomous systems to study the stability of equilibria. Using computer simulations, we investigate whether the results of the autonomous case carry over to the case where the coefficients are functions of time. (Received September 26, 2018)

35 ► Partial differential equations

1145-35-61 **John Cobb** and **Alex Kasman*** (kasmana@cofc.edu), Department of Mathematics, 66 George Street, Charleston, SC 29424, and **Albert Serna** and **Monique Sparkman**. *Quaternion-valued Solutions to the Korteweg-deVries Equation.* Preliminary report.

Soliton equations are nonlinear PDEs whose solutions have surprising particle-like behavior and which can be solved exactly using algebro-geometric methods. Because there has been recent interest in *non-commutative* generalizations, we have undertaken a study of quaternion-valued solutions to the KdV equation as a student research project. The solutions produced by our methods include rational solutions, periodic solutions and breather soliton solutions. Among the theorems we prove about them is one in which the surprising effect of non-commutativity on the phase shift (essentially, the “bounce” when two solitons collide) is made apparent. The talk will end with a list of open questions that we hope the experts at this session will be able to help us to answer. (Received July 15, 2018)

1145-35-131 **John K. Hunter** and **Jingyang Shu*** (jyshu@ucdavis.edu), Department of Mathematics, University of California at Davis, One Shields Ave., Davis, CA 95616, and **Qingtian Zhang**. *Fronts for the SQG Equation.*

Temperature discontinuities in the Surface Quasi-Geostrophic (SQG) equations support surface waves. For weakly nonlinear surface waves on SQG fronts that are described as a graph, we derive a nonlocal and nonlinear equation with logarithmic dispersion. With the help of Weyl quantization, dispersive decay, and modified scattering, we prove global-in-time well-posedness of the initial value problem for the SQG front equation with sufficiently small and smooth initial data. (Received August 06, 2018)

1145-35-174 **Ugur G Abdulla** and **Adam L Prinkey*** (aprinkey2009@my.fit.edu), 150 W. University Blvd., Melbourne, FL 32901. *Analysis of interfaces for the nonlinear double degenerate parabolic equation of turbulent filtration with absorption.*

We prove the short-time asymptotic formula for the interfaces and local solutions near the interfaces for the nonlinear double degenerate reaction-diffusion equation of turbulent filtration with fast diffusion and strong absorption

$$u_t = (|(u^m)_x|^{p-1}(u^m)_x)_x - bu^\beta;\ u = u(x,t),\ 0 < mp < 1,\ \beta > 0,\ b \in \mathbb{R}.$$

Full classification is pursued in terms of the nonlinearity parameters m, p, β and asymptotics of the initial function near its support. In the case of an infinite speed of propagation of the interface, the asymptotic behavior of the local solution is classified at infinity. Similar classification for the slow diffusion case ($mp > 1$) was presented in a recent paper *Abdulla et al., Mathematics and Computers in Simulation, 153 (2018), 59-82.* (Received August 15, 2018)

1145-35-176 **Adam Larios**, 203 Avery Hall, Lincoln, NE 68588, **Yuan Pei*** (yuan.pei@wwu.edu), 516 High St., Bellingham, WA 98225, and **Leo Rebholz**, O-109 Martin Hall, Clemson University, Clemson, SC 29634. *On the velocity-vorticity-Voigt formulation of the 3D Navier-Stokes equations.* Preliminary report.

In this talk, we propose a new regularization of the 3D Navier-Stokes equations, which we call the 3D velocity-vorticity-Voigt (VVV) model, with a Voigt regularization term added to momentum equation in velocity-vorticity form, but with no regularizing term in the vorticity equation. We prove global well-posedness and regularity of this model along with an energy identity. We also show convergence of the model's velocity and vorticity to their counterparts in the 3D Navier-Stokes equations as the Voigt modeling parameter tends to zero. Further, we provide a criterion for finite-time blow-up of the 3D Navier-Stokes equations based on this inviscid regularization. This is joint work with Adam Larios and Leo Rebholz. (Received August 15, 2018)

1145-35-184 **Joshua Ballew*** (joshua.ballew@sru.edu), Slippery Rock University, 106 Central Loop, Suite 200 VSC, Slippery Rock, PA 16057. *Asymptotic Analysis for a Homogeneous Bubbling Regime Vlasov-Fokker-Planck/Navier-Stokes System.* Preliminary report.

The evolution of a cloud of particles in a compressible fluid can be modeled with a Vlasov-Fokker-Planck equation for the distribution function of the particles coupled with Navier-Stokes or Euler equations for the density and velocity of the fluid. Formal calculations have established the convergence of solution to the mesoscopic model to solutions to the macroscopic Navier-Stokes or Euler model coupled with a Smoluchowski equation as the ratio of the settling time for the microscopic velocity fluctuation of the particles to the characteristic macroscopic time scale goes to zero. This talk discusses a rigorous asymptotic analysis for a homogeneous mesoscopic fluid-particle interaction model for particles dispersed in a compressible fluid is provided for the bubbling regime. A relative entropy inequality for a mixed hyperbolic/parabolic system of equations is employed. (Received August 16, 2018)

1145-35-185 **Gustavo Ponce*** (ponce@math.ucsb.edu), Departemnt of Mathematics, University of California-Santa Barbara, Santa Barbara, CA 93106, and **Claudio Munoz** (claumuno@gmail.com). *Breathers and the dynamics of solutions in KdV type equations.*

In this paper our first aim is to identify a large class of non-linear functions $f(\cdot)$ for which the IVP for the generalized Korteweg-de Vries equation does not have breathers or "small" breathers solutions. Also we prove that all uniformly in time $L^1 \cap H^1$ bounded solutions to KdV and related "small" perturbations must converge to zero, as time goes to infinity, locally in an increasing-in-time region of space of order $t^{1/2}$ around any compact set in space. This set is included in the linearly dominated dispersive region $x \ll t$. Moreover, we prove this result independently of the well-known supercritical character of KdV scattering. In particular, no standing breather-like nor solitary wave structures exists in this particular regime. (Received August 16, 2018)

1145-35-190 **Michail E Filippakis*** (mfilip@unipi.gr), University of Piraeus Research Center, 122 Gr, 18532 Piraeus, Greece, Greece. *Resonant (p, q)-equations with Robin boundary condition.*

In this paper we consider a nonlinear nonhomogeneous Robin problem. We consider the sum of a p-Laplacian and of q-Laplacian(a (p, q)-equation). The reaction term is a Caratheodory function which is resonant at $\pm\infty$ with respect to any nonprincipal variational eigenvalue of the Robin p-Laplacian. We use Morse theory (critical groups) and variational methods , in order to prove the existence of nontrivial smooth solutions.

The publication of this paper has been partly supported by the University of Piraeus Research Center. (Received August 18, 2018)

1145-35-209 **Xueping Zhao*** (xzhao@email.sc.edu), 800 State Street, Apt. 260, West Columbia, SC 29169, and **Qi Wang**. *A Second Order Fully-discrete Linear Energy Stable Numerical Scheme of a Binary Compressible Viscous Fluid Model.*

A thermodynamically consistent hydrodynamic phase field model of binary compressible fluid flow mixtures derived using the generalized Onsager Principle, which warrants not only the variational structure, but also the mass, linear momentum conservation, and the energy dissipation law in the isothermal case. We present a linear, second order fully discrete numerical scheme to solve this mathematical model on a staggered grid. The fully discrete scheme respects a discrete energy dissipation law. We present the scheme in two dimensional space for simplicity. Results apply to a 3D case as well. We prove the unique solvability of the linear scheme rigorously. We present several numerical examples, including phase separation due to the spinodal decomposition of two polymeric fluids and the calculation of the equilibrium states of a gas-liquid mixture, to show the convergence property, stability and efficiency of the new scheme. (Received August 19, 2018)

1145-35-214 **Zachary Bradshaw*** (zb002@uark.edu) and **Tai-Peng Tsai**. *Properties of infinite energy solutions to the Navier-Stokes equations.*

Leray's classical theory of weak solutions for the Navier-Stokes equations is formulated for finite energy initial data. The ensuing solutions preserve energy and satisfy useful a priori bounds. In many mathematical settings, the initial data does not have finite energy and so the global energy methods of Leray's weak solution fail. This led Lemarie-Rieusset to introduce the class of local Leray solutions, which satisfy local analogues of the useful properties of Leray's solutions. These solutions and their associated a priori bounds have proved useful in a number modern applications. However, less is known about local Leray solutions in comparison to Leray's solutions. This talk focuses on results that begin to address this deficit. (Received August 20, 2018)

1145-35-217 **Ugur G. Abdulla** and **Lamees K. Alzaki*** (lalzaki2013@my.fit.edu). *Analysis of Interfaces for the Nonlinear Degenerate Diffusion Equation with Convection.*

We present full classification of the short-time behavior of interfaces and local structure of solutions near the interfaces in the Cauchy problem with compactly supported initial function for the nonlinear degenerate second order parabolic PDE

$$u_t = (u^m)_{xx} + b(u^\gamma)_x,\ m > 1, \gamma > 0, b \in \mathbb{R}$$

modeling diffusion-convection processes arising in fluid or gas flow in a porous media, plasma physics, population dynamics in mathematical biology and other applications. Due to the property of the finite speed of propagation the problem develops interfaces or free boundaries separating the region where solution is positive from the region where it vanishes. The interface may expand, shrink, or remain stationary as a result of the competition of the diffusion and convection forces near the interface, expressed in terms of the parameters $m, \gamma, sign\ b$, asymptotics of the initial function near its support, and whether interface is the right or left boundary curve. In all cases, we prove the explicit formula for the interface and the local solution with accuracy up to constant coefficients. The methods of the proof are based on nonlinear scaling laws, and a barrier technique using special comparison theorems in irregular domains with characteristic boundary curves. (Received August 20, 2018)

1145-35-221 **Ariel Barton*** (aeb019@uark.edu). *Extrapolation of well posedness for higher order elliptic systems with rough coefficients.*

We establish well posedness of certain boundary value problems for higher order differential equations in the divergence form $\nabla^m \cdot A\nabla^m u = \nabla^m \cdot \dot{H}$, where m is a positive integer and where $\dot{H}$ and A are given functions.

Specifically, we establish well posedness for the Dirichlet problem with boundary data in a Besov space $\dot{B}^s_{p,p}$, $p \leq 1$, given well posedness for appropriate values of s and $p > 1$. We work with smoothness parameter s between 0 and 1; this allows us to consider inhomogeneous differential equations, that is, $\nabla^m \cdot A\nabla^m u = \nabla^m \cdot \dot{H}$ rather than $\nabla^m \cdot A\nabla^m u = 0$.

Combined with results of Maz'ya, I. Mitrea, M. Mitrea, and Shaposhnikova, this allows us to establish new well posedness results for higher order operators whose coefficients are in or close to the space VMO, for the biharmonic operator, and for fourth-order operators close to the biharmonic operator. (Received August 21, 2018)

1145-35-264 **Murat Akman*** (murat.akman@uconn.edu), 341 Mansfield Road, Unit 1009, Department of Mathematics, University of Connecticut, Storrs, CT 06269. *Perturbations of elliptic operators on non-smooth domains.* Preliminary report.

In this talk, we study perturbations of elliptic operators on domains with rough boundaries. In particular, we focus on the following problem: suppose that we have "good estimates" for the Dirichlet problem for a uniformly elliptic operator L_0, under what optimal conditions, are those good estimates transferred to the Dirichlet problem for uniformly elliptic operator L which is a "perturbation" of L_0?

We prove that if discrepancy between L_0 and L satisfies certain smallness assumption then the elliptic measure ω_L corresponding to L is in the reverse Hölder class with exponent 2 with respect to the elliptic measure ω_{L_0} corresponding to L_0 when the domain is 1-sided NTA satisfying the capacity density condition. Our work extends classical results of Fefferman, Kenig, and Pipher in Lipschitz domains, and Milakis, Pipher, and Toro in chord-arc domains to 1-sided NTA domains satisfying the CDC.

This is a joint work in progress with Steve Hofmann, José María Martell, and Tatiana Toro. (Received August 27, 2018)

1145-35-268 **Brian Allen*** (brianallenmath@gmail.com). *Using geometric evolution equations to show stability in mathematical relativity.*

In this talk we will discuss the recent papers by the author where the geometric evolution equation, Inverse Mean Curvature Flow (IMCF), has been used to define special coordinates in order to show stability of important theorems in mathematical relativity. We will start by introducing the fully nonlinear, parabolic equation and discussing its important geometric properties, as well as introduce theorems from mathematical relativity with little prior background needed. (Received August 27, 2018)

1145-35-284 **Dat T Cao***, Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409, and **Luan T Hoang**, Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409. *Large-time asymptotic expansions in general systems of decaying functions for the Navier-Stokes equations.*

We study the large time behavior of solutions to the three-dimensional Navier-Stokes equations with periodic boundary conditions. It is shown that if the force has an asymptotic expansion, as time goes to infinity, with respect to certain families of decaying functions in Sobolev-Gevrey space, then any weak solution admits an asymptotic expansion of the same type. In particular, we establish the expansions in terms of power decaying forces and the logarithmic and iterated logarithmic decaying ones. This is a joint work with Luan Hoang (Texas Tech University). (Received August 28, 2018)

1145-35-308 **Xinyao Yang*** (xinyao.yang@xjtlu.edu.cn) and **Yuri Latushkin**. *Differential manifolds near a traveling front for multi-dimensional reaction diffusion systems.*

We establish the existence of a stable manifold in the vicinity of a traveling front solution for systems of reaction diffusion equations in multi-dimension that arise in the study of chemical reactions models and solid fuel combustion. In this way we complement the orbital stability results from earlier papers by A. Ghazaryan, Y. Latushkin and X. Yang. The essential spectrum of the differential operator obtained by linearization at the front touches the imaginary axis. In spaces with exponential weights, one can shift the spectrum to the left. We study the nonlinear equation on the intersection of the unweighted and weighted spaces. Small translations of the front form a center unstable manifold. For each small translation we prove the existence of a stable manifold containing the translated front and show that the stable manifolds foliate a small ball centered at the front. (Received August 29, 2018)

1145-35-310 **Giovanni S. Alberti*** (alberti@dima.unige.it), Dipartimento di Matematica, Universita di Genova, Via Dodecaneso 35, 16146 Genova, Italy. *Non-zero constraints in quantitative coupled physics imaging.*

The reconstruction in quantitative coupled physics imaging often requires that the solutions of certain PDEs, e.g. the conductivity equation, the Helmholtz equation or Maxwell's equations, satisfy certain non-zero constraints, such as the absence of critical points. From the mathematical point of view, it is then interesting to see whether one can construct suitable boundary values (the illuminations used to probe the object), possibly independently of the unknown coefficients, in such a way that the corresponding solutions satisfy the required properties. In this talk, I will discuss several techniques used for this aim, as well as some negative results. (Received August 30, 2018)

1145-35-315 **Xin Liu*** (xliu@math.tamu.edu), Department of mathematics, Texas A&M university, College Station, TX 77843-3368, and **Edriss S. Titi**, Department of mathematics, Texas A&M university, College Station, TX 77843-3368. *On the existence and uniqueness of the 3D compressible primitive equations of atmospheric dynamics.*

The vertical scale in the atmosphere is relatively much smaller than the relevant horizontal scales. Capitalizing on this small aspect ratio, formal asymptotic analysis yields the compressible primitive equations for the atmospheric dynamics, which are obtained by replacing the vertical momentum equation in the compressible Navier-Stokes equations by the hydrostatic balance equation. In this talk, we report about recent advances concerning the well-posedness of the 3D compressible primitive equations, in particular, of how to overcome the difficulty caused by the absence of an evolutionary equation for the vertical momentum. (Received September 01, 2018)

1145-35-322 **amna Ali S. Abu Weden*** (aabuweden2014@my.fit.edu) and **ugur Abdulla**. *Interface Development for the Nonlinear Degenerate Multidimensional Parabolic Equations Modeling Reaction-Diffusion Processes.*

We present a full classification of the short-time behavior of the interface in the Cauchy problem for the nonlinear second order degenerate parabolic PDE

$$u_t - \Delta u^m + bu^\beta = 0,\ x \in \mathbb{R}, t > 0$$

with nonnegative and radially symmetric initial function u_0 such that

$$supp\ u_0 \subset \{|x| < R\},\ u_0 \sim C(R - |x|)^\alpha, \quad as\ |x| \to R - 0,$$

where $m > 1, C, \alpha, \beta > 0, b \in \mathbb{R}$. Interface surface $t = \eta(x)$ may shrink, expand or remain stationary depending on the relative strength of the diffusion and reaction terms near the boundary of support, expressed in terms of the parameters $m, \beta, \alpha, sign\ b$ and C. In all cases we prove explicit formula for the interface asymptotics, and local solution near the interface. (Received August 31, 2018)

1145-35-345 **Marie-Therese Wolfram*** (m.wolfram@warwick.ac.uk), Mathematics Institute, University of Warwick, Gibbet Hill Road, Coventry, CV47AL, United Kingdom, and **Adriano Festa** and **Andrea Tosin**. *A kinetic model for pedestrian dynamics.*

In this talk we propose and study a kinetic model for pedestrian dynamics. In this model individuals move in a desired direction, while avoiding collisions with others by stepping aside. These minimal microscopic interaction rules lead to complex emergent macroscopic phenomena, such as velocity alignment in unidirectional flows and lane or stripe formation in bidirectional flows. We start by discussing collision avoidance mechanisms at the microscopic scale, then we study the corresponding Boltzmann-type kinetic description and its hydrodynamic mean-field approximation in the grazing collision limit. In the spatially homogeneous case we prove directional alignment under specific conditions on the sidestepping rules for both the kinetic and the mean-field model. In the spatially inhomogeneous case we illustrate, by means of various numerical experiments, the rich dynamics that the proposed model is able to reproduce. (Received September 03, 2018)

1145-35-362 **Kamran Sadiq*** (kamran.sadiq@ricam.oeaw.ac.at), Altenbergerstrasse 69, 4040 Linz, Austria. *The A-analytic approach to X-ray tomography.*

In this talk I will recall Bukhgeim's approach to the tomography problem in the plane and exemplify it by the reconstruction and range characterization of the attenuated X-ray of symmetric tensors. This is joint work with Alexandru Tamasan and Otmar Scherzer. (Received September 04, 2018)

1145-35-371 **Alexander Pankov***, Department of Mathematics, Morgan State University, E Cold Spring Ln, Baltimore, MD 21251. *Traveling waves in Fermi-Pasta-Ulam lattices with non-local interaction.*

The talk is devoted to traveling waves in FPU type particle chains assuming that each particle interacts with several neighbors on both sides. Making use of variational techniques, we prove that under natural assumptions there exist monotone traveling waves with periodic velocity profile (periodic waves) as well as waves with localized velocity profile (solitary waves). In fact, we obtain periodic waves by means of a suitable version of the Mountain Pass Theorem. Then we get solitary waves in the long wave length limit. (Received September 04, 2018)

1145-35-379 **Yuri Latushkin*** (latushkiny@missouri.edu). *Stability of multidimensional fronts via exponentially weighted spaces.*

We study fronts for systems of reaction diffusion equations of a special type that often appear in combustion theory and chemical reaction models. The spectrum of the linearized operator touches the imaginary axis and therefore the system is studied in the intersection of the original Sobolev space and the space with an exponential weight. In the one-dimensional case we prove the existence of a stable foliation in vicinity of the front and thus

explain orbital stability. In the multidimensional case we prove algebraic decay of perturbations of the planar front.

This is a joint project with Anna Ghazaryan (Miami University), Ronald Schnaubelt (Karlsruhe Institute of Technology, and Xinyao Yang (Xi'an Jiaotong-Liverpool University, Suzhou, China) (Received September 04, 2018)

1145-35-402 **Atanas Stefanov*** (stefanov@ku.edu), Department of Mathematics, 1460, Jayhawk Blvd., Lawrence, KS 66045, and **Iurii Posukhovskyi**. *On the ground states of the Ostrovskyi equation and their stability.*

The Ostrovskyi (Ostrovskyi-Vakhnenko/short pulse) equations are ubiquitous models in mathematical physics. They describe water waves under the action of a Coriolis force as well as the amplitude of a "short" pulse in an optical fiber.

We rigorously construct ground traveling waves for these models. The existence argument proceeds via the method of compensated compactness, but it requires surprisingly detailed Fourier analysis arguments to rule out the non-triviality of the limits of the minimizing sequences. In addition, we show that the waves are strongly spectrally stable, along with other properties: smoothness with respect to parameters, weak non-degeneracy of the waves etc. (Received September 05, 2018)

1145-35-406 **Caleb Mayer** and **Eric Stachura*** (estachur@kennesaw.edu). *Traveling wave solutions for a cancer stem cell invasion model.* Preliminary report.

The study of the dynamics of cellular movement throughout the body has been an area at the forefront of mathematical and biological research in recent years. Understanding the processes inherent to tumor cell movement and migration over time could prove key in better comprehending and finding effective treatments for various cancers.

Despite the importance of the movement of cancer cells, few studies have focused on how more specific populations of cancer cells (as opposed to simply general tumor cell populations) distinctly undertake this invasion. The cancer stem cell (CSC) hypothesis says that the majority of tumor growth is caused by a select sub-population of cancer cells, termed cancer stem cells, which are particularly resistant to the usual treatment strategies. This hypothesis implies that to effectively eliminate tumors and tumor cells, treatment needs to be specifically targeted at CSCs.

In this talk, I will discuss a new model that accounts for the motility of the concentrations of cancer stem cells, differentiated cancer cells, and extracellular matrix within the body. The model is aimed at melanoma cell invasion. This is joint work with Caleb Mayer. (Received September 05, 2018)

1145-35-453 **John David Cobb*** (jdcobb3@gmail.com), **Alex Kasman**, **Albert Serna** and **Monique Sparkman**. *Breather Soliton Interactions for the Quaternionic KdV Equation.*

The KdV equation is fundamental in the description of a wide array of physical phenomena. It remains the prototypical example of a completely integrable nonlinear partial differential equation because of its *n-soliton* solutions, which appear to be composed of n traveling waves that collide in particle-like fashions. Despite this fame, little has been said about KdV solitons in a noncommutative setting. In this project, Darboux transformations were used to produce quaternion-valued solutions to the non-commutative KdV equation. I will describe the nonlinear superposition principle governing the interactions of the breather soliton solutions with other solutions including rational and periodic solutions. Finally, I will examine the kinetics of the general 2-soliton interaction, including a formula for the phase shift which, unlike the commutative case, is not determined by the wave numbers of the constituent 1-solitons. (Received September 06, 2018)

1145-35-464 **Gigliola Staffilani*** (gigliola@mit.edu), MIT room 2-251, Cambridge, MA 02139, and **Bobby Wilson**. *On long time instability of the zero solution to a certain Nonlinear Schrodinger equation.*

The aim of this talk is to analyze the long time instability of the zero solution of the 2D periodic defocusing cubic NLS, while outlining the differences between the dynamics on rational versus irrational tori. In particular we will analyze the structure of the resonance sets in these two different set ups. This instability can also be related to well known phenomena such as energy transfer and forward cascades. (Received September 06, 2018)

1145-35-467 **S Weng***, Room 216, Northeast buliding, College of Science, Wuhan University, Wuhan, Peoples Rep of China. *Subsonic and Transonic shock flows in bounded nozzles.*

This talk basically contains two parts. Part I will treat the structural stability of the radial symmetric transonic shock solution under an axisymmetric perturbation of the nozzle wall. The axisymmetric perturbation of supersonic incoming including a nonzero swirl velocity is also considered. Part II will give a new decomposition of 3D steady Euler system which we call it as deformation-curl decomposition. This is based on the new reformulation of the density equation by using the Bernoulli's law. (Received September 06, 2018)

1145-35-481 **Dipendra Regmi*** (dipendra.regmi@ung.edu), University of North Georgia, 3820 Mundy Mill Rd, Oakwood, GA 30566. *The 2D magneto-micropolar equations with partial dissipation.*

The magneto-micropolar equations model the motion of electrically conducting micro-polar fluids in the presence of a magnetic field. We study the global existence and regularity of classical solutions to the 2D incompressible magneto-micropolar equations with partial dissipation. We establish the global regularity for one case and conditional regularity for other two cases. (Received September 07, 2018)

1145-35-485 **Kazuo Yamazaki*** (kyamazak@ur.rochester.edu), 1017 Hylan Hall, Department of Mathematics, University of Rochester, Rochester, NY 14627. *Magnetohydrodynamics related systems forced by noise.*

The magnetohydrodynamics system consists of the Navier-Stokes equations forced by Lorentz force, coupled with the Maxwell's equations from electromagnetism. In this talk I will discuss some recent results on this system forced by noise, white in time or white in both space and time. The discussion may also include other equations such as the Navier-Stokes equations, Boussinesq system, Hall-magnetohydrodynamics system, Kardar-Parisi-Zhang equation. (Received September 07, 2018)

1145-35-511 **Jean-Daniel Djida** (jeandaniel.djida@usc.es), Departamento de Estatıstica, Analise, Analise Matematica e Optimizacion, Universidade de Santiago de Compostela, 15782 Santiago de Compost, Spain, **Gisele Mophou** (gisele.mophou@univ-antilles.fr), African Institute for, Mathematical Sciences (AIMS), Limbe, 608, Cameroon, and **Pasquini Fotsing Soh*** (pasquini.soh@aims-cameroon.org), African Institute for, Mathematical Sciences (AIMS), Limbe, 608, Cameroon. *Optimal control of diffusion equation with missing data governed by Dirichlet fractional Laplacian.*

We consider an optimal control problem of diffusion equation with missing data governed by the fractional Laplacian with homogeneous Dirichlet boundary conditions on an arbitrary interaction domain disjoint from the domain of the state equation. We assume that the unknown initial condition belongs to an appropriate space of infinite dimension, the so-called space of uncertainties. The key tools we used in order to characterize the optimal control is the no-regret and low-regret control developed by J.L Lions (Received September 08, 2018)

1145-35-515 **W. Y. Chan*** (wychan@tamut.edu), Department of Mathematics, Texas A&M University - Texarkana, 7101 University Drive, Texarkana, TX 75503. *Determining Approximated Critical Domains for Coupled Semilinear Parabolic Equations with a Localized Source.*

Let Ω_1 and Ω_2 be two squared-shape bounded domains in R^2, and $\partial\Omega_1$ and $\partial\Omega_2$ be their boundary, respectively. Suppose that (0,0) is inside Ω_1 and Ω_2. In this paper, we study the quenching set of the first initial-boundary value problem of quenching problems for the following coupled semilinear parabolic equations with localized sources:

$$\begin{aligned}
\frac{\partial u}{\partial t} &= \Delta u + \frac{1}{1-v(0,0,t)} \text{ in } \Omega_1 \times (0,\infty)\,, \\
\frac{\partial v}{\partial t} &= \Delta v + \frac{1}{1-u(0,0,t)} \text{ in } \Omega_2 \times (0,\infty)\,, \\
u(x,y,0) &= 0 \text{ for } (x,y) \in \bar{\Omega}_1 \text{ and } v(x,y,0) = 0 \text{ for } (x,y) \in \bar{\Omega}_2, \\
u(x,y,t) &= 0 \text{ for } t > 0 \text{ and } (x,y) \in \partial\Omega_1 \text{ and } v(x,y,t) = 0 \text{ for } t > 0 \text{ and } (x,y) \in \partial\Omega_2.
\end{aligned}$$

Using a numerical method, we are going to determine the approximated critical domains of the above problem. (Received September 08, 2018)

1145-35-533 **Yavdat Ilyasov*** (ilyasov02@gmail.com), 112, Chernyshevsky str., Ufa, 450008, Russia. *Stable and unstable compact support solutions of non-Lipschitz evolution problems.* Preliminary report.

We consider compact support ground states of the Dirichlet problem for semilinear autonomous elliptic equations with a strong absorption term given by a non-Lipschitz function. We show that these type of solutions for the associated parabolic problems are unstable for dimensions $N = 1, 2$. Then we demonstrate that they can be stable for $N \geq 3$, with certain suitable exponent values of the involved nonlinearites. Furthermore, we discuss a nonuniqueness of (non-)compact support stable solutions of elliptic equations with non-Lipschitz nonlinearities, where the exponent values of these nonlinearites are chosen according to the dimension N. The approach is based on variational methods where Pohozaev's identity together with certain fibering type arguments play a crucial role.

This talk is based on joint work with J. I. Díaz, Y. Egorov and J. Hernández. (Received September 09, 2018)

1145-35-536 **Andrew Lawrie**, **Jonas Luhrmann*** (luehrmann@math.jhu.edu), **Sung-Jin Oh** and **Sohrab Shahshahani**. *Local smoothing estimates for Schrodinger equations on hyperbolic space and applications.*

We establish frequency-localized local smoothing estimates for Schrodinger equations on hyperbolic space. The proof is based on the positive commutator method and a heat flow based Littlewood-Paley theory. Our results and techniques are motivated by applications to the problem of stability of solitary waves to nonlinear Schrodinger-type equations on hyperbolic space. (Received September 09, 2018)

1145-35-556 **Milena Stanislavova*** (stanis@ku.edu), Snow Hall, University of Kansas, Lawrence, KS 66045, and **Satbir Malhi**. *On the energy decay rates for the 1D damped fractional Klein-Gordon equation.*

We consider the fractional Klein-Gordon equation in one spatial dimension, subject to a damping coefficient, which is non-trivial and periodic, or more generally strictly positive on a periodic set. We show that the energy of the solution decays at the polynomial rate $O(t^{-\frac{s}{4-2s}})$ for $0 < s < 2$ and at some exponential rate when $s \geq 2$. Our approach is based on the asymptotic theory of C_0 semigroups in which one can relate the decay rate of the energy in terms of the resolvent growth of the semigroup generator. The main technical result is a new observability estimate for the fractional Laplacian, which may be of independent interest. (Received September 09, 2018)

1145-35-560 **Jing Zhang*** (jizhang@vsu.edu) and **Roberto Triggiani**. *Weak solution and long time behavior of a fluid-plate interaction model.*

We consider a dynamical system consisting of a 3D Stokes equation coupled with a 2D viscoelastic plate equation under the assumption that the transversal displacement of the plate is negligible (therefore the interface can be treated as static). For this model, we prove the existence of the weak solution. We also prove that the system generates a strongly continuous semigroup that is exponentially stable and there exists a compact finite-dimensional global attractor for the system. (Received September 10, 2018)

1145-35-571 **Matthew Badger*** (matthew.badger@uconn.edu). *Free boundary regularity for harmonic measure on multi-phase configurations.*

In free boundary regularity problems for harmonic measure, one seeks to determine the extent to which analytic regularity of the harmonic measure of a domain (with respect to surface measure on the boundary or harmonic measure of a complementary domain) controls the geometric regularity of the boundary of the domain. Work over the last twenty years by several authors have revealed a rich landscape of results in both the one-phase and two-phase settings. In this talk, I will pose a multi-phase extension of Kenig and Toro's two-phase free boundary regularity problem and present our initial findings about blowups of harmonic measure on multi-phase NTA configurations. This is joint work with Murat Akman. (Received September 10, 2018)

1145-35-577 **Junping Wang*** (jwang@nsf.gov), National Science Foundation, 2415 Eisenhower Avenue, Alexandria, VA 22314. *The Basic Principles and Recent Developments of Weak Galerkin Finite Element Methods.*

This talk will introduce the basic principles and some recent developments in weak Galerkin finite element methods for PDEs. The topics to be discussed are: (1) basic concepts of discrete weak differential operators, (2) weak continuity through the use of stabilizers, (3) discretization techniques via constrained minimization, (4) weak Galerkin algorithms for some typical PDEs, (5) numerical integration on general polytope, (6) superconvergence and discrete maximum principles for weak Galerkin approximations, and (7) $W^{2,p}$ theory in weak Galerkin FEM. (Received September 10, 2018)

1145-35-601 **Ngoc Do***, dothanhngocctsp@math.arizona.edu, and **Leonid Kunyansky**. *Theoretically exact solution of the inverse source problem for the wave equation with spatially and temporally reduced data.*

The inverse source problem for the wave equation arises in several promising emerging modalities of medical imaging. Of special interest here are theoretically exact inversion formulas, explicitly expressing solution of the problem in terms of the measured data. Almost all known formulas of this type require data to be measured on a closed surface completely surrounding the object. This, however, is too restrictive for practical applications.

I will present an alternative approach that, under certain restriction on geometry, yields explicit, theoretically exact reconstruction from the data measured on a finite open surface. Numerical simulations illustrating the work of the method will be presented. (Received September 11, 2018)

1145-35-608 **Kristin M. Kurianski*** (kmdett@mit.edu) and **Gigliola Staffilani** (gigliola@math.mit.edu). *Smoothing effect for solutions to the Dysthe equation.* Preliminary report.

The surface behavior of an incompressible, inviscid, irrotational fluid can be described in two dimensions by the Dysthe equation. This equation is derived through a multiple scale expansion in the deep water, small slope regime of the kinematic boundary condition at the surface carried out to the 4th order. Recently, it has been used to model extraordinarily large waves occurring on the ocean's surface called rogue waves. In this talk, we will give a brief derivation of the Dysthe equation along with some theoretical results. We consider an initial profile bounded in L^2 norm and prove a smoothing effect in which we are able to bound uniformly in space the L^2 norm in time of a fractional derivative of the linear solution by the L^2 norm in space of the initial data. This is the Kato smoothing effect. (Received September 11, 2018)

1145-35-625 **Anna L Mazzucato***, Penn State University, University Park, PA 16802. *On the two-dimensional Kuramoto-Sivashinsky equation.*

I will discuss recent results concerning the Kuramoto-Sivashinky equation in two space dimensions with periodic boundary conditions. In particular, I will present a global existence result in the Wiener algebra, when growing modes are absent, and bounds on the analyticity radius when the data is only L^2. This is joint work with David Ambrose (Drexel University). (Received September 11, 2018)

1145-35-649 **Manuel Friedrich**, Einsteinstr. 62, Muenster, Germany, and **Martin Kruzik***, Pod vodarenskou vezi 4, 1 Prague, Czech Rep. *On the passage from nonlinear to linearized viscoelasticity.*

We formulate a quasistatic nonlinear model for nonsimple viscoelastic materials at a fi nite-strain setting in the Kelvin-Voigt rheology where the viscosity stress tensor complies with the principle of time-continuous frame indifference. We identify weak solutions in the nonlinear framework as limits of time-incremental problems for vanishing time increment. Moreover, we show that linearization around the identity leads to the standard system for linearized viscoelasticity and that solutions of the nonlinear system converge in a suitable sense to solutions of the linear one. The same property holds for time-discrete approximations, and we provide a corresponding commutativity result. Our main tools are the theory of gradient flows in metric spaces and Γ-convergence. (Received September 12, 2018)

1145-35-654 **Manuel Friedrich***, manuel.friedrich@uni-muenster.de, and **Martin Kruzik**. *Derivation of von Karman plate theory in the framework of three-dimensional viscoelasticity.* Preliminary report.

We apply a quasistatic nonlinear model for nonsimple viscoelastic materials at a finite-strain setting in the Kelvin's-Voigt's rheology to derive a viscoelastic plate model of von Karman type. We start from solutions to a model of three-dimensional viscoelasticity where the viscosity stress tensor complies with the principle of timecontinuous frame-indifference. Combining the derivation of nonlinear plate theory by Friesecke, James and Mueller, and the abstract theory of gradient flows in metric spaces by Sandier and Serfaty we perform a dimension-reduction from 3D to 2D and identify weak solutions of viscoelastic form of von Karman plates. (Received September 12, 2018)

1145-35-656 **Janak R Joshi*** (janak.joshi@oswego.edu), 198 E Albany Street, Apt 16D, Oswego, NY 13126, and **Joseph Iaia**. *Infinitely many solutions for a semilinear problem on exterior domains with nonlinear boundary condition.*

In this article we prove the existence of an infinite number of radial solutions to $\Delta u + K(r)f(u) = 0$ with a nonlinear boundary condition on the exterior of the ball of radius R centered at the origin in $\mathbb{R}^N$ such that $\lim_{r\to\infty} u(r) = 0$ with any given number of zeros where $f : \mathbb{R} \to \mathbb{R}$ is odd and there exists a $\beta > 0$ with $f0$ on (β, ∞) with f superlinear for large u, and $K(r) \sim r^{-\alpha}$ with $0 < \alpha < 2(N-1)$. (Received September 12, 2018)

1145-35-696 **Zhiyuan Zhang*** (zhiyuan_zhang1@brown.edu), 151 Thayer St, Providence, RI 02906. *Linear Stability Analysis of the Relativistic Vlasov-Maxwell System in an Axisymmetric Domain.*

We consider the plasma confined in a general axisymmetric spatial domain with perfect conducting boundary which reflects particles specularly, and look at a certain class of equilibria, assuming axisymmetry in the problem.

We prove a sharp criterion of spectral stability under these settings. Moreover, we provide several explicit families of stable/unstable equilibria using this criterion. (Received September 13, 2018)

1145-35-710 **Earl H Dowell*** (earl.dowell@duke.edu), **Kevin McHugh** and **Maxim Freydin**. *Nonlinear Response of an Inextensible, Cantilevered Beam/Plate Subjected to a Nonconservative Force.*

The dynamic stability of a cantilevered beam/plate excited by a nonconservative follower force has been studied previously for its interesting dynamical properties and its application to engineering systems such as launch vehicles under thrust loads. However most of the literature considers a linear model. Here a system of nonlinear ordinary differential equations is derived from a new Hamilton's Principle approach for an inextensible beam/plate with a non-conservative force acting upon it. The equations are solved numerically by a time marching algorithm and agreement is shown with published data for the critical bifurcation force. The model readily allows the determination of both in-plane and out of plane deflections. The nonlinear post-critical limit cycle oscillations are also studied. Then it is shown how a different nonconservative force can be incorporated into the model due to the hypersonic flow over the beam/plate. (Received September 13, 2018)

1145-35-758 **Fioralba Cakoni***, Department of Mathematics, Rutgers University, Busch Campus, 228 Hill Center - 110 Frelinghuysen Road, Piscataway, NJ 08854-8019, and **Houssem Haddar** and **Thi Phong Nguyen**. *Single Floquet-Bloch Mode Imaging of Local Perturbations in Periodic Media.*

This paper considers the imaging of local perturbations of an infinite penetrable periodic layer. A cell of this periodic layer consists of several bounded inhomogeneities situated in a known homogeneous media. We use a differential linear sampling method to reconstruct the support of perturbations without using the Green's function of the periodic layer nor reconstruct the periodic background inhomogeneities. The mathematical justification of this imaging method relies on the well-posedeness of a nonstandard interior transmission problem, which until now was an open problem except for the special case when the local perturbation didn't intersect the background inhomogeneities. We show some numerical examples that confirm the theoretical behavior of the differential indicator function determining the reconstructable regions in the periodic layer. (Received September 14, 2018)

1145-35-764 **Alessia E. Kogoj*** (alessia.kogoj@uniurb.it), University of Urbino, Piazza della Repubblica 13, 61029 Urbino, PU, Italy, and **Ermanno Lanconelli** (ermanno.lanconelli@unibo.it), University of Bologna, Piazza di Porta San Donato 5, 40126 Bologna, Italy. *On the Dirichlet problem in cylindrical domains for evolution Oleinik–Radkevic PDE's : a Thychonov-type theorem.*

We are concerned with linear second order PDE's of the type:

$$\mathcal{L} = \mathcal{L}_0 - \partial_t := \sum_{i,j=1}^{n} \partial_{x_i}(a_{i,j}\partial_{x_j}) - \sum_{j=i}^{n} b_j \partial_{x_j} - \partial_t.$$

We assume $\mathcal{L}_0$ with nonnegative characteristic form and satisfying the Oleinik-Radkevic rank hypoellipticity condition. By using Potential Theory, these hypotheses allow to construct Perron-Wiener solutions of the Dirichlet problems for $\mathcal{L}$ and $\mathcal{L}_0$ on bounded open subsets of $\mathbb{R}^{n+1}$ and of $\mathbb{R}^n$, respectively.

Our main result is the following Thychonov-type Theorem:

Let $O := \Omega\times]0,T[$ be a bounded cylindrical domain of $\mathbb{R}^{n+1}$, $\Omega \subset \mathbb{R}^n, x_0 \in \partial\Omega$ and $0 < t_0 < T$. Then $z_0 = (x_0, t_0) \in \partial O$ is $\mathcal{L}$-regular for O if and only if x_0 is $\mathcal{L}_0$-regular for Ω.

As an application of our Main Theorem we show some regularity criteria for the boundary point in the Dirichlet problem for degenerate Ornstein- Uhlenbeck operators, as consequences of analogous criteria for Kolmogorov-Fokker-Planck equations. (Received September 14, 2018)

1145-35-779 **Alex A. Himonas**, **Dionyssios Mantzavinos*** (mantzavinos@ku.edu) and **Fangchi Yan**. *Initial-Boundary Value Problems for the Reaction-Diffusion Equation.*

The reaction-diffusion equation supplemented with Dirichlet boundary conditions either on the half-line or on a finite interval is shown to be locally well-posed in the sense of Hadamard for data in Sobolev spaces H^s. In both domains, the proof takes advantage of a novel solution formula for the forced linear heat equation obtained via the unified transform method of Fokas. This formula provides the basis for setting up a Picard iteration scheme for the nonlinear problem and for establishing the various linear estimates required for showing local well-posedness via a contraction mapping argument. In this latter context, interesting and somewhat unexpected estimates are derived not only at the level of the initial-boundary value problems but also in connection with the linear heat initial value problem. (Received September 14, 2018)

1145-35-788 **Laszlo P. Kindrat***, laszlokindrat@gmail.com, and **Marianna Shubov**. *Asymptotics of the eigenfrequencies of the Euler-Bernoulli beam with fully non-dissipative boundary feedback.*

This talk is concerned with the distribution of natural frequencies of the Euler-Bernoulli beam subject to fully non-dissipative boundary conditions. The beam is clamped at the left end and equipped with a 4-parameter $(\alpha, \beta, k_1, k_2)$ linear boundary feedback law at the right end. The 2×2 boundary feedback matrix of control parameters relates the control input (a vector of velocity and its spatial derivative at the right end), to the output (a vector of shear and moment at the right end). The role of the control parameters is examined and asymptotic results about the spectrum of the dynamics generator are presented. (Received September 14, 2018)

1145-35-804 **Marco Bonacini**, **Elisa Davoli** and **Marco Morandotti*** (marco.morandotti@polito.it), Italy. *Analysis of a perturbed Cahn-Hilliard model for Langmuir-Blodgett films.* Preliminary report.

An advective Cahn-Hilliard model motivated by thin film formation is studied in this paper. The one-dimensional evolution equation under consideration includes a transport term, whose presence prevents from identifying a gradient flow structure. Existence and uniqueness of solutions, together with continuous dependence on the initial data and an energy equality are proved by combining a minimizing movement scheme with a fixed point argument. Finally, it is shown that, when the contribution of the transport term is small, the equation possesses a global attractor and converges, as the transport term tends to zero, to a purely diffusive Cahn-Hilliard equation. (Received September 15, 2018)

1145-35-827 **Alex Timonov*** (atimonov@uscupstate.edu). *A Regularisation of the Robin Problem for Functions of The Weighted Least Gradient.*

The inverse conductivity problem of Current Density Imaging is considered. It is formulated in terms of the weighted Robin least gradient problem. The problem can also be recast as the weighted 1-Laplacian subject to the Robin boundary condition. Such a model is equivalent to Complete Electrode Model. Since the boundary voltage potential is not assumed, the inverse problem does not possess uniqueness. Therefore, the problem needs to be regularised to obtain an approximate solution. The regularised weighted least gradient functionals are introduced, and their relaxation property is established. The latter is exploited as a theoretical basis for constructing the relaxation iterative algorithm. The computational effectiveness of the proposed algorithm is demonstrated in the numerical experiments. This is the joint project with Alexandru Tamasan. (Received September 15, 2018)

1145-35-833 **Viktoria Savatorova** (viktoria.savatorova@unlv.edu) and **Aleksei Talonov*** (aleksei.talonov@unlv.edu). *High-frequency homogenization for modeling acoustic waves propagation in multi-scale periodic media.* Preliminary report.

An asymptotic high-frequency homogenization procedure is developed for acoustic waves propagation in multi-scale periodic heterogeneous medium. There are several characteristic length scales in our model. The medium consists of representative elementary volumes (REVs) repeating themselves periodically. Each REV has its own periodic structure of smaller blocks of heterogeneous materials. The smallest spatial scale is the size of a heterogeneity that is a miscrocrack or a micropore. The wave length exceeds the size of particular heterogeneity and the size of a block of heterogeneities, but it has the same order of magnitude as the REV. Resulting homogenized equations are deduced explicitly dependent on the macroscale with micro- and mesoscale represented by integral quantities. Dispersion relation has been derived for the case of one-dimensional periodic medium. Its solution reveals waves' attenuation and indicates that due to peculiarities of structure on micro and mezo levels some frequencies of waves can be forbidden from propagating through the material. (Received September 15, 2018)

1145-35-848 **Xiaokai Huo***, G2056, Thuwal, Makkah 63955, Saudi Arabia, and **Ansgar Jüngel** and **Athanasios Tzavaras**. *Euler flows for multicomponent fluids.*

We consider the high-friction limit of Euler-Korteweg equations for fluid mixtures. The convergence of the solutions towards the zeroth-order limiting system and the first-order correction is shown, assuming suitable uniform bounds. Using the relative entropy method, we establish the weak-strong convergence to the first order expansion system: a Maxwell-Stefan type hyperbolic-parabolic system. Finally, the limit towards the zeroth-order system is shown for smooth solutions in the isentropic case and for weak-strong solutions in the Euler-Korteweg case, also including constant capillarities. (Received September 16, 2018)

1145-35-850 **B Chase Russell*** (bchaserussell@psu.edu), 1 Prischak Building, Penn State, Erie–The Behrend College, Erie, PA 16563. *Quantitative homogenization with relatively soft inclusions.*

From filled resins in a dentist's office to fiberglass on an airplane wing, composite materials are used in a variety of ways. Unfortunately, complex microstructures make composite materials difficult to analyze; constituents generally vary at a fine scale ε and affect the global behavior of the material. In this talk, we discuss homogenization of systems of linear elasticity with rapidly oscillating periodic coefficients and Dirichlet boundary conditions in domains with periodically placed inclusions of size $\mathcal{O}(\varepsilon)$ and magnitude δ by establishing H^1-convergence rates. From these rates, interior estimates at the macroscopic scale may be derived directly without the use of compactness via a Campanato-type scheme presented by S. Armstrong and C.K. Smart and further developed for uniformly elliptic equations in by Armstrong and Z. Shen. (Received September 16, 2018)

1145-35-854 **Jianliang Qian*** (jqian@msu.edu), Department of Mathematics, Michigan State University, East Lansing, MI 48824, and **Wangtao Lu** and **Robert Burridge**. *Hadamard-Babich ansatz for Maxwell's equations in inhomogeneous media.*

Starting from Hadamard's method, we extend Babich's ansatz to the frequency-domain point-source (FDPS) Maxwell's equations in an inhomogeneous medium in the high-frequency regime. First, we develop a novel asymptotic series, dubbed Hadamard's ansatz, to form the fundamental solution of the Cauchy problem for the time-domain point-source (TDPS) Maxwell's equations in the region close to the source. Governing equations for the unknowns in Hadamard's ansatz are then derived. In order to derive the initial data for the unknowns in the ansatz, we further propose a condition for matching Hadamard's ansatz with the homogeneous-medium fundamental solution at the source. Directly taking the Fourier transform of Hadamard's ansatz in time, we obtain a new ansatz, dubbed the Hadamard-Babich ansatz, for the FDPS Maxwell's equations. Next, we elucidate the relation between the Hadamard-Babich ansatz and a recently proposed Babich-like ansatz for solving the same FDPS Maxwell's equations. Finally, incorporating the first two terms of the Hadamard-Babich ansatz into a planar-based Huygens sweeping algorithm, we solve the FDPS Maxwell's equations at high frequencies in the region where caustics occur. Numerical experiments demonstrate the accuracy of our method. (Received September 16, 2018)

1145-35-862 **Ru-Yu Lai*** (rylai@umn.edu), 206 Church St. SE, Minneapolis, MN 55455, and **Yi-Hsuan Lin** (yihsuanlin3@gmail.com), P.O. Box 35 (MaD), 40014 Jyvaskyla, Jyvaskyla, Finland. *Global uniqueness for the semilinear fractional Schrödinger equation.*

We study global uniqueness in an inverse problem for the fractional semilinear Schrödinger equation $(-\Delta)^s u + q(x,u) = 0$ with $s \in (0,1)$. We show that an unknown function q(x,u) can be uniquely determined by the Cauchy data set. In particular, this result holds for any space dimension greater than or equal to 2. Moreover, we demonstrate the comparison principle and provide a L^∞ estimate for this nonlocal equation under appropriate regularity assumptions (Received September 16, 2018)

1145-35-878 **Lina Wu*** (lwu@bmcc.cuny.edu), 529 West 42nd Street Apt. 5K, New York, NY 10036, and **Jia Liu**. *Numerical Iterative Method in solutions to Navier-Stokes Equations as In-compressible Fluid Flow Models.* Preliminary report.

We are interested in discovering new numerical solvers for Navier-Stokes equations by using preconditioned Krylov subspace iterative methods. We would like to show the robust behaviors for Navier-Stokes problems as fluid flow models, such as in fluid motion, in fluid pressure, and in fluid force. At the end of this presentation, we will test the stability from equilibrium solutions to Navier-Stokes equations with regards to interruptions. (Received September 16, 2018)

1145-35-880 **Jared Speck*** (jared.speck@vanderbilt.edu), Department of Mathematics, Vanderbilt University, 1412 Stevenson Center, Nashville, TN 37240. *Singularity Formation in General Relativity.*

I will discuss new results, joint with Rodnianski, that yield constructive information about the formation of singularities in solutions to Einstein's equations without symmetry. Specifically, we showed that for an open set of smooth initial data falling under the scope of Hawking's incompleteness theorem, the geodesic incompleteness coincides with curvature blowup. Compared to our prior work, our analytical framework is more robust and is not based on approximate monotonicity identities. This allows us to treat initial data exhibiting moderate spatial anisotropy, thus going beyond the regime of nearly spatially isotropic initial data. Our approach applies to open sets of initial data for the Einstein-vacuum equations in high spatial dimensions and to the Einstein-scalar field system in any number of spatial dimensions. From an analytic perspective, the main theorems are stable blowup results for quasilinear systems of elliptic-hyperbolic PDEs. I will survey these results and explain how they are tied to some of the main themes of investigation by the mathematical general relativity community. I will also discuss the role of geometric and gauge considerations in the proofs, as well as intriguing connections to other problems concerning stable singularity formation. (Received September 16, 2018)

1145-35-887 **Felipe Linares*** (linares@impa.br), IMPA, Estrada Dona Castorina, 110, Rio de Janeiro, 22460-320. *Large Data Scattering for Supercritical Generalized KdV.*

We study the long time behavior of solutions to the generalized Korteweg-de Vries equation. Our approach is based on the Kenig-Merle concentration-compactness/rigidity Theory. This is joint work with L. Farah, A. Pastor and N. Visciglia (Received September 17, 2018)

1145-35-905 **Zachary J Bailey*** (zbailey0130@gmail.com), Temple University, 1805 N Broad St, Wachman Hall 522, Philadelphia, PA 19122. *Some Inverse Problems For Hyperbolic Partial Differential Equations.*

We consider four inverse problems for hyperbolic PDEs with two of them associated with one space dimension and two of them associated with three space dimensions.

The first two problems are inverse problems associated to one space dimensional hyperbolic systems of PDEs with complex coefficients where the goal is the recovery of a single complex coefficient from either the reflection data or the transmission data. We show that the map sending the coefficient to the reflection/transmission data is injective and stable and we also characterize the range of this map for the transmission data case.

The other two problems are associated with a single hyperbolic PDE with a zero order coefficient and the goal is the recovery of this coefficient from two different types of "backscattering data" - backscattering data coming from a fixed offset distribution of sources and receivers on the boundary or backscattering data coming from a single incoming spherical wave. For these problems we prove a stability result provided the difference of the two coefficients is horizontally or angularly controlled respectively.

Our work adapts the techniques used by Eemeli Blåsten, Rakesh and Gunther Uhlmann to solve problems similar to theirs. (Received September 17, 2018)

1145-35-906 **George H Lytle*** (george.lytle@uky.edu), 715 Patterson Office Tower, Lexington, KY 40506. *Approximations in the Direct Problem for Impedance Tomography.* Preliminary report.

The medical imaging technique known as electrical impedance tomography (EIT) is related to the inverse conductivity problem first posed by Calderón in 1980. In dimension two, Nachman made the breakthrough by providing a solution for the recovery of a sufficiently regular conductivity from the corresponding Dirichlet-to-Neumann map. This occurs by solving for the trace of complex geometric optic (CGO) solutions on the boundary and using these to define the nonphysical scattering transform. In this talk, we show that Nachman's integral equations still hold for bounded conductivities σ in the unit disk $\mathbb{D}$ if there is an $r \in (0,1)$ such that $\sigma(x) \equiv 1$ for $|x| \geq r$. We also show that if σ_n is a sequence of smooth functions that converge to σ pointwise, the corresponding scattering transforms converge as well.

This is joint work with Peter Perry and Samuli Siltanen. (Received September 17, 2018)

1145-35-945 **Subhash Subedi*** (sxs2754@louisiana.edu), P.O. Box 41315, Lafayette, LA 70504, and **Aghalaya S. Vatsala**. *Blow-up Results for One Dimensional Caputo Fractional Reaction Diffusion Equation.*

We study the blow up problems for ordinary Caputo fractional differential equation and the time dependent Caputo-fractional reaction diffusion equation in one dimensional space. We establish that the solution of the differential equation of integer order can be used as a tool to construct a lower solution to the equation of the fractional order, under suitable condition. Hence, we obtain the blow up of the solution of the differential equation of integer order implies that the blow up of the solution of the differential equation of fractional order.For that purpose, we use the known comparison results of Caputo ordinary fractional and Caputo fractional reaction diffusion equation. (Received September 17, 2018)

1145-35-984 **Alex A. Himonas** (himonas@nd.edu), **Dionyssios Mantzavinos** (mantzavinos@ku.edu) and **Fangchi Yan*** (fyan1@nd.edu). *Well-posedness of initial-boundary value problems for NLS and KdV via the Fokas Method.*

We shall discuss the well-posedness of initial-boundary value problems (ibvp) for the Korteweg-de Vries (KdV) and the nonlinear Schödinger (NLS) equations using a novel approach which is based on the solution formula produced via Fokas' unified transform method for the associated forced linear ibvp. Replacing in this formula the forcing by the nonlinearity and using data in Sobolev spaces suggested by the space-time regularity of the Cauchy problem of the corresponding linear equation gives an iteration map for the ibvp which is shown to be a contraction in an appropriately chosen solution space. (Received September 17, 2018)

1145-35-1035 **Katharine Ott*** (kott@bates.edu). *The mixed problem for the linear Stokes system.* Preliminary report.

This talk will report on progress on the study of well-posedness of the L^p mixed boundary value problem for the linear Stokes system in Lipschitz domains in the plane. This is a continuation of joint work with S. Kim and R. Brown. (Received September 18, 2018)

1145-35-1036 **Tahir Bachar Issa***, 230 Opelika Road Apt 201, Auburn, AL 36830, and **Wenxian Shen**. *Dynamics in Chemotaxis Models of Parabolic-Elliptic Type on Bounded Domain with Time and Space Dependent Logistic Sources.*

This paper considers the dynamics of a chemotaxis system of parabolic-elliptic type with local as well as nonlocal time and space dependent logistic source on bounded domains. We first prove the local existence and uniqueness of classical solutions for various initial functions. Next, under some explicit conditions on the coefficients, the chemotaxis sensitivity χ and the space dimension n, we prove the global existence and boundedness of classical solutions with certain given integrable or uniformly continuous nonnegative initial functions. Then, under the same conditions for the global existence, we show that the system has an entire positive classical solution. Finally, under some further explicit assumptions, we prove that the system has a unique entire positive solution which is globally stable. Furthermore, if the coefficients are periodic or almost periodic in t, then the unique entire positive solution is also periodic or almost periodic in t. (Received September 18, 2018)

1145-35-1038 **Olivier Pinaud***, pinaud@math.colostate.edu. *A backscattering model based on corrector theory of homogenization for the random Helmholtz equation.*

This work concerns the analysis of wave propagation in random media. Our medium of interest is sea ice, which is a composite of a pure ice background and randomly located inclusions of brine and air. From a pulse emitted by a source above the sea ice layer, the main objective is to derive a model for the backscattered signal measured at the source/detector location. The problem is difficult in that, in the practical configuration we consider, the wave impinges on the layer with a non-normal incidence. Since the sea ice is seen by the pulse as an effective (homogenized) medium, the energy is specularly reflected and the backscattered signal vanishes in a first order approximation. What is measured at the detector consists therefore of corrections to leading order terms, and we focus in this work on the homogenization corrector. We describe the propagation by a random Helmholtz equation, and derive an expression of the corrector in this layered framework. We moreover obtain a transport model for quadratic quantities in the random wavefield in a high frequency limit. This is joint work with W. Jing. (Received September 18, 2018)

1145-35-1051 **Eric A. Autry*** (eric.autry@duke.edu), **Alvin Bayliss** and **Vladimir A. Volpert**. *Biological Control with Nonlocal Interactions.*

We consider a three-species food chain model with ratio-dependent predation, where species u is preyed upon by species v, which in turn is preyed upon by species w. Our primary focus is on biological control, where the bottom species u is an important crop, and v is a pest that has infested the crop. The superpredator w is introduced into this pest-infested environment in an attempt to restore the system to a pest-free state. We assume that the species can behave nonlocally, where individuals will interact over a distance, and incorporate this nonlocality into the model. For this model, we consider two types of nonlocality: one where the crop species u competes nonlocally with itself, and the other where the superpredator w is assumed to be highly mobile and therefore preys upon the pest v in a nonlocal fashion. We examine how biological control can prove to be highly susceptible to noise, and can fail outright if the pest species is highly diffusive. We show, however, that control can be restored if the superpredator is sufficiently diffusive, and that robust partial control can occur if the superpredator behaves nonlocally. Since the superpredator is generally introduced artificially, our results point to properties of the superpredator which can lead to successful control. (Received September 18, 2018)

1145-35-1053 **Xuming Xie*** (xuming.xie@morgan.edu), Dept. of Math., Morgan State University, Baltimore, MD 21251. *Existence and Selection of Saffman-Taylor Fingers by Kinetic Undercooling.*

The selection of Saffman-Taylor fingers by surface tension has been extensively investigated. In this paper we are concerned with the existence and selection of steadily translating symmetric finger solutions in a Hele-Shaw cell by small but non-zero kinetic undercooling (ϵ^2). We rigorously conclude that for relative finger width λ near one half, symmetric finger solutions exist in the asymptotic limit of undercooling $\epsilon^2 \rightarrow 0$ if the Stokes multiplier for a relatively simple nonlinear differential equation is zero. This Stokes multiplier S depends on the parameter $\alpha \equiv \frac{2\lambda-1}{(1-\lambda)}\epsilon^{-\frac{4}{3}}$ and earlier calculations have shown this to be zero for a discrete set of values of α. While this result is similar to that obtained previously for Saffman-Taylor fingers by surface tension, the analysis for the problem with kinetic undercooling exhibits a number of subtleties. The main subtlety is the behavior of the Stokes lines at the finger tip, where the analysis is complicated by non-analyticity of coefficients in the governing equation.
(Received September 18, 2018)

1145-35-1055 **Jeremy LeCrone*** (jlecrone@richmond.edu), **Ivan Blank** and **Brian Benson**. *Mean Value Theorems for Riemannian Manifolds via the Obstacle Problem.*

In this talk, we discuss recent results regarding a formulation of the Mean Value Theorem for the Laplace-Beltrami operator on smooth Riemannian manifolds. We define the sets upon which mean values of (sub)-harmonic functions are computed via a particular obstacle problem in geodesic balls. After discussing obstacle problems are leveraged to produce our Mean Value Theorem, we explore local and global theory for our family of mean value sets and connections between the properties of these sets and the geometry of the underlying manifold. (Received September 18, 2018)

1145-35-1085 **Curtis A Holliman***, 620 Michigan Ave NE, Washington, DC 20064, and **Alex A Himonas**. *Ill-Posedness for a Camassa-Holm-type equations with cubic nonlinearities.*

We consider nonlocal integrable PDEs with cubic nonlinearities that are related to the Camassa-Holm equation. We use the fact that these equations have multipeakon solutions to construct specific solutions that generate peakon collisions. We examine the collisions in Sobolev spaces with exponent less than 3/2 to show that at the collision time, the properties of the solution and the time reversibility of the equations lead to ill-posedness. This talk is based on work with Professor Alex Himonas (University of Notre Dame) and Professor Carlos Kenig (University Chicago). (Received September 18, 2018)

1145-35-1087 **Alex A. Himonas*** (himonas.1@nd.edu), Department of Mathematics, University of Notre, Hurley 255, Notre Dame, IN 46556. *Lower bounds on the radius of spatial analyticity for nonlinear evolution equations.*

In this talk we will discuss lower bounds on the radius of spatial analyticity for solutions of the Cauchy problem of two important integrable evolutions equations, namely, the Camassa-Holm and Korteweg-de Vries equations. For a class of analytic initial data with a given uniform radius of analyticity, we shall present asymptotic lower bounds on the uniform radius of analyticity at time t, as t goes to infinity. The talk is based on works with Professors G. Petronilho, R. Barostichi, S. Selberg, H. Kalisch. (Received September 18, 2018)

1145-35-1095 **Barbara Lee Keyfitz*** (keyfitz.2@osu.edu), Department of Mathematics, The Ohio State University, 231 West 18th Avenue, Columbus, OH 43210-1174. *Where Do Solutions to Conservation Laws Live?* Preliminary report.

Systems of conservation laws in a single space variable are (roughly speaking) well-posed in the space of functions of bounded variation. Linear multidimensional hyperbolic partial differential equations are well-posed in Sobolev spaces H^s (for any s) and quasilinear systems enjoy short-time well-posedness for sufficiently large s. A number of researchers have looked at weak solutions of one-dimensional conservation laws with a view to bridging the gap between these theories. I will summarize their results, and outline some approaches that will not work, and some that may have some promise. (Received September 18, 2018)

1145-35-1100 **Baoling Ma*** (baoling.ma@millersville.edu) and **Qihua Huang** (qihua@swu.edu.cn). *A Juvenile-Adult Model for an Amphibian Population with Distributed Birth and Metamorphosis Rates.* Preliminary report.

Habitat destruction, alteration and fragmentation, climate change, and pollution are most serious causes of amphibian population declines worldwide. Amphibian larvae respond to environmental changes by varying metamorphosis rate, or size at metamorphosis. A general mathematical model is developed where larvae may metamorphose into adult frogs of different sizes and at different rates. A finite difference scheme is developed to numerically solve the model. Convergence of this scheme to a weak solution with bounded total variation is proved. Numerical simulations are provided to understand the effects of distributed metamorphosis rates in an urban American green tree frog (*Hyla cinerea*) population. (Received September 18, 2018)

1145-35-1107 **Suleyman Ulusoy*** (suleyman.ulusoy@aurak.ac.ae), American University of Ras Al Khaimah, Ras Al Khaimah, RAK 10021, United Arab Emirates. *On nonlocal Keller-Segel type equations.*

In the first part of the talk we will investigate a Keller-Segel model with quorum sensing and a fractional diffusion operator. This model describes the collective cell movement due to chemical sensing with flux limitation for high cell densities and with anomalous media represented by a nonlinear, degenerate fractional diffusion operator. The purpose here is to introduce and prove the existence of a properly defined entropy solution. In the second part of the talk we will analyze an equation that is gradient flow of a functional related to Hardy-Littlewood-Sobolev inequality in whole Euclidean space R^d, $d \geq 3$. Under the hypothesis of integrable initial data with finite second moment and energy, we show local-in-time existence for any mass of "free-energy solutions", namely weak solutions with some free energy estimates. We exhibit that the qualitative behavior of solutions is decided by a critical value. The motivation for this part is to generalize Keller-Segel model to higher dimensions. (Received September 19, 2018)

1145-35-1141 **Jeffrey Schenker**, **F Zak Tilocco** and **Shiwen Zhang*** (zhangshiwen@math.msu.edu). *Diffusion in the Mean for a Periodic Schrödinger Equation Perturbed by a Fluctuating Potential.*

We consider the solution to a tight-binding, periodic Schrödinger equation with a random potential evolving stochastically in time. If the potential evolves according to a stationary Markov process we obtain a positive, finite diffusion constant for the evolution of the solution. More generally, we show that the square amplitude of the wave packet, after diffusive rescaling, converges to a solution of the heat equation. This work generalizes the previous results of Y. Kang and J. Schenker on the free Laplacian and J. Schenker on the Anderson model (Joint work with J. Schenker and F Zak Tilocco). (Received September 19, 2018)

1145-35-1144 **Laura Dawn Croyle*** (lcroyle@bw.edu), Baldwin Wallace University, Department of Mathematics, 275 Eastland Rd, Berea, OH 44017, and **Russell Brown**. *Estimates for the L^p Mixed Boundary Value Problem in $C^{1,1}$ Domains.* Preliminary report.

We look at the mixed boundary value problem for elliptic operators in a bounded $C^{1,1}$ domain. The boundary of the domain Ω is decomposed into disjoint parts, D and N, with Dirichlet and Neumann 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 19, 2018)

1145-35-1179 **Anudeep Kumar Arora***, ana001@fiu.edu, and **Svetlana Roudenko**. *Singularities and global solutions in the Schrödinger Hartree equation.*

We consider a nonlinear Schrödinger type equation with nonlocal nonlinearity, of a convolution type, called the generalized Hartree equation. In the focusing case we investigate global behavior of solutions and formation of stable singularities. In the inter-critical regime we first obtain a dichotomy for global vs finite time existing solutions exhibiting two methods of obtaining scattering: one via Kenig-Merle concentration - compactness and another one is using Dodson-Murphy approach via Morawetz on Tao's scattering criteria. Next, we investigate stable blow-up solutions in a critical regime and describe the blow-up dynamics, which is similar to NLS. This work is a part of the PhD dissertation under the supervision of Svetlana Roudenko. (Received September 19, 2018)

1145-35-1187 **Luiz G Farah*** (lgfarah@gmail.com), UFMG - ICEx - Dep. Matemática, Av. Antônio Carlos, 6627 - Caixa Postal 702, CEP: 31270-901, Belo Horizonte, MG 30380300, Brazil. *On the supercritical gKdV equation.*

In this talk, I plan to discuss some results for the supercritical gKdV equation, such as well-posedness, existence of maximizers for Airy-Strichartz inequalities, concentration of blow-up solutions and scattering. These results were obtained in collaboration with Ademir Pastor, Brian Pigott, Felipe Linares, Henrique Versieux and Nicola Visciglia. The author was partially supported by CNPq-Brazil and FAPEMIG-Brazil. (Received September 19, 2018)

1145-35-1192 **Guoping Zhang*** (guoping.zhang@morgan.edu), 1700 E Cold Spring Ln, Baltimore, MD 20854, and **Mingchao Cai** (mingchao.cai@morgan.edu). *Normal Mode Analysis of 3D Incompressible Viscous Fluid Flow Models.* Preliminary report.

In this talk, we investigate the normal mode solutions of 3D incompressible viscous fluid flow models with no-slip boundary condition. The obtained theoretical results are then applied to analyze several time-stepping schemes for the numerical solutions of the 3D incompressible fluid flow models. (Received September 19, 2018)

1145-35-1195 **Pelin Guven Geredeli*** (pguvengeredeli2@unl.edu), University of Nebraska Lincoln, 1400 R St Department of Mathematics, Lincoln, NE 68588, and **George Avalos** and **Justin Webster**. *Semigroup Wellposedness of A Linearized Compressible Flow-Plate Interaction Under Varying Boundary Interface Coupling Conditions.*

We address semigroup wellposedness for a linear, compressible viscous fluid interacting at its boundary with an elastic plate. We derive the model by linearizing the compressible Navier-Stokes equations about an arbitrary flow state, so the fluid PDE includes an ambient flow profile $\mathbf{U}$. The non-dissipative flow structure model is considered (i) with a pure velocity matching condition at the interface; (ii) with an interface condition given in terms of the material derivative of the structure, $(\partial_t + \mathbf{U} \cdot \nabla)w$. We adopt here a Lumer-Phillips approach, with a view of associating fluid-structure solutions with a C_0-semigroup $e^{\mathcal{A}t}{}_{t\geq 0}$ on a suitable finite energy space of initial data. (Received September 19, 2018)

1145-35-1203 **Jun Geng** and **Jinping Zhuge*** (jinping.zhuge@uky.edu). *Oscillatory integrals and homogenization of elliptic systems with Robin boundary condition.*

In this talk, we will consider elliptic systems with rapidly oscillating coefficients and a Robin boundary condition,

$$\begin{cases} -\mathrm{div}(A(x/\varepsilon)\nabla u_\varepsilon) = F & \text{in } \Omega, \\ \dfrac{\partial u_\varepsilon}{\partial \nu_\varepsilon} + b(x/\varepsilon)u_\varepsilon = g & \text{on } \partial\Omega, \end{cases}$$

where $\partial/\partial\nu_\varepsilon$ denotes the conormal derivative. We assume A and b are both 1-periodic and $\varepsilon > 0$ is a small parameter. To study the above equation under minimal assumptions, we consider the oscillatory integral $\int_S f(\lambda x)g(x)d\sigma$, where $S = \partial\Omega$ is a Lipschitz surface. We show that if S satisfies a non-resonance condition, $f(y)$ is continuous and 1-periodic, and $g \in L^1(S, d\sigma)$, then

$$\lim_{\lambda\to\infty} \int_S f(\lambda x)g(x)d\sigma = \int_{[0,1]^d} f(x)dx \int_S g(x)d\sigma.$$

We show this result implies the qualitative homogenization theorem for the previous equation, if $\partial\Omega$ satisfies a resonance condition. Furthermore, under additional geometric and smooth conditions, we also obtain a rate of convergence. (Received September 20, 2018)

1145-35-1206 **Shijun Zheng*** (szheng@georgiasouthern.edu), Department of Mathematical Sciences, Georgia Southern University, Statesboro, GA 30460. *Virial identity for nonlinear dispersive equations.* Preliminary report.

I will discuss the use of virial type identity for showing scattering, blowup and asymptotic stability for dispersive equations including nonlinear magnetic Schroedinger equation, fractional hartree equation as well as Dirac equation. In the energy-subcritical regime, the proof might involve local versions for the virial and Pohozaev identities. (Received September 20, 2018)

1145-35-1211 **Peng Xie*** (xiep14@mails.tsinghua.edu.cn), Zhou Pei-Yuan Center for Applied Mathematics, Tsinghua University, Beijing, 100084, Peoples Rep of China, and **Yi Zhu** (yizhu@tsinghua.edu.cn), Zhou Pei-Yuan Center for Applied Mathematics, Tsinghua University, Beijing, 100084, Peoples Rep of China. *Wave-packet dynamics in a slowly modulated photonic graphene.* Preliminary report.

Mathematical analysis on electromagnetic waves in photonic graphene, a photonic topological material which has a honeycomb structure, is one of the most important current research topics. By modulating the honeycomb structure, numerous topological phenomena have been observed recently. The electromagnetic waves in such a media are generally described by the 2-dimensional wave equation. It has been shown that the corresponding elliptic operator with a honeycomb material weight has Dirac points in its dispersion surfaces. In this article, we study the time evolution of the wave-packets spectrally concentrated at such Dirac points in a modulated honeycomb material weight. We prove that such wave-packet dynamics is governed by the Dirac equations with a varying mass in a large but finite time. Our analysis provides mathematical insights to those topological phenomena in photonic graphene. (Received September 20, 2018)

1145-35-1221 **Zilong Song*** (buctsongzilong@163.com), **Xiulei Cao** and **Huaxiong Huang**.
Electro-neutral models for a dynamic Poisson-Nernst-Planck System.

The Poisson-Nernst-Planck (PNP) system is a standard model for describing ion transport. In many applications, e.g., ions in biological tissues, the presence of thin boundary layers poses both modelling and computational challenges. In this talk, we derive simplified electro-neutral (EN) models in multi-dimensional space where the thin boundary layers are replaced by effective boundary conditions. First of all, it is much cheaper to solve the EN models numerically. Secondly, EN models are easier to deal with compared with the original PNP system, therefore it is also easier to derive macroscopic models for cellular structures using EN models. The multi-ion case with general boundary is considered, for a variety of boundary conditions including either Dirichlet or flux boundary conditions. Using systematic asymptotic analysis, we derive a variety of effective boundary conditions directly applicable to the EN system for the bulk region. To validate the EN models, numerical computations are carried out for both the EN and original PNP system, including the propagation of action potential for both myelinated and unmyelinated axons. Our results show that solving the EN models is much more efficient than the original PNP system. (Received September 20, 2018)

1145-35-1225 **Audison Beaubrun*** (abeaubrun2013@my.fit.edu), Florida Institute of Technolgy, Department of Mathematical Sciences, 150 W University Blvd, Melbourne, FL 32901, and **Tariel Kiguradze**, Florida Institute of Technology, Department of Mathematical Sciences, 150 W University Blvd, Melbourne, FL 32901. *Periodic Problems for Higher Order Nonlinear Hyperbolic Equations.*

For the equation

$$u^{(\mathbf{m})} = f(\mathbf{x}, \widehat{\mathcal{D}}^{\mathbf{m}}[u]), \tag{1}$$

consider the periodic

$$u(\mathbf{x} + \boldsymbol{\omega}_j) = u(\mathbf{x}) \quad (j = 1, \ldots, n) \tag{2}$$

and the initial-periodic

$$u^{(\mathbf{k}_j)}(0, \hat{\mathbf{x}}_j) = \varphi_{k_j}(\hat{\mathbf{x}}_j) \;\; (k_j = 0, \ldots, m_j - 1; j = 1, \ldots, n_0), \;\; u(\mathbf{x} + \boldsymbol{\omega}_j) = u(\mathbf{x}) \;\; (j = n_0 + 1, \ldots, n) \tag{3}$$

conditions. Here $\mathbf{x} = (x_1, \ldots, x_n)$, $\boldsymbol{\omega} = (\omega_1, \ldots, \omega_n)$, $\boldsymbol{\omega}_j = (0, \ldots, \omega_j, \ldots, 0)$, $\mathbf{m} = (m_1, \ldots, m_n)$, $\widehat{\mathcal{D}}^{\mathbf{m}}[u] = \left(u^{(\boldsymbol{\alpha})}\right)_{\boldsymbol{\alpha} < \mathbf{m}}$,

$$\boldsymbol{\alpha} < \mathbf{m} \Leftrightarrow \alpha_j \le m_j \ (j = 1, \ldots, n) \text{ and } \boldsymbol{\alpha} \neq \mathbf{m},$$

$\widehat{\mathbf{x}}_i = (x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_n)$ and $\mathbf{k}_j = (0, \ldots, k_j, \ldots, 0)$. Necessary and sufficient conditions of solvability, unique solvability and well-posedness of problems (1), (2) and (1), (3) are established. (Received September 20, 2018)

1145-35-1236 **Pradeep Godar Chhetri*** (pgc9509@louisiana.edu), P.O.Box 40384, Lafayette, LA 70504, and **Aghalaya S Vatsala**. *Existence of the Solution in the Large for the Caputo Fractional Reaction Diffusion Equation by Picard's method.*

In this work, we have developed Picard's iterative method to prove the existence and uniqueness of the solution of the nonlinear Caputo fractional reaction diffusion equation in one dimensional space. The order of the fractional time derivative q is such that $0.5 \le q \le 1$. The existence result has been proved by a priori assuming the solution is bounded. The method has also been extended to the Caputo fractional reaction diffusion system. (Received September 20, 2018)

1145-35-1240 **Francois S Monard** (fmonard@ucsc.edu) and **Donsub Rim*** (dr2965@columbia.edu).
Reconstruction of anisotropic conductivites from power densities in three dimensions.

We present reconstruction algorithms of anisotropic conductivity tensors in three dimensions, from knowledge of a finite family of power density functionals. Such a problem arises in the coupled-physics imaging modality Ultrasound Modulated Electrical Impedance Tomography for instance. We improve on previously existing algorithms derived for both isotropic and anisotropic cases, and we address the well-known issue of vanishing determinants in particular. Numerical validations will be presented. (Received September 20, 2018)

1145-35-1246 **Leonardo Abbrescia** and **Willie W-Y Wong*** (wongwwy@math.msu.edu). *Long-time behavior of nonlinear waves near plane symmetry.*

I will report on some recent results that establish global existence and nonlinear stability of nearly simple-plane-symmetric solutions to classes of quasilinear wave equations in low spatial dimensions. These equations satisfy a strong form of null condition. This is in contrast to the case where the equations are genuinely nonlinear where it has been previously shown that nearly simple-plane-symmetric solutions always stably form shock singularities. (Received September 20, 2018)

1145-35-1282 **Kamran Sadiq** and **Alexandru Tamasan*** (tamasan@math.ucf.edu), Department of Mathematics, University of Central Florida, 4000 Central Florida Blvd., Orlando, FL 32816. *On some new applications of the theory of A-analytic maps in Tomography.* Preliminary report.

The theory of A-analytic maps have been developed since late 1990s by A. Bukhgeim in connection with the the inversion of the Attenuated X-ray transform in the plane. We will present some new applications in imaging through a weakly scattering media. (Received September 20, 2018)

1145-35-1285 **Michelle DeDeo*** (mdedeo@unf.edu), 1 UNF Dr., Department of Mathematics and Statistics, Jacksonville, FL 32224. *The Heat Equation on the Poincare′ Upper Half-Plane.*

Solving for the fundamental solution to the heat equation on a bounded domain is a classical problem in partial differential equations. When the domain is the circle, for instance, the fundamental solution of the heat equation can be described by a theta function. We talk about using a differential-difference operator $\frac{\delta}{\delta t} - \Delta$ with Δ the combinatorial Laplacian to model the heat equation on a finite graph analogue of Poincare′'s upper half-plane.

Finite analogues of the classical theta functions are shown to be solutions to the heat equation in this setting. The solutions involve zonal spherical functions which come with a natural periodicity. In addition, the related theta functions are automorphic forms. The resultant periodicity interweaves representation theory with the heat equation. (Received September 20, 2018)

1145-35-1298 **Dorina Mitrea*** (mitread@missouri.edu). *Fatou's Theorem, Poisson's Integral, and Local Maximum Principle for second order systems.*

Let L be a second order, homogeneous, constant (complex) coefficient system satisfying the Legendre-Hadamard ellipticity condition in $\mathbb{R}^n$. Then any null-solution u of L in the upper-half space $\mathbb{R}^n_+$ subject to the subcritical growth condition $\int_1^\infty \big(R^{-2} \sup_{B^+(0,R)} |u|\big)\, dR < \infty$ has a non-tangential boundary trace at a.e. point on $\mathbb{R}^{n-1} \equiv \partial\mathbb{R}^n_+$, the function u may be expressed as the convolution of its boundary trace with the Poisson kernel associated with L in $\mathbb{R}^n_+$, and u satisfies a suitable Maximum Principle. The above growth condition is in the nature of best possible.

In particular, these results may be employed to establish the well-posedness of the Dirichlet boundary value problem for L in $\mathbb{R}^n_+$ with boundary datum in a class of functions allowed to have sublinear growth at infinity. (Received September 20, 2018)

1145-35-1299 **Aseel Farhat**, **Evelyn M. Lunasin*** (lunasin@usna.edu) and **Edriss S. Titi**. *On the Charney Conjecture of Data Assimilation Employing Temperature Measurements Alone: The Paradigm of 3D Planetary Geostrophic Model.*

Analyzing the validity and success of a data assimilation algorithm when some state variable observations are not available is an important problem in meteorology and engineering. We present an improved data assimilation algorithm for recovering the exact full reference solution (i.e. the velocity and temperature) of the 3D Planetary Geostrophic model, at an exponential rate in time, by employing coarse spatial mesh observations of the temperature alone. This provides, in the case of this paradigm, a rigorous justification to an earlier conjecture of Charney which states that temperature history of the atmosphere, for certain simple atmospheric models, determines all other state variables. (Received September 20, 2018)

1145-35-1301 **Marius Mitrea*** (mitream@missouri.edu). *On the existence of nontangential boundary traces for solutions of elliptic PDE's.*

We have recently discovered that null-solutions of injectively elliptic first order (constant complex coefficient) systems in uniformly rectifiable domains in $\mathbb{R}^n$, whose nontangential maximal operator is p-th power integrable (with respect to the $(n-1)$-dimensional Hausdorff measure on the boundary) for some $p > \frac{n-1}{n}$, necessarily have pointwise nontangential limits a.e. on the boundary. It turns out a similar Fatou-type property holds for solutions of elliptic second order systems which exhibit sufficient regularity measured on the scales of Besov and Triebel-Lizorkin spaces. (Received September 20, 2018)

1145-35-1310 **Hung D Le*** (hdlgw3@mail.missouri.edu), Columbia, MO 65201. *On the existence and instability of solitary water waves with a finite dipole.*

We investigate the existence and instability of two-dimensional traveling capillary-gravity water waves with a finite dipole. In particular, we consider the case where the fluid has infinite depth, and the vorticity is a sum of two weighted δ-functions. Using the implicit function theorem, we can construct a family of solitary waves for the finite dipole problem. Our main result is that this family is orbitally unstable. This is proved using a modification of the Grillakis–Shatah–Strauss method recently introduced by Varholm, Wahlén, and Walsh. (Received September 20, 2018)

1145-35-1326 **Jean-Luc Fattebert***, Oak Ridge National Laboratory, One Bethel Valley Rd, Oak Ridge, TN 37831, and **Balasubramaniam Radhakrishnan** and **John A. Turner**. *Recent progress and challenges using phase-field models for quantitative modeling of rapid solidification.*

The phase-field model is a very powerful method that allows tracking of interfaces in 3D. While the basic idea is rather simple — using a field that takes a different constant value on each side of the interface and smoothly changes value near that interface — and leads to beautiful pictures without too much efforts, making it a tool for quantitative predictions is much more challenging. More specifically, it is desirable that numerical results do not depend on the interfacial width associated with this diffuse interface. Obtaining results that also do not depend on numerical noise in the case of interface instabilities can also be challenging. In this talk we will describe some of these challenges for applications to rapid solidification of metallic alloys as they occur in the additive manufacturing process, as well as some recent progress towards this goal. (Received September 21, 2018)

1145-35-1330 **Wonlyul Ko*** (kowl@korea.ac.kr), Institute of Basic Science, Korea university, 145 Anam-ro, Seongbuk-gu, Seoul, 02841, South Korea. *Asymptotic behavior of positive solutions to a diffusive predator-prey system with hunting cooperation in predators.*

In this talk, we introduce a diffusive predator-prey system with a functional response describing the situation in which predators work together when hunting. We study the effects of the partial vanishing of the non-negative predator-cooperation coefficient function in the predator-prey system. Moreover, we study the behavior of the positive steady states of the predator-prey system as the cooperation coefficient are small or large. (Received September 21, 2018)

1145-35-1331 **Huanyao Wen*** (mahywen@scut.edu.cn), Block 4, 381 Wushan, Tianhe District, Guangzhou, Guangdong 510641, Peoples Rep of China. *Global existence of weak solution to a two-fluid model without the equivalence condition.*

In this talk, I will introduce our very recent work on the global existecne of weak solutions to a two-fluid model in three dimensions. The main ingredient is that the solution space is large enough such that the case of transition to single phase is allowed, and that the initial data can be large. (Received September 21, 2018)

1145-35-1332 **Stefan Krömer*** (skroemer@utia.cas.cz), ÚTIA AV ČR, Pod Vodárenskou věží 4, 18208 Praha 8, Czech Rep, and **Jan Valdman**. *Injective nonlinear elasticity: recent developments and new ideas for a computational approach.*

I will present some recent developments in the variational theory of nonlinear elasticity with a global injectivity constraint preventing self-interpenetration of the elastic body, the Ciarlet-Necas condition, in the presence of higher order derivatives in the internal elastic energy density. Such terms can appear either for modelling purposes, i.e., for non-simple materials, or as regularization term with a small coefficient converging to zero. The main focus of the talk are penalization terms replacing the Ciarlet-Necas condition as a soft constraint, recovering the original condition in a limiting sense while being more suitable for numerical purposes. (Received September 21, 2018)

1145-35-1380 **K.-Y. Lam** and **X. Wang*** (xueying@math.wsu.edu), Department of Mathematics and Statistics, Washington State University, Pullman, WA 99163, and **T. Zhang**. *Traveling waves for a class of diffusive disease-transmission models with network structures.*

In this paper, the necessary and sufficient conditions for the existence of traveling wave solutions are derived for a class of diffusive disease-transmission models with network structures. The existence of traveling semi-fronts is obtained by Schauder's fixed-point theorem and these traveling semi-fronts are shown to be bounded by transforming the boundedness problem into the classification problem of non-negative solutions to a linear elliptic system on $\mathbb{R}$. To overcome the reducibility problem arising in the proofs, a Harnack's inequality for positive supersolutions on $\mathbb{R}$ is proved. (Received September 21, 2018)

1145-35-1430 **Linhan Li** and **Jill Pipher*** (jill_pipher@brown.edu). *Boundary behavior of solutions of elliptic operators in divergence form with a BMO anti-symmetric part.*

We consider the boundary behavior of solutions to divergence-form operators with an elliptic symmetric part and a BMO anti-symmetric part in non-tangentially accessible (NTA) domains. We establish the Hölder continuity of the solutions at the boundary, existence of elliptic measures ω_L associated to such operators, and the well-posedness of the continuous Dirichlet problem as well as the $L^p(d\omega)$ Dirichlet problem in NTA domains. The equivalence in the L^p norm of the square function and the non-tangential maximal function under certain conditions remains valid. When specialized to Lipschitz domains, it is possible to extend, to these operators, various criteria for determining mutual absolute continuity of elliptic measure with surface measure. The L^p-solvability of the Dirichlet problem for operators with more regular coefficients is in progress. (Received September 21, 2018)

1145-35-1454 **Dan Andrei Geba***, University of Rochester, Department of Mathematics, 806 Hylan Building, Rochester, NY 14627, and **Evan Witz**, University of Rochester. *Well-posedness issues for generalized Boussinesq equations.* Preliminary report.

In this talk, we plan to discuss a series of problems that are related to the well-posedness of generalized Boussinesq equations. In particular, by rewriting these equations as nonlinear Schrödinger equations, we see that one expects their behavior to be better than what is currently known for generic Schrödinger problems. This is joint work with Evan Witz. (Received September 22, 2018)

1145-35-1457 **R Rakesh*** (rakesh@udel.edu). *Inverse problems for the perturbed wave equation.*

We describe partial results on some formally determined inverse problems for the perturbed wave equation and also talk about some basic unsolved inverse problems for the perturbed wave equation. This is based on work done with Zach Bailey. (Received September 22, 2018)

1145-35-1458 **Henok Mawi*** (henok.mawi@howard.edu), Department of Mathematics, 2441 Sixth street NW, Washington, DC 20059. *On Mathematical Problems in Geometric Optics.*

Mathematical problems in geometric optics which deal with determining a surface that is capable of reshaping a light beam from a source with a given illumination intensity into a prescribed intensity distribution on a target, have in recent years received a lot of attention. Interest to investigate several theoretical and numerical aspects of these inverse problems has risen mainly because the techniques used in their analysis interweave ideas from the mathematics of mass transportation theory, calculus of variations and nonlinear partial differential equations of Monge-Ampère type. In this talk we will discuss an overview of these problems and describe an iterative method for approximating a solution to one such problem called the refractor problem. This is a joint work with Roberto De Leo and Cristian Gutiérrez. (Received September 22, 2018)

1145-35-1490 **George Avalos*** (gavalos@math.unl.edu), Department of Mathematics, University of Nebraska-Lincoln, Avery Hall 323, Lincoln, NE 68588. *Rational Decay rates for a PDE Fluid-Structure Interaction.*

In this talk, we will consider a fluid-structure PDE model of longstanding interest within the mathematical and biological sciences. Here, a three dimensional Stokes system and three dimensional vector-valued wave equation comprise the coupled PDE system under study; these respective PDE components come into contact via a boundary interface. For this fluid structure system, our main result is as follows: Under an appropriate geometric assumption which precludes imaginary point spectrum for the associated semigroup generator, then for smooth initial data - i.e., data in the domain of the generator – the corresponding solutions decay at a certain polynomial rate. (Received September 22, 2018)

1145-35-1510 **Agnid Banerjee** (agnidban@gmail.com), Bangalore, India, **Donatella Danielli*** (dgarofal@purdue.edu), Department of Mathematics, West Lafayette, IN, **Nicola Garofalo** (rembrandt54@gmail.com), DICEA, Padova, Italy, and **Arshak Petrosyan** (arshak@purdue.edu), Department of Mathematics, West Lafayette, IN. *The obstacle problem for the fractional heat equation: properties of the free boundary.*

In this talk we will discuss the structure of the free boundary in the obstacle problem for fractional powers of the heat operator. First introduced by M. Riesz in 1938, this nonlocal operator represents a basic model of the continuous time random walks studied by Montroll and Weiss. Our results are derived from the study of a lower-dimensional obstacle problem for a class of local, but degenerate, parabolic operators. (Received September 22, 2018)

1145-35-1578 **Nicola Garofalo**, **Arshak Petrosyan** and **Mariana Smit Vega Garcia*** (mariana.smitvegagarcia@wwu.edu). *Recent developments in the thin obstacle problem.*

The study of the classical obstacle problem began in the 60's with the pioneering works of G. Stampacchia, H. Lewy and J. L. Lions. During the past five decades, it has led to beautiful and deep developments in the calculus of variations and geometric partial differential equations. One of its crowning achievements has been the development, due to L. Caffarelli, of the theory of free boundaries. In broad terms free boundaries appear when the solution to a problem consists of a pair: a function (often satisfying a partial differential equation), and a set associated to this function. Nowadays the obstacle problem continues to offer many challenges and its study is as active as ever. In particular, over the past years there has been some interesting progress the thin obstacle problem, also called Signorini problem. In this talk, I will overview the thin obstacle problem and describe a few methods used to tackle two fundamental questions: what is the optimal regularity of the solution, and what can be said about the free boundary. The proofs are based on Almgren, Weiss and Monneau type monotonicity formulas. (Received September 23, 2018)

1145-35-1588 **Upama Neupane*** (un936618@cameron.edu), Cameron University, Lawton, OK, 73505, and **Joseph Morgan** (joseph.morgan@cameron.edu), **Sharan Khanal** (sk936393@cameron.edu) and **Narayan Thapa** (nthapa@cameron.edu), Cameron University, 2800 W. Gore Blvd, Lawton, OK 73505. *Pricing European and American Options Using Numerical Methods.* Preliminary report.

This article introduces numerical methods for pricing both European and American options governed by the Black-Scholes equation. After a careful treatment on boundary conditions, we use explicit, implicit, and Crank-Nicolson schemes for numerical solutions to the resulting problem. We present computational algorithm and display numerical results. We estimate relative error in L_1 norm to test the accuracy of the schemes. (Received September 23, 2018)

1145-35-1631 **Adam Larios**, **Evelyn Lunasin*** (lunasin@usna.edu) and **Edriss S. Titi**. *Global well-posedness for the 2D Boussinesq system with anisotropic viscosity and without heat diffusion.*

Our result improves the previous work of Danchin and Paicu 2008 [Global existence results for the anisotropic Boussinesq system in dimension two, Math. Models Methods Appl. Sci. 21 (2011), no. 3, 421—457.] We require a weaker initial data to establish uniqueness and doing so using only elementary tools from Sobolev spaces, avoiding the use of para-calculus and para-product formula from harmonic analysis. To achieve this, we use a new approach of defining an auxiliary "stream function" associated with the density, analogous to the stream-function associated with the vorticity in the 2D incompressible Euler equations and then proceed using the techniques of Yudovich (1963) for proving uniqueness for the 2D incompressible Euler equations. (Received September 23, 2018)

1145-35-1645 **Jason Metcalfe*** (metcalfe@email.unc.edu), Department of Mathematics, University of North Carolina - Chapel Hill, Chapel Hill, NC 27599-3250. *Local energy estimates for wave equations on asymptotically flat backgrounds.*

We will discuss recent results concerning local energy estimates on asymptotically flat backgrounds. This will include results on the nontrapping case. We will also discuss the case of degenerate trapping where a certain algebraic loss of derivatives is necessary and sufficient to recover such estimates. (Received September 23, 2018)

1145-35-1656 **Marius Ionescu**, Annapolis, MD, **Kasso Okoudjou*** (kasso@mit.edu), MIT, Department of Mathematics, Cambridge, MA , and **Luke Rogers**, CT. *The strong maximum principle for Schrödinger operators on PCF fractals.* Preliminary report.

Let Δ be the standard self-similar Laplacian on a PCF fractal K. We consider the associated Schrödinger operator $L = -\Delta + a$ where $a \geq 0$ on K. We prove a number of Maximal Principles for L for a in various function classes. (Received September 23, 2018)

1145-35-1658 **Jason S Howell*** (howell4@cmu.edu), Department of Mathematical Sciences, 5000 Forbes Avenue, Pittsburgh, PA 15213, and **Varun Gudibanda** and **Justin T Webster**. *Dynamics of the Inextensible Inverted Flag with Piston-Theoretic Forcing Term.*

In this talk we discuss observations of the dynamics of an inexstensible elastic beam immersed in potential flow. The boundary configuration of the beam is that of an inverted flag, i.e. a free leading end and clamped trailing end with respect to the direction of the flow. The coupled nonlinear PDE system is simplified with an assumption (piston theory) that describes the effect of the flow on the beam, and reduces the system to a single nonlinear PDE for the beam dynamics.

The dynamics of the inverted inextensible flag were analyzed using a spectral approach, as well as a standard finite element approach. Comments on observations in the dynamics, such as the onset of instabilities and non-equilibrium steady states, will be discussed. (Received September 23, 2018)

1145-35-1691 **Yongjin Lu*** (ylu@vsu.edu). *Feedback stabilization of a 2D fluid-structure interaction model.*

We study the feedback stabilization of a fluid-structure interaction (FSI) where a solid is submerged in the surrounding viscous incompressible fluid and interaction takes place at the interface between the fluid and the solid. The dynamics of this FSI model is described by a nonlinear system of partial differential equations (PDEs) coupling Navier-Stokes equation together with wave equation. We explore a few strategies of (boundary and/or interior) feedback stabilization that could produce uniform exponential decay rate of energy to an unstable equilibrium. These results are achieved by building special multipliers that could account for the interactive and hybrid nature of the coupled dynamics. The theoretical results are verified by numerical simulation using a monolithic approach to construct finite elements. (Received September 23, 2018)

1145-35-1707 **Oreoluwa Adekoya*** (oadekoya@ou.edu) and **John P Albert**. *Stable travelling-wave solutions of the periodic dispersion-managed NLS equation.*

The dispersion-managed nonlinear Schrodinger equation is an equation that models optical pulses in a "dispersion-managed" fiber. This fiber is made of lengths of glass whose sections of large positive dispersion alternate with sections of large negative dispersion. The method of alternating dispersion eliminates unwanted spreading of signals and gives rise to a well-localized stable pulse that changes periodically along the fiber. It is common that in such fibers, the average dispersion is nearly zero, which is reflected in the fact that the energy functional associated with the equation lacks coercivity. Nevertheless, recent studies have shown that minimizing sequences for the energy functional converge to stable solitary-wave solutions.

We will consider the periodic dispersion-managed NLS equation, which models periodic waves in a dispersion-managed fiber. The minimization problem for the energy functional is more subtle in the periodic case. We will study the existence of minimizers and their correspondence to stable travelling-wave solutions. (Received September 25, 2018)

1145-35-1749 **Ghada Alobaidi*** (galobaidi@aus.edu), Department of Mathematics and Statistics, Sharjah, 26666, United Arab Emirates. *Asymptotic Analysis of Shout Options Close to Expiry.*

We use an asymptotic expansion to study the behavior of shout options close to expiry. Series solutions are obtained for the location of the free boundary and the price of the option in the limit.

keywords: Free boundary, Asymptotics
MSC: 91B28 (Received September 24, 2018)

1145-35-1796 **Christina Knox*** (knox@math.ucr.edu) and **Amir Moradifam**. *Determining both the source of a wave and its speed in a medium from boundary measurements.*

In this talk we will discuss the inverse problem of determining both the source of a wave and its speed inside a medium from measurements of the solution of the wave equation on the boundary. This problem arises in photoacoustic and thermoacoustic tomography. We will present a brief overview of previous uniqueness results and then present our two original uniqueness results. If the reciprocal of the wave speed squared is harmonic in a simply connected region and identically one elsewhere then a non-trapping wave speed can be uniquely determined from the solution of the wave equation on the boundary of domain without knowledge of the source. If the wave speed is known and only assumed to be bounded, then, under a natural admissibility assumption, the source of the wave can be uniquely determined from boundary measurements. (Received September 24, 2018)

1145-35-1805 **Wen Li*** (liw2@clarkson.edu), **G.R. Liu**, **Guangming Yao** and **Michelle Crimi**. *Simulation of groundwater flow captured by the horizontal reactive media well using cell-based smoothed radial point interpolation method.*

The Horizontal Reactive Media Treatment well (HRX well) is a novel technology for in-situ treatment of contaminated groundwater. The most significant technical performance risk associated with field-scale implementation of the HRX well is installation and construction. Therefore, the groundwater capture simulation plays a very important role in the design of HRX well. We propose a cell-based smoothed radial point interpolation method (CS-RPIM) for simulating groundwater flow captured by HRX well. This numerical formulation is based on tetrahedral background meshes which can be generated automatically. The cell-based local smoothing domain makes CS-RPIM an ideal way for simulating groundwater flow in the environment with multiple hydraulic conductivities. The generalized smoothed Galerkin weak form makes it possible to select local support nodes more flexibly than the standard weak form. The use of multiquadric (MQ) radial basis in creating RPIM shape functions ensures the non-singularity of moment matrix. Numerical experiments show CS-RPIM has higher accuracy and convergence rate than FEM based on the same meshes. We also analyze the effect of the in-well hydraulic conductivity and the dimension of well on the groundwater capture zone. (Received September 24, 2018)

1145-35-1870 **Vincent Calvez** and **King-Yeung Lam*** (lam.184@osu.edu), The Ohio State University, 100 Math Tower, 231 W 19th Avenue, Columbus, OH 43210. *Uniqueness in constrained Hamilton-Jacobi equation and the dynamics of adaptation.* Preliminary report.

Viscosity solutions of Hamilton-Jacobi equations appear naturally in the asymptotic limit of selection-mutation models when the population variance vanishes. They have to be solved together with an unknown function I(t) that describes population burden at each time. Although the uniqueness of viscosity solutions is known for many classical variants of Hamilton-Jacobi equations, the uniqueness for this particular type of constrained problem was not resolved, except in a few particular cases. Here, we provide a general answer to the uniqueness problem, based on three main assumptions: convexity of the Hamiltonian function H(I,x,p) with respect to p, monotonicity of H with respect to I, and BV regularity of I (t). We also describe a result illustrating the pessimization principle. (Received September 24, 2018)

1145-35-1882 **Razvan Mosincat*** (r.o.mosincat@sms.ed.ac.uk), School of Mathematics, University of Edinburgh, EH9 3FD, United Kingdom. *Unconditional well-posedness for the Benjamin-Ono equation.*

The Benjamin-Ono equation (a model PDE for the propagation of internal waves in deep stratified fluids) poses analytical difficulties due to its quasilinear character. In this talk, we are interested in the unconditional uniqueness of solutions problem for the Benjamin-Ono equation. After briefly surveying prior uniqueness statements, we will discuss a method based on normal form reductions for showing uniqueness of solutions without any auxiliary condition. (Received September 24, 2018)

1145-35-1890 **Bryan Carrillo*** (carrillo@math.ucr.edu), **Xinghong Pan** and **Qi S Zhang**. *Decay and vanishing of some axially symmetric D-solutions of the Navier-Stokes equations.*

One open question in the study of the steady incompressible three-dimensional Navier-Stokes equations is if the only solution with finite Dirichlet integral and vanishing condition at infinity is the trivial solution. Several partial results have been proven by requiring certain integral or decay conditions on the solution. We will explore a certain class of solutions, called axially-symmetric D-solutions, and discuss some results about these solutions. (Received September 24, 2018)

1145-35-1894 **David Evans*** (daeva13@morgan.edu), 3103 Tyndale Avenue, Baltimore, MD 21214, and **Mingchao Cai** (mingchao.cai@morgan.edu), 1700 E Cold Spring Ln, Baltimore, MD 21251. *Fast solvers for Biot model using a multiphysics reformulation.*

Based on a multiphysics reformulation, the Biot model is split into a mixed form of linear elasticity model and a reaction diffusion model. We apply Finite element methods to discretize these models. Then, we discuss how to apply multigrid method to improve the efficiency of the solvers. (Received September 24, 2018)

1145-35-1895 **H Semiyari*** (semiyari@american.edu), 4400 Massachusetts Avenue, NW, Washington, DC 20016. *A power series solution to partial differential equation problrms.* Preliminary report.

In this article, we introduce a simple straightforward and powerful method involving symbolic manipulation, Picard iteration, and auxiliary variables for approximating solutions of partial differential problems. The method is easy to implement, computationally efficient, and it is highly accurate. The output of the method is a function that approximates the exact solution. (Received September 24, 2018)

1145-35-1899 **Ramesh Karki*** (rkarki@iue.edu), 2325 Chester Blvd, Richmond, IN 47374. *A finite sampling method for approximating initial data in some linear evolution equations.* Preliminary report.

We study an inverse problem of recovering initial datum in a one-dimensional linear evolution equation with the Dirichlet boundary conditions when finitely many values (samples) of the solution at a suitably fi xed space location and suitably chosen fi nitely many later time instances are known. (Received September 24, 2018)

1145-35-1915 **Mihai Tohaneanu*** (mihai.tohaneanu@uky.edu), 749 Patterson Office Tower, Lexington, KY 40506. *Quasilinear wave equations on Kerr black holes.*

We study the quasilinear wave equation $\Box_g u = 0$, where the metric g depends on u and equals the Kerr metric with small angular momentum when u is identically 0. Under a couple of assumptions on the metric g near the trapped set and the light cone, we prove global existence of solutions. The main technical result is proving an estimate for the linear wave equation on small perturbations of Kerr. This is joint work with Hans Lindblad. (Received September 24, 2018)

1145-35-1938 **Albert Ai*** (aai@math.berkeley.edu). *Low Regularity Solutions for Gravity Water Waves.*

We consider the local well-posedness of the Cauchy problem for the gravity water waves equations, which model the free interface between a fluid and air in the presence of gravity. It has been known that by using dispersive effects, one can lower the regularity threshold for well-posedness below that which is attainable by energy estimates alone. Using a paradifferential reduction of Alazard-Burq-Zuily and low regularity Strichartz estimates, we apply this idea to the well-posedness of the gravity water waves equations in arbitrary space dimension. Further, in two space dimensions, we discuss how one can apply local smoothing effects to further extend this result. (Received September 24, 2018)

1145-35-1942 **Pierre Millien*** (pierre.millien@espci.fr), Institut Langevin, 1 rue jussieu, 75018 Paris, France. *Direct reconstruction method in Magneto acoustic tomography.*

We present a direct method for reconstructing the electrical conductivity of a medium in a magneto-acoustic experiment. A medium is embedded in a strong magnetic field while ultrasonic impulses propagate inside. An electrical current is measured on the boundary of the medium. From this an internal electrical current can be reconstructed, and we show how to recover the conductivity from these measurements by solving a first order transport equation. (Received September 24, 2018)

1145-35-1945 **Kay Kirkpatrick*** (kkirkpat@illinois.edu). *Long-range Schrödinger Dynamics.*

We want to justify certain model equations proposed in the biophysics literature for charge transport on polymers like DNA and protein, so we consider a general class of discrete nonlinear Schroedinger equations on lattices, and prove that in the continuum limit, the limiting dynamics are given by a nonlinear Schroedinger equation (NLS) with a fractional Laplacian. In particular, a range of fractional powers arise from long-range lattice interactions in this limit, whereas the usual NLS with the non-fractional Laplacian arises from short-range interactions. We also obtain equations of motion for the expected position and momentum, the fractional counterpart of the well-known Newtonian equations of motion for the standard Schroedinger equation, and use a numerical method to suggest that the nonlocal Laplacian introduces decoherence, but that effect can be mitigated by the nonlinearity. Joint work with Gigliola Staffilani, Enno Lenzmann, Yanzhi Zhang, Peter Hislop, Stefano Olla, and Jeffrey Schenker. (Received September 24, 2018)

1145-35-2032 **Amir Moradifam*** (amirm@ucr.edu). *Existence and structure of minimizers of least gradient problems.*

I will talk about existence of minimizers of the general least gradient problem

$$\inf_{u\in BV_f}\int_\Omega \varphi(x,Du),$$

where $BV_f=\{u\in BV(\Omega): \quad u|_{\partial\Omega}=f\}$, $f\in L^1(\partial\Omega)$, and $\varphi(x,\xi)$ is convex, continuous, and homogeneous function of degree 1 with respect to the ξ variable. We will show that there exists a divergence free vector field $T\in (L^\infty(\Omega))^n$ that determines the structure of level sets of all (possible) minimizers, i.e. T determines $\frac{Du}{|Du|}$, $|Du|-$ a.e. in Ω, for all minimizers u. We also prove that every minimizer of the above least gradient problem is also a minimizer of

$$\inf_{u\in\mathcal{A}_f}\int_{R^n}\varphi(x,Du),$$

where $\mathcal{A}_f=\{v\in BV(R^n): \quad v=f \quad \text{on} \quad \Omega^c\}$ and $f\in W^{1,1}(R^n)$ is a compactly supported extension of $f\in L^1(\partial\Omega)$, and show that T also determines the structure of level sets of all minimizers of the latter problem. This relationship between minimizers of the above two least gradient problems could be exploited to obtain information about existence and structure of minimizers of the former problem from that of the latter, which always exist. (Received September 24, 2018)

1145-35-2063 **Eduardo Garcia-Juarez*** (edugar@math.upenn.edu). *Global regularity for parabolic incompressible fluid interfaces.*

In this talk we consider several fluid dynamics scenarios where sharp interfaces between immiscible incompressible fluids appear. The main question will be whether the initial regularity of the interface is preserved in time or, on the other hand, the system develops singularities. We will start showing recent results on global regularity for P.L. Lions' conjecture on density patches evolving by inhomogeneous Navier-Stokes equations. Later, we will extend these results to piecewise-Hölder temperature fronts modeled by Boussinesq approximation, and we will end commenting some new results of global regularity for the Muskat problem with viscosity jump. (Received September 24, 2018)

1145-35-2166 **Katrina Morgan*** (katri@live.unc.edu). *Wave decay on asymptotically flat stationary spacetimes.*

The current work considers solutions to the wave equation on asymptotically flat stationary spacetimes in (1+3) dimensions. We investigate the relationship between the rate at which the geometry tends to flat and the pointwise decay rate of waves. We include a weak local energy decay assumption on the evolution of the equation. Geometrically this corresponds to no stable trapping on the manifold (i.e. geodesics which stay within a compact region). The weak local energy decay estimate is also deeply connected to the existence of the resolvent at zero frequency, which is used to obtain the final decay rate. In Tataru 2013 a t^{-3} decay rate was found for the case where the spacetime tends toward flat at a rate of $|x|^{-1}$. We know by Sharp Huygens' Principle that waves decay infinitely fast in the flat setting. Here we obtain pointwise decay for cases in between, where the geometry is curved but tends toward flat at a rate faster than $|x|^{-1}$. (Received September 24, 2018)

1145-35-2167 **Sean Deyo**, **Shawtaroh Granzier-Nakajima*** (shawtarohg@email.arizona.edu), **Patricia Puente**, **H AH Shehadeh**, **Kevin Tully** and **J J B Webb**. *A Mathematical Model For Meat Cooking.* Preliminary report.

We present an accurate mathematical model for steak cooking based on Flory-Rehner theory for which we simulate numerically in two-dimensions. We model meat as a fluid-saturated poroelastic medium composed of a solid matrix (polymer) and fluid. As the temperature increases during cooking, a pressure gradient builds and induces fluid motion and deformation of the solid matrix, which also contributes to the motion of the fluid. Temperature distribution, fluid velocity field, moisture content, surface evaporation, and shrinkage are all modeled during the cooking process. Numerical simulations indicate good agreement with multiple sources of experimental data. Moreover, this work presents a new and computationally non-expensive method to account for shrinkage. (Received September 24, 2018)

1145-35-2191 **Junshan Lin***, 231 Paker Hall, Department of Mathematics and Statistics, Auburn Unviversity, Auburn, AL 36830. *Resonances for Photonic Nanocavities and Their Optimal Design.*

Photonic nanocavities are periodic arrays of dielectric materials embedded with defects, and they have applications in many areas of physics and engineering. In practice, it is desirable to design photonic nanocavity with high quality factor, which is closely related to the scattering resonances of the underlying structure. In this talk, I will present mathematical studies of resonances for such photonic structure and a closely related Schrodinger operator. I will begin with a study on a 1D finite symmetric photoinc structure to illustrate the convergence behavior of resonances. Then a general perturbation approach will be introduced for the analysis of near bound-state resonances in higher dimensions. (Received September 25, 2018)

1145-35-2192 **Sedar Ngoma*** (ngoma@geneseo.edu), Department of Mathematics, South Hall 323, 1 College Circle, Geneseo, NY 14454. *On an inverse source problem for a parabolic equation with an integral constraint.*

We investigate an inverse source problem with a Neumann boundary condition and subject to an integral overdetermination for a parabolic partial differential equation. The unknown source function depends on time only. Thanks to a certain transformation, we derive the existence, uniqueness, and continuous dependence of solutions in Hölder spaces. The proof of the existence and uniqueness of solutions yields an algorithm that we used to approximate solutions of the inverse problem by means of a finite element discretization. Due to instability in inverse problems, we employ the Tikhonov regularization and report the error. Our results show that the proposed scheme is an accurate way for approximating solutions of this inverse problem. (Received September 25, 2018)

1145-35-2254 **Claudio Torres***, ctorres@inf.utfsm.cl, **Alejandro Sazo**, asazo@alumnos.inf.utfsm.cl, **Maria Emelianenko**, memelian@gmu.edu, and **Dmitry Golovaty**, dmitry@uakron.edu. *Modeling nucleation using vertex code with stored energy.* Preliminary report.

In this talk we will provide a brief overview of recent advances in mathematical modeling of grain growth. In particular, we will focus on vertex models and their use in studying nucleation of three-sided grains by means of the stored energy formalism. Analytical results concerning stability of a triple junction motion and energy dissipation during nucleation will be discussed. We will also provide a brief overview of a GPU-based parallelization strategy for managing grain boundary flippings. (Received September 25, 2018)

1145-35-2308 **Dhanapati Adhikari*** (dadhikari@marywood.edu), 2300 Adams Avenue, Scranton, PA 18509. *On the global well-posedness of the 2D Boussinesq equations with partial dissipation.*

The two-dimensional incompressible Boussinesq equations model geophysical fluids and play an important role in the study of Rayleigh–Bénard convection. One of the fundamental issues concerning Boussinesq equations is whether or not its solution remain smooth for all time or they blow up in finite time. In this talk, we consider the 2D Boussinesq equations with partial dissipation and establish the global (in time) regularity of classical solutions with smooth initial data. (Received September 25, 2018)

1145-35-2400 **Faouzi Triki*** (faouzi.triki@univ-grenoble-alpes.fr), LJK -Batiment IMAG Universite Grenoble Alpes, 700 Avenue Centrale, Campus de Saint Martin d'Heres, Grenoble, France, and **Tao Yin** (taoyin89@caltech.edu), Dept. Comp. Math. Sci., California Institute of Technology, 355 S. Holliston Ave., Pasadena, CA 91125. *On the inverse conductivity problem with a single internal measurement.*

In the talk I will present recent results on recovering the conductivity map from a single internal measurement. This inverse problem originated from multi-wave imaging. The objective is to stabilize and improve the resolution in imaging biological tissues. I will first show a stability estimate of Hoelder type without any assumptions on the conductivity map. Then, I will give a convergence result for the reconstruction of the conductivity coefficient using discontinuous Galerkin method (DG). Finally, I will present some numerical results on synthetic data to validate the theoretical approach. (Received September 25, 2018)

1145-35-2434 **Robert Paul Viator*** (rviator@smu.edu) and **Braxton Osting** (osting@math.utah.edu). *Steklov eigenvalues of reflection-symmetric nearly-circular planar domains.* Preliminary report.

We consider Steklov eigenvalues of reflection-symmetric, nearly-circular planar domains. Treating such domains as perturbations of the disk, we obtain a second-order formal asymptotic estimate in the domain perturbation parameter. We conclude with a discussion of implications for isoperimetric inequalities. Namely, our results corroborate the results of Weinstock and Brock which state, respectively, that the disk is the maximizer for the area and perimeter constrained problems. They also support the result of Hersch, Payne, and Schiffer that the product of the first two eigenvalues is maximal among all open planar sets of equal perimeter. In addition, our results imply that the disk is not the maximizer of the area constrained problems for higher even-numbered Steklov eigenvalues, as suggested by previous numerical results. (Received September 25, 2018)

1145-35-2465 **Xinxiang Li** and **Thir R. Dangal*** (tdangal@alcorn.edu), 1401 Highway 80 E, K122, Clinton, MS 39056, and **Bin Lei**. *Localized method of particular solutions with polynomial basis functions.*

The method of particular solutions (MPS) using polynomials as the basis functions has been successfully developed for solving a large class of partial differential equations. However, when a large number of collocation points are required, the above mentioned approach is not feasible since the resultant matrix is dense and ill-conditioned. This restriction is common for global methods. One of the alternative approaches is to employ the localized scheme in which only a small number of neighboring points are being used in the solution process. As a result, the resultant matrix of the localized method is sparse and thus can be solved efficiently. In this work, the localized method has been employed to extend the recently developed MPS using polynomial basis functions for solving large-scale science and engineering problems. Overall, the proposed approach is stable and highly accurate. Two numerical examples are presented to validate the proposed numerical method. (Received September 25, 2018)

1145-35-2472 **Dana Sydney Mendelson***, dana@math.uchicago.edu. *Almost sure wellposedness for some nonlinear dispersive equations.*

In this talk, I will discuss several problems on nonlinear wave and dispersive equations with random initial data. I will present several almost sure well-posedness results for these equations and contrast the ways in which random data techniques can be exploited in these different contexts. (Received September 25, 2018)

1145-35-2477 **Timothy E Faver*** (t.e.faver@math.leidenuniv.nl). *Nanopteron traveling waves for mass-in-mass lattices in the small mass limit.*

The mass-in-mass (MiM), or mass-with-mass, lattice consists of an infinite chain of identical particles that are both nonlinearly coupled to their nearest neighbors and linearly coupled to a distinct resonator particle. The MiM lattice is a prototypical model in the field of granular metamaterials, a large class of artificially constructed materials that possess certain highly tunable properties useful in experimental settings. This talk will present ongoing investigations into the existence and properties of traveling waves in the MiM lattice in the limit as the mass of the resonator goes to zero, at which point the MiM lattice reduces to a classical monatomic Fermi-Pasta-Ulam-Tsingou (FPUT) lattice. We are therefore interested in traveling waves in the MiM lattice whose profiles remain close to the well-known solitary wave that exists in the monatomic FPUT lattice. Following the methods of Hoffman and Wright for diatomic FPUT lattices with small mass ratio, we first discuss the existence of periodic traveling waves in this small mass limit and then construct from them nanopteron traveling waves, which are the superposition of one of these periodic waves, the FPUT solitary wave, and an exponentially decaying remainder. (Received September 25, 2018)

1145-35-2486 **Michael Demmin***, Cameron University, Lawton, OK, and **Nadab JuarezFlores** (nj908349@cameron.edu), **Gregory Herring** (gherring@cameron.edu) and **Narayan Thapa** (nthapa@cameron.edu), Cameron University, Lawton , OK. *Parameter Identification in an Initial Boundary Value Problem through Finite Difference Method.* Preliminary report.

Inverse problems are one of the oldest most important mathematical problems in science and engineering. However, the field of inverse problems has undergone rapid development in last two decades due to the massive increase in computing power and the development of powerful numerical techniques such as finite difference method, finite element method, finite volume method, and spectral method. In this article, we consider an Initial Boundary Value Problem (IBVP)with time dependent parameter and a source function. We use over-specified condition and a pair of transformations to transform the given IBVP free from parameter. We then use the Crank-Nicolson method to estimate the parameter. We develop computational algorithms and display numerical results. We present examples to test the accuracy of the scheme. (Received September 25, 2018)

1145-35-2591 **Jay M Appleton*** (appletj@clarkson.edu), 8 Clarkson Ave. Box 5815, Potsdam, NY 13699, and **Brian T Helenbrook** (bhelenbr@clarkson.edu). *A Lower-Triangular Mass Matrix Approach to Explicit Time Advancement for Continuous Triangular Finite Element Methods.*

When using explicit time advancement with continuous high order finite elements for unsteady partial differential equations, a mass matrix is formed which must be inverted to advance the solution in time. For the Gauss-Lobatto-Lagrange basis typically used on quadrilaterals, an accurate approximate diagonal mass matrix exists which makes explicit time stepping methods efficient while achieving p^{th}-order spatial convergence rates. No such approach exists for the triangles. This work introduces a lower triangular mass matrix for triangles that achieves p^{th}-order convergence. This lower-triangular method allows for computationally efficient time advancement without sacrificing spatial accuracy. (Received September 25, 2018)

1145-35-2619 **Manoussos G Grillakis*** (mng@math.umd.edu), Dept. of Math, University of Maryland, College Park,, MD 20742, and **Matei Machedon**. *A-priori estimates for the Hartree-Fock-Bogoliubov approximation of N Bosons.*

We consider a certain type of approximation of N (where N is large) Bosons which is called Hartree-Fock-Bogoliubov. The approximation consists of a system of coupled dispersive equations in $6+1$ dimensions and depends on the parameter N (number of particles). The limit system as $N \to \infty$ is singular and we are interested in obtaining a-priori estimates for the HFB system which are independent of N. In order to achieve this goal we have to work with novel norms i.e. use apriori estimates beyond the standard Strichartz estimates and the associated norms. This work is in collaboration with Matei Machedon. (Received September 25, 2018)

1145-35-2663 **Malcolm Gabbard*** (malcolmga@gmail). *Computations on the Koch Snowflake with Boundary and Interior Energies.*

At the end of the 20th century studies had been conducted on the Koch Snowflake which had been motivated through work done by physicists on "fractal drum" experiments. These investigations focused on the eigenfunctions of the negative Dirichlet Lapcian generated on a planar domain with a fractal boundary, particularly with the condition that the boundary be set to zero. Here we study the eigenfunctions on the Koch Snowflake with a non-zero boundary condition and we consider a Laplacian defined on the boundary. This then gives us insight into the eigenvalues and visualization of the corresponding eigenfunctions on the Koch Snowflake. Initial observations indicate a kind of localization of the eigenfunctions on the fractal boundary. (Received September 25, 2018)

1145-35-2712 **Neil Jerome A. Egarguin*** (naegarguin1@up.edu.ph), Houston, TX, and **Daniel Onofrei** and **Eric Platt**. *Active Control of Acoustic Fields using Almost Non-Radiating Sources.*

In this talk, we present a sensitivity analysis of our numerical scheme for the active control of the three-dimensional Helmholtz equation in the case of an almost non-radiating source with controllable near fields. We consider a free space environment containing an almost non-radiating source. This source is set to generate a prescribed pattern in a near field control region and a very low field amplitude beyond a fixed radius.

The desired field is generated using a method of moments and a Morozov regularization routine. To make the numerics more accurate, the moments were computed using a truncated series representation of the fundamental solution of the Helmholtz equation involving spherical harmonics, spherical Hankel and spherical Bessel functions. We study the accuracy of this scheme with respect to different variations in the size of the near control and its distance from the source. This includes analysis of the stability measure for the solution, the over-all power on the source, the L^2-relative error on the near control and the L^∞- error on the far field. We will consider the case of a single source and of arrays (collection of compact regions along a line and a plane). (Received September 25, 2018)

1145-35-2731 **Niles Armstrong*** (niles@math.ksu.edu) and **Ivan Blank**. *Nonconvexity and Compact Containment of Mean Value Sets for General Elliptic Operators.*

In his Fermi Lectures on the obstacle problem, Caffarelli stated a mean value theorem for second order uniformly elliptic divergence form operators with the form $L := D_i a^{ij}(x) D_j$. This theorem is a clear analog to the standard mean value theorem for Euclidean balls for the Laplacian, with the only difference being the sets over which the averages are taken. I will discuss the initial regularity results that were known for these sets, show a new compact containment result, and finally give an example of an operator with smooth coefficients and nonconvex mean value sets. (Received September 25, 2018)

1145-35-2734 **Eric Brian Platt*** (eplatt@math.uh.edu), 5415 Scott St, Apt 1, Houston, TX 77021-1553. *On the active control of Helmholtz Fields on mutually disjoint exterior domains.*

By use of the Morozov-Tychonov regularization method density patterns on a radiating source can be found such that the generated field matches a desired pattern in on region of space while leaving another region of space mostly unperturbed. Combinations of these generated fields can be used for creating different patterns in the specified exterior mutually disjoint regions. An interesting application to be presented is the case when a desired pattern is produced behind an obscuring region. A time domain simulation performed via a Fourier synthesis will be presented as well. (Received September 25, 2018)

1145-35-2756 **Jaffar Ali Shahul Hameed*** (jashahulhameed@fgcu.edu), 10501 FGCU Blvd. S., Fort Myers, FL 33965, and **Seshadev Padhi**. *Multiplicity of Positive Radial Solutions to Elliptic Equations in an Annulus.* Preliminary report.

In this talk, we establish existence of multiple positive radial solutions of the equation

$$-\Delta u = \lambda g(|x|) f(u), \ \ R_1 < |x| < R_2,$$

$x \in R^N$, $N \geq 2$ subject to the following mixed boundary condition at R_1 and R_2:

$$\left.\begin{aligned} u = 0 \text{ on } |x| = R_1 \text{ and } |x| = R_2, \\ u = 0 \text{ on } |x| = R_1 \text{ and } \frac{\partial u}{\partial r} = 0 \text{ on } |x| = R_2, \\ \frac{\partial u}{\partial r} = 0 \text{ on } |x| = R_1 \text{ and } u = 0 \text{ on } |x| = R_2. \end{aligned}\right\} \quad (1)$$

We use Leggett-Williams multiple fixed point theorems to obtain sufficient conditions for the existence of at least one or two positive radial solutions. (Received September 25, 2018)

1145-35-2770 **Foteini Tsitoura*** (ftsitoura@gmail.com), 196 N.Pleasant St., Amherst, MA 01002. *Observation of domain walls in Stokes waves on deep water.*

Experiments of nonlinear phase domain walls in weakly nonlinear deep water surface gravity waves are presented. The domain walls presented are connecting homogeneous zones of weakly nonlinear plane Stokes waves of identical amplitude and wave vector but differences in phase. By exploiting symmetry transformations within the framework of the nonlinear Schrödinger equation we demonstrate the existence of exact analytical solutions representing such domain walls in the weakly nonlinear limit. The walls are in general oblique to the direction of the wave vector and stationary in moving reference frames. Experimental and numerical studies confirm and visualize the findings. (Received September 25, 2018)

1145-35-2802 **Russ F. deForest*** (russ.f.deforest@gmail.com), 109 McAllister Bldg, University Park, PA 16802. *Cross-diffusive instabilities and pattern formation in a nonlinear public goods game.*

Evolutionary game models have been used to investigate coexistence of multiple types (strategies, phenotypes) within a single population in a variety of settings, from yeast or tumor cells to flour beetles or lizards. In these settings the fitness of a particular expressed type depends on its relative frequency within the larger population. Of particular interest are public goods game models where socially cooperative behavior coexists alongside behavior that is exploitative. We consider a system of quasilinear partial differential equations as a spatial model of a nonlinear public goods game. Each type is represented by a density and the fitness of each type depends locally on the density of all types. We demonstrate conditions for the existence of a cross-diffusive instability, leading to pattern formation and the advantageous aggregation of the cooperative type (Received September 25, 2018)

1145-35-2833 **Stacey Levine*** (levines@duq.edu), Duquesne University, Department of Mathematics & Computer Science, 440 College Hall, Pittsburgh, PA 15282. *Learning Geometry for Image Decomposition.* Preliminary report.

In recent work we developed several frameworks for image denoising that attempt to recover an image from a smoothed version of some geometric feature of the image, e.g. level line curvature. These methods have successfully been used to improve upon denoising an image directly with variational and patch based approaches. The challenge in working with this data is that mathematically sound mechanisms developed for handling natural image data do not always readily carry over, and this data can be quite ill behaved. To mitigate this problem, in this work we use a structured convolutional neural network to learn both the geometric data from noisy observations and their corresponding regularizers. Our preliminary analyses and experiments indicate that the benefits of this approach can be significant, and that the learned regularizers can feed into mathematically sound variational approaches. (Received September 25, 2018)

1145-35-2836 **Hans Lindblad*** (lindblad@math.jhu.edu). *On the asymptotic behavior of solutions to the Einstein equations and related equations.*

We will discuss various recent results on the asymptotic behavior of solutions to Einstein's and related equations close to Minkowski. We will give asymptotics and scattering for various matter fields. (Received September 25, 2018)

1145-35-2901 **Elisabeth MM Brown*** (embrown5@ncsu.edu) and **Michael Shearer**. *A Scalar Conservation Law for Plume Migration in Carbon Sequestration.*

A quasi-linear hyperbolic partial differential equation with a discontinuous flux models geologic carbon dioxide (CO_2) migration and storage. Two flux functions characterize the model, giving rise to flux discontinuities. One convex flux describes the invasion of the plume into pore space, and the other captures the flow as the plume leaves CO_2 bubbles behind, which are then trapped in the pore space. We investigate the method of characteristics, the structure of shock and rarefaction waves, and the result of binary wave interactions. The dual flux property introduces unexpected differences between the structure of these solutions and those of a scalar conservation law with a convex flux. During our analysis, we introduce a new construction of cross-hatch characteristics in regions of the space-time plane where the solution is constant, and there are two characteristic speeds. This construction is used to generalize the notion of the Lax entropy condition for admissible shocks, and is crucial to continuing the propagation of a shock wave if its speed becomes characteristic. (Received September 25, 2018)

1145-35-2942 **Maxim Zyskin*** (maxim.zyskin@eng.ox.ac.uk), Department of Engineering Science, University, of Oxford, Oxford, Oxfordshir OX1 3PJ, United Kingdom. *Thermodynamics-based nonlinear electrochemistry transport problems.*

In my talk I will describe thermodynamics-based method of deriving nonlinear equations of electochemical transport, some analytical and numerical approaches to solving such equations, and molecular dynamics based methods of parameter estimation. This work has applications to multi-physics modeling of electric batteries and other electrochemistry transport problems. (Received September 25, 2018)

1145-35-2943 **Montgomery Taylor*** (mtaylo35@vols.utk.edu), 1515 Claiborne Place, Knoxville, TN 37917. *The Diffusion Phenomenon with Time-Dependent Dirichlet Forms.*

We discuss a method for studying the long-time behavior of solutions to damped wave equations, where the operators in the equations are time-dependent and correspond to time-dependent Dirichlet forms. We show that solutions exhibit the diffusion phenomenon, connecting their asymptotic behaviors with the asymptotic behaviors of solutions to corresponding parabolic equations. Decay estimates for solutions to damped wave equations are given, and decay estimates for components of their energies are also discussed. (Received September 25, 2018)

1145-35-3008 **Tian Xiang*** (txiang@ruc.edu.cn), No. 59, Zhongguancun Street, Haidian, Beijing, 100872. *On global and blow-up solutions for a short-ranged chemical signaling loop.*

In this talk, we consider the global boundedness and blow-up of solutions to a two-species and two-stimulus chemotaxis model, in which the process of the species results in a short-ranged chemical signaling loop. Explicit conditions on the initial data are given for the existence of simultaneous global boundedness and simultaneous finite-time blow up of classical solutions. More precisely, since the dynamics of one species are expected to be essentially determined by the other through this chemotactic signaling loop between two cell types, we find that only smallness of mass of one species implies global solvability, whereas, largeness of masses induce blow-up to occur. These in particular improve the known existing knowledge where smallness of total masses of both two species is required (Received September 26, 2018)

1145-35-3026 **Jun Wang*** (wangj1816@gmail.com), 1384 S Mount Vernon Ave, Apt B, Williamsburg, VA 23185. *Uniqueness and convergence on equilibria of the Keller-Segel system with subcritical mass.*

This talk is concerned with the uniqueness of solutions to the nonlocal semi-linear elliptic equation. This equation arises as the stationary problem of the well-known classical Keller-Segel model describing chemotaxis. As an application of the uniqueness results, we prove that the radially symmetric solution of the classical Keller-Segel system with subcritical mass subject to Neumann boundary conditions will converge to the unique constant equilibrium as time tends to infinity if the domain is a disc in two dimensions. As far as we know, this is the first result that asserts the exact asymptotic behavior of solutions to the classical Keller-Segel system with subcritical mass in two dimensions. (Received September 26, 2018)

37 ► Dynamical systems and ergodic theory

1145-37-1 **Maleafisha Joseph Stephen Tladi*** (maleafisha.tladi@gmail.com), Department of Mathematics & Applied Mathemati, University of Limpopo, Polokwane, Limpopo 0727. *Well-Posedness and Long-Time Dynamics of Geophysical Fluid Flows.*

The author elucidate in a concrete way dynamical challenges concerning approximate inertial manifolds (AIMS), i.e., globally invariant, exponentially attracting, finite-dimensional smooth manifolds, for nonlinear dynamical systems on Hilbert spaces. The goal of this theory is to prove the basic theorem of approximation dynamics, wherein it is shown that there is a fundamental connection between the order of the approximating manifold and the well-posedness and long-time dynamics of the rotating Boussinesq and quasi-geostrophic equations. Although this article is motivated by challenges in PDE, we consider a two-mode Faedo-Galerkin approximation given by a system of singularly perturbed ordinary differential equations. We note that the foundation for the study of the low-dimensional model of turbulence, which capture the dominant focus energy bearing scales, from the flow for the thermal convection of viscoelastic fluids, is the Lorenz equations extended through singular perturbation. In order to utilize geometric singular perturbation theory and Melnikov techniques, we perturb the problem and carry the nonlinear analysis further to the question of the persistence of inclination-flip homoclinic orbits. (Received March 10, 2018)

1145-37-29 **Adam Kanigowski**, **Kurt Vinhage** and **Daren Wei*** (darenwei@psu.edu), Department of Mathematics, Penn State University, State College, PA 16801. *Slow Entropy of Some Parabolic Flows.*

We study nontrivial entropy invariants in the class of parabolic flows on homogeneous spaces, quasi-unipotent flows. We show that topological complexity (ie, slow entropy) can be computed directly from the Jordan block structure of the adjoint representation. Moreover using uniform polynomial shearing we are able to show that the metric orbit growth (ie, slow entropy) coincides with the topological one, establishing hence variational principle for quasi-unipotent flows (this also applies to the non-compact case). Our results also apply to sequence entropy. We establish criterion for a system to have trivial topological complexity and give some examples in which the measure-theoretic and topological complexities do not coincide for uniquely ergodic systems, violating the intuition of the classical variational principle. (Received June 22, 2018)

1145-37-48 **Bryna Kra*** (kra@math.northwestern.edu), Department of Mathematics, Northwestern University, 2033 Sheridan Road, Evanston, IL 60208. *Dynamics of systems with low complexity.*

One way to classify dynamical systems is by their entropy, which roughly speaking gives a measure of the disorder in the system. Deterministic systems have zero entropy, but in spite of this structure, many basic questions about systems with zero entropy remain open. Even when placing strong constraints on the complexity of the system, easily formulated questions remain intractable. I will give an overview of the relations among complexity, algebraic properties, and dynamical characteristics of the system (such as periodicity, minimality, and transitivity), and their relations to combinatorial problems. (Received July 05, 2018)

1145-37-89 **Louis M Pecora***, louis.pecora@nrl.navy.mil, and **Francesco Sorrentino**, **Aaron Hagerstrom**, **Abu Siddique**, **Joseph Hart**, **Rajarshi Roy** and **Thomas Murphy**. *Dealing with Cluster Synchronization in undirected networks.*

Complex networks of oscillators or other dynamical systems can break down into subsets of nodes that are synchronized among each other, but not synchronized to node in other subsets. We call these subsets Clusters. For large networks finding such clusters is difficult to humanly impossible. The solution is to use computational group theory to find the symmetries of the network and, hence, the clusters. In addition, other clusters that are not formed from symmetries are also possible. Such clusters are called equitable clusters or Laplacian clusters. It turns out these are intimately related to the symmetry clusters and we can construct all of them from the original symmetry clusters making the symmetry clusters the building blocks of all synchronized clusters in undirected networks. We can also use group representation theory to derive the variational equations for the stability of the symmetry, equitable, and Laplacian clusters along with their desynchronization bifurcation modes. I also show some experimental results that demonstrate the success of our analysis.

[*] Collaborators: Francesco Sorrentino (U. New Mexico), Aaron Hagerstrom (NIST Boulder), Abu Siddique (U. New Mexico), Joe Hart (U. Maryland), Rajarshi Roy (U. Maryland), Thomas Murphy (U. Maryland) (Received July 26, 2018)

1145-37-146 **Mariusz Urbanski*** (urbanski@unt.edu), Department of Mathematics, University of North Texas, 1155 Union Circle #311430, Denton, TX 76203-5017, and **Vasilis Chousionis** and **Dmitry Leykehman**. *Dimension spectrum for complex and real continued fractions with restricted entries.*

In 1999 D. Mauldin and M. Urbański showed that if $\mathcal{S}$ is a conformal iterated function system with alphabet E and θ_S is its finiteness parameter, then

$$\mathrm{DimSp}(\mathcal{S}) := \{\mathrm{HD}(J_F) : F \subset E\}$$

the dimension spectrum of S, contains the interval $(\theta_S, \mathrm{HD}(J_S)]$. They conjectured that if $\mathcal{G}$ is the Gauss system, i.e. $\mathcal{G}$ consists of maps

$$[0,1] \ni x \mapsto \frac{1}{n+x} \in [0,1],\ n \in \mathbb{N},$$

then, the dimension spectrum of $\mathcal{G}$ is full: $\mathrm{DimSp}(\mathcal{S}) = [0,1]$.

In 2006 M. Kesseboehmer and S. Zhu named this conjecture Texan and proved it. D. Mauldin and M. Urbański considered in 1996 a direct complex analog $\mathcal{G}_{\mathbb{C}}$ of of the Gauss system. It consists of the maps

$$\overline{B}(1/2,1/2) \ni z \mapsto \frac{1}{b+z} \in \overline{B}(1/2,1/2),\ b \in E = \{m+ni : m \in \mathbb{N},\ n \in \mathbb{Z}\}$$

I will show that the spectrum of $\mathcal{G}_{\mathbb{C}}$ is also full, i.e.

$$\mathrm{DimSp}(\mathcal{G}_{\mathbb{C}}) = [0, \mathrm{HD}(J_{\mathcal{G}_{\mathbb{C}}})].$$

I will discuss fullness of spectrum for many subsets of E and methods of approximation of Hausdorff dimensions of the limit sets of J_F for arbitrary subsets of E. (Received August 08, 2018)

1145-37-171 **A. J. M. Hardin*** (ahardin@ou.edu) and **U. A. Rozikov** (rozikovu@yandex.ru). *A Quasi-Strictly Non-Volterra Quadratic Stochastic Operator.*

We consider a family of non-Volterra operators defined on the two-dimensional simplex and show that, with one exception, each such operator has a unique fixed point. Depending on the parameters, we establish the type of this fixed point. We study the set of limit points for each trajectory and show that this set can be a single point or can contain a 2-periodic trajectory. Such operators arise frequently in models of population genetics. (Received August 15, 2018)

1145-37-195 **Michail E Filippakis*** (mfilip@unipi.gr), University of Piraeus Research Center, 122 Gr, Greece, and **Maria Eleni Poulou** (mpoulou@math.ntua.gr). *A fractional nonlinear Schrödinger-Poisson system.*

We are concerned with the following dampted fractional nonlinear Schrödinger Poisson system,

$$\begin{cases} u_t + \gamma u + i(-\Delta)^s u + iu\phi = f, \\ \pm(-\Delta)^t \phi = |u|^2, \end{cases} \tag{1}$$

where $\gamma > 0, (-\Delta)^\alpha$ is the fractional Laplacian operator for $\alpha = s, t \in (0, 1)$.

The fractional Schrödinger equation provides us with a general point of view on the relationship between statistical properties of quantum-mechanical path and structure of the fundamental equations of quantum mechanics.First we analyse how the different orders of the Laplacian operator affect the existence and uniqueness of solutions as well as the existence of a global attractor.Next step to address is the discrete counterpart of the continuous dynamical systems (1).The aim is to prove that such a semi-discrete equation provides a discrete infinite dimensional dynamical system that possesses a global attractor.

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1145-37-457 **Nour elhouda Berguellah*** (berguellahnour85@hotmail.com), Bp 438 teleghma, 43250 Mila, Algeria, and **Nasr eddine Hamri**. *Synchronization of a chaotic system by generalized active control.*

This paper designs a scheme for controlling a chaotic system to a period system using active control technique. We have discussed about the synchronization scheme between two identical coupled chaotic system (fourscroll attractor) via active control. Numerical sumilation results are presented to show the effectiveness of the proposed scheme (Received September 06, 2018)

1145-37-470 **Ryan Chakmak**, **Colleen Chan**, **Gal Dimand** and **Aaron George*** (ageorge4@umd.edu). *Decomposition of Nonlinear System Dynamics into Multiple Time Scales.*

The United States Air Force Research Laboratory at Edwards Air Force Base investigates how Hall thrusters are used to stabilize spacecraft orbits. The physics of these thrusters are determined by chaotic systems, where slight perturbations in initial conditions lead to unpredictable results. In the case of Hall thrusters, experimental data suggests there is an interference of either noise or signal. Since this data is determined by nonlinear dynamics, traditional methods such as the Fourier transform fail. We present an algorithm which takes two causally-related signals and separates them from their interference. This process is an extension of the "convergent cross mapping" (CCM) technique developed by Sugihara et al. in 2012. We extend CCM to reconstruct signals while adding implementations of ways to deterministically select optimal tuning parameters. We find that while our method fails to outperform traditional smoothing methods on noisy signals, it succeeds on separating a composite signal into its parts. This algorithm is then applied to analyze experimental Hall thruster data, from which we are able to recreate two distinct constituent signals. (Received September 06, 2018)

1145-37-883 **Leonard Carapezza**, **Marco Antonio López*** (lopezma@wfu.edu) and **Donald Robertson**. *Equilibrium States for (α, β)-transformations.*

We consider interval maps of the form $x \mapsto \alpha + \beta x \mod 1$ and their associated shift spaces, where $\beta > 1$. In 2013, Climenhaga and Thompson proved that every Hölder potential has a unique equilibrium state in the case when $\alpha = 0$. In our work we investigate uniqueness of equilibrium states in the general case. (Received September 17, 2018)

1145-37-1010 **Kevin McGoff*** (kmcgoff1@uncc.edu). *Pressure and escape rates for random subshifts of finite type.* Preliminary report.

This talk concerns aspects of the thermodynamic formalism in a randomized setting. Let X be a non-trivial mixing shift of finite type, and let $f : X \to \mathbb{R}$ be a Hölder continuous potential with associated Gibbs measure μ. Further, fix a parameter $\alpha \in (0, 1)$. For each $n \geq 1$, let $\mathcal{F}_n$ be a random subset of words of length n, where each word of length n that appears in X is included in $\mathcal{F}_n$ with probability $1 - \alpha$, independently of all other words. Then let $Y_n = Y(\mathcal{F}_n)$ be the random subshift of finite type obtained by forbidding the words in $\mathcal{F}_n$ from X. In our first result, for α sufficiently close to 1 and n tending to infinity, we show that the pressure of f on Y_n converges in probability to the value $P_X(f) + \log(\alpha)$, where $P_X(f)$ is the pressure of f on X. Additionally, let $H_n = H(\mathcal{F}_n)$ be the random hole in X consisting of the union of the cylinder sets of the words in $\mathcal{F}_n$. In our second result, for α sufficiently close to one and n tending to infinity, we show that the escape rate of μ-mass through H_n converges in probability to the value $-\log(\alpha)$ as n tends to infinity. (Received September 18, 2018)

1145-37-1089 **Sebastian Donoso** and **Wenbo Sun*** (sun.1991@osu.edu), 364 W Lane Ave Apt 315, Columbus, OH 43201. *Topological models characterizing multiple ergodic averages.*

Using ingredients from symbolic dynamics, Jewett proved that every measure preserving system has a strictly ergodic topological models in 1970's. After Jewett's result, the existence of topological models in various settings have been studied extensively. Recently, applications of topological models were found in the study of pointwise multiple averages. In this talk, I will talk about the development of topics on topological models, as well as their applications in ergodic theory. This is joint work with Sebastian Donoso. (Received September 18, 2018)

1145-37-1143 **Simone Evans*** (evanss3@hawkmail.newpaltz.edu), 1 Hawk Dr., Department of Mathematics, New Paltz, NY 12561, and **Anca Radulescu**. *Universality of the configuration-dynamics relationship in nonlinear networks.*

We study how architecture affects dynamics in nonlinear networks. First, we discuss our results from coupled quadratic nodes. While single-map complex quadratic iterations have been studied over the past century, considering ensembles of such functions, organized as coupled nodes in a network, generates new questions with potentially interesting applications to the life sciences. We discuss extensions of concepts like escape radius and Julia and Mandelbrot sets (as parameter loci in $\mathbb{C}^n$, where n is the size of the network).

We then review ongoing research on two other nonlinear network models from neuroscience: threshold-linear networks and a reduced model of spiking inhibitory networks. Threshold-linear networks are networks that consist of simple, perceptron-like neurons with continuous-time dynamics. The inhibitory clusters model captures spiking activity and neuron synchronization in an all-to-all network of reduced Hodgkin-Huxley neurons. For each of these models, we seek out graph properties which can be used to predict or classify dynamics. Finally, we search for graph properties which are robust within each model, but that also translate between the three models. (Received September 19, 2018)

1145-37-1160 **Anca Radulescu*** (radulesa@newpaltz.edu), 1 Hawk Dr., Department of Mathematics, New Paltz, NY 12561, and **Kelsey Butera** and **Brandee Williams**. *Template iterations of quadratic maps and hybrid Mandelbrot sets.*

As a particular problem within the field of non-autonomous discrete systems, we consider iterations of two quadratic maps $f_{c_0} = z^2 + c_0$ and $f_{c_1} = z^2 + c_1$, according to a prescribed binary sequence (template). We study the parameter locus for which critical orbits are bounded (the "Mandelbrot set"). For a fixed template, one may consider this locus as a subset of $(c_0, c_1) \in \mathbb{C}^2$; for fixed quadratic parameters, one may consider the subset of templates which produce a bounded critical orbit. We consider both situations, as well as "hybrids", and study topological properties of these sets.

We discuss the potential of using this mathematical framework (in which one can apply a "good" transformation f_{c_1} versus an "erroneous" f_{c_0}) to study the effect of errors in copying mechanisms (such as DNA replication). We consider problems that a sustainable replication system may have to solve when facing the potential for errors. We find that it is possible to tell which specific errors are more likely to affect the system's dynamics. We find that it is possible to tell which specific errors are more likely to affect the system's dynamics, in absence of prior knowledge of their timing. (Received September 19, 2018)

1145-37-1181 **Claire Merriman*** (emerrim2@illinois.edu), 1409 W Green St, Urbana, IL 61801, and **Florin P. Boca**. *Coding geodesic flows and various continued fractions.*

I will connect continued fractions with even or odd partial quotients to geodesic flows on modular surfaces. The connection between geodesics on the modular surface PSL(2, Z)ãnd regular continued fractions was established by Series, and we extend this to the odd and grotesque continued fractions and even continued fractions. (Received September 20, 2018)

1145-37-1184 **Florin P Boca*** (fboca@illinois.edu) and **Claire Merriman**. *α-expansions with odd partial quotients.*

Nakada's α-expansions interpolate between three classical continued fractions: regular (obtained at $\alpha = 1$), Hurwitz singular (obtained at α =little golden ratio), and nearest integer (obtained at $\alpha = 1/2$). This talk will consider α-expansions in the situation where all partial quotients are asked to be odd positive integers. We will describe the natural extension of the underlying Gauss map and the ergodic properties of these transformations. (Received September 19, 2018)

1145-37-1200 **Azmy S. Ackleh** (ackleh@louisiana.edu), Department of Mathematics, University of Louisiana at Lafayette, Lafayette, LA 70504, **Md Istiaq Hossain*** (hossain.istiaq@louisiana.edu), Department of Mathematics, University of Louisiana at Lafayette, Lafayette, LA 70504, and **Amy Veprauskas** (aveprauskas@louisiana.edu), Department of Mathematics, University of Louisiana at Lafayette, Lafayette, LA 70504.
The effect of prey evolution on predator-prey dynamics. Preliminary report.

Continuous exposure to a toxicant may result in the evolution of toxicant resistance in relatively short-lived species. In this study, we investigate the effect of such evolution of toxicant resistance in the prey population on the overall dynamics of a predator-prey system. We first derive and analyze a discrete time predator-prey model. We establish conditions for the existence and stability of various equilibria, as well as conditions for the persistence of both predator and prey populations. We then extend this model to an evolutionary model by applying the Darwinian evolutionary game theory methodology. This methodology couples the population dynamics with the dynamics of an evolving phenotypic trait, which we assume provides a measure for the level of toxicant resistance developed by the prey. The predator is impacted by prey evolution indirectly, through changes in prey density, and directly, through an assumed trade-off between toxicant resistance and the ability of the prey to escape predation. We study the dynamics of this model and establish conditions for when the prey is able to evolve toxicant resistance. In particular, we show that the evolution of toxicant resistance may allow both the predator and prey to persist when, without the evolution, both may go extinct. (Received September 21, 2018)

1145-37-1300 **Sean Gasiorek*** (sgasiore@ucsc.edu). *Billiards Inside, Circles Outside: Dynamics of a Charged Particle in a Piecewise Constant Magnetic Field.*

Consider a magnetic field orthogonal to the Euclidean plane which is zero inside a fixed convex domain while having constant strength B outside. The dynamics of a charged particle starting in the domain can be viewed as a perturbation of usual billiard dynamics, the perturbation parameter being $\sim 1/B$. If the boundary is sufficiently smooth and B is greater than the maximum of the curvature of the boundary we show that the resulting map is a twist map, with all the consequences regarding periodic orbits, etc. ensuing. (Received September 20, 2018)

1145-37-1379 **Anh N Le*** (anhle@math.northwestern.edu), Department of Mathematics, 2033 Sheridan Rd, Evanston, IL 60208. *Almost periodic along subsequences.* Preliminary report.

An *almost periodic sequence* is a bounded sequence of the form $f(n) = \sum_{i=k}^{\infty} c_k e^{2\pi i n \alpha_k}$ where $\alpha_k \in \mathbb{R}$. A sequence $(r_n)_{n\in\mathbb{N}}$ is called *free* if one can obtain any bounded sequence by evaluating an almost periodic sequence along (r_n). In this talk, I'll present a criterion for a sequence to be free and sketch why every lacunary sequence, like (2^n), is free. This result answers a question in Frantzikinakis' list of open questions in multiple ergodic averages. I'll also provide some examples of non-free sequences. (Received September 21, 2018)

1145-37-1421 **Henry Adams**, **Veronica Ciocanel**, **Kelsey Houston-Edwards**, **Lauren Lazarus*** (lauren.lazarus@trincoll.edu), **Mark J. Panaggio**, **Bin Xu** and **Chad Topaz**.
Network reconstruction from temporal data for coupled oscillators.

In a complex system, the interactions between individual agents often lead to emergent collective behavior like spontaneous synchronization, swarming, and pattern formation. The topology of the network of interactions can have a dramatic influence over those dynamics. In many studies, researchers start with a specific model for both the intrinsic dynamics of each agent and the interaction network, and attempt to learn about the dynamics that can be observed in the model. Here we consider the inverse problem: given the dynamics of a system, can one learn about the underlying network? We investigate arbitrary networks of coupled phase-oscillators whose dynamics are characterized by synchronization. We demonstrate that, given sufficient observational data on the transient evolution of each oscillator, one can use machine learning methods to reconstruct the interaction network and simultaneously identify the parameters of a model for the intrinsic dynamics of the oscillators and their coupling. (Received September 21, 2018)

1145-37-1436 **Katherine Meyer*** (meye2098@umn.edu) and **Richard McGehee**. *Quantifying intensity of dynamic attractors using bounded, non-autonomous control.* Preliminary report.

A topological definition of an attractor leaves out metric information relevant to modeling real-world systems, particularly how far the attractor persists against perturbations and error. This talk will review some existing approaches to measuring the strength of an attractor in metric terms and will introduce the quantity "intensity" to generalize basin steepness to systems of autonomous ODEs in arbitrary dimension. One can compute an attractor's intensity by probing a domain of attraction with bounded, non-autonomous control and tracking the sets reachable from the attractor. A connection between reachable sets and isolating blocks implies that an attractor's intensity not only reflects its capacity to retain solutions under time-varying perturbations, but also gives a lower bound on the distance the attractor continues in the space of vector fields. (Received September 21, 2018)

1145-37-1511 **Angelika Manhart**, **Dhananjay Bhaskar**, **Jesse Milzman**, **John Nardini*** (jtnardin@ncsu.edu), **Chad Topaz**, **Kathleen Storey** (storeyk@umich.edu) and **Lori Ziegelmeier** (lziegel1@macalester.edu). *Deducing dynamical rules via machine learning and topology.*

The D'Orsogna model is an agent-based model frequently used to describe biological aggregations, such as schools of fish or flocks of birds, in which self-propelling individuals interact through tunable attractive and repulsive forces. In this study, we analyze simulations of the D'Orsogna model using a topological tool known as the CROCKER plot, which captures the persistent homology of particle positions and velocities over time. We use the topological data as input for machine learning techniques, both supervised and unsupervised, in order to classify emergent simulation behavior and to identify model parameters generating this behavior. We compare the classification performance of topological features with a more traditional parameter identification approach, involving the calculation of order parameters that describe global properties (avg. angular momentum, polarization, etc.) of swarms. (Received September 22, 2018)

1145-37-1602 **Elyssa N Sliheet*** (elyssasliheet@gmail.com), 6704 Swainson Trail, Arlington, TX 76002, and **J Montgomery Maxwell**. *Mathematical models linking within-host to between-host HIV dynamics.*

In this study, we develop mathematical models linking within-host and between-host HIV dynamics. In particular, we incorporate antibody responses into within-host viral dynamics model to accurately estimate the probability of virus transmission from an infected individual to an uninfected individual. Using the probability of infection resulting from within-host models, we then develop models to describe the dynamics of between-host transmission. With these models, we evaluate the role of within-host HIV dynamics on the between-host spread of HIV within communities. (Received September 23, 2018)

1145-37-1612 **Terry Soo** and **Amanda Wilkens*** (awilkens@ku.edu). *Finitary isomorphisms of Poisson point processes.*

We consider Poisson point processes over $\mathbb{R}^d$. As part of general theory for the isomorphism problem for actions of amenable groups, Ornstein and Weiss (1987) proved that any two Poisson point processes are isomorphic as factors, where the factor map commutes with the isometries of $\mathbb{R}^d$. We give a sketch of an elementary construction of an isomorphism of Poisson point processes that is finitary. This is joint work with Terry Soo (University of Kansas). (Received September 23, 2018)

1145-37-1654 **Zhenghe Zhang***, Skye Hall 202, 900 University Ave, Riverside, CA 92521. *Positivity of the Lyapunov exponent for potentials generated by hyperbolic base dynamics.*

In this talk, I will introduce some recent progress in showing positivity of the Lyapunov exponent for Schrodinger operators with potentials generated by hyperbolic base dynamics. They immediately imply absence of absolutely continuous spectrum and are strong indications of Anderson Localization. Part of the works are joint with A. Avila and D. Damanik. (Received September 23, 2018)

1145-37-1685 **Mrinal K Roychowdhury***, University of Texas Rio Grande Valley, 1201 West University Drive, Edinburg, TX 78539. *Quantization for Probability Distributions.*

The basic goal of quantization for probability distribution is to reduce the number of values, which is typically uncountable, describing a probability distribution to some finite set and thus to make an approximation of a continuous probability distribution by a discrete distribution. Quantization dimension gives the speed how fast the specified measure of the error goes to zero as n approaches to infinity. It has broad application in signal processing, and data compression. I will talk about the quantization for some fractal probability measures. (Received September 23, 2018)

1145-37-1727 **Daniel J. Ingebretson***, 1400 E Hanna Ave, Indianapolis, IN 46227. *Dimension and differential structures on cookie-cutter Cantor sets.*

Each differential structure on a Cantor set is determined by a scaling function on its dual, which is defined symbolically. For smooth cookie-cutter Cantor sets, we will study the relations between the scaling function, differential structures, and the Hausdorff dimension of the Cantor set. (Received September 24, 2018)

1145-37-1760 **Adam Kanigowski***, adkanigowski@gmail.com, College Park, MD. *On the Bernoulli property for some partially hyperbolic systems.*

We study the Bernoulli property for partially hyperbolic systems for which the central direction has zero exponents, but is not isometric. The main object of interest are skew products over Anosov diffeomorphisms with fibers of zero entropy. More precisely, let $A : M \to M$ be an Anosov map, (K_t) a weakly mixing flow on N and $\phi : M \to \mathbb{R}$ a smooth cocycle. We consider the skew product

$$A_\phi(x, y) = (Ax, K_{\phi(x)}(y)).$$

We provide sufficient conditions (on (K_t)) for A_ϕ to be Bernoulli and also give examples of (K_t) for which A_ϕ is not Bernoulli. (Received September 24, 2018)

1145-37-1848 **Kariane Calta**, **Cor Kraaikamp** and **Thomas A. Schmidt*** (toms@math.orst.edu), Department of Mathematics, Oregon State University, Corvallis, OR 97331. *α-continued fractions for infinitely many triangle groups.* Preliminary report.

Nakada's (1981) much studied α-continued fractions are a one-parameter family of interval maps related to an action of the modular group. We study a collection of one such family for each of a countably infinite family of Fuchsian triangle groups. We discuss aspects of the maps such as invariant measures, entropy, natural extensions, and associated sections for the geodesic flow on the unit tangent bundle of the surface uniformized by the corresponding group. (Received September 24, 2018)

1145-37-1851 **Scott Schmieding*** (schmiedi@math.northwestern.edu) and **Kitty Yang** (kyang@math.northwestern.edu). *The mapping class group of a minimal subshift (part 2).* Preliminary report.

The mapping class group $\mathcal{M}(\sigma)$ of a subshift (X, σ) is the group of isotopy classes of self homeomorphisms of the suspension space associated to (X, σ). $\mathcal{M}(\sigma)$ plays the role of a symmetry group for the flow equivalence relation on subshifts. We will discuss constraints on $\mathcal{M}(\sigma)$ when σ is a low complexity minimal subshift, and its relation to the group of automorphisms of the subshift σ. In particular, when (X, σ) is a minimal subshift associated to a substitution, we show that $\mathcal{M}(\sigma)$ is an extension of $\mathbb{Z}$ by a finite quotient of the automorphism group. This is joint work with Kitty Yang. (Received September 24, 2018)

1145-37-1880 **Md Nazmul Hassan*** (md.nazmul.hassan@ttu.edu), 303 Detroit Ave Apt 204, Lubbock, TX 79415, and **Angela Peace**. *Stoichiometry and Toxicity in Aquatic Food Webs.*

Accurately assessing the risks of contaminants requires more than an understanding of the effects of contaminants on individual organism, but requires further understanding of complex ecological interactions, elemental cycling, and the interactive effects of natural stressors, such as resource limitations, and contaminant stressors. There is an increasing evidence that organisms experience interactive effects of contaminant stressors and food conditions, such as resource stoichiometry and nutrient availability. We are developing and analyzing a series of empirically testable and robust mathematical models of populations dynamics subject to stoichiometric and contaminant stressors. In parallel to developing the models, we will integrate sufficient data from existing and new experiments to parameterize, test, and improve them. The synthesis of the models and experiments will result in the development of a robust theoretical framework appropriate for improved risk assessment applications in ecotoxicology that incorporate the effects of stoichiometric constraints on concurrent ecological and toxicological processes. In particular, we are presenting how the toxicant bioaccumulates to the upper food webs. (Received September 24, 2018)

1145-37-1971 **Joanna Furno*** (jfurno@math.uh.edu) and **Lorelei Koss**. *Relating singularly perturbed rational maps to families of entire maps.*

In joint work with Lorelei Koss, we study families of rational maps that converge uniformly on compact sets to families of entire maps. Through conjugation, these families are related to extensively studied singularly perturbed rational maps and families of exponential maps. We examine the convergence of attracting regions in parameter space. (Received September 24, 2018)

1145-37-2062 **Kitty Yang***, kyang@math.northwestern.edu, and **Scott Schmieding**. *The mapping class group of a minimal subshift (Part I).*

Let (X, σ) be a minimal subshift and Aut(X) denote its automorphism group. The suspension of (X, σ) is defined to the be quotient $\Sigma_\sigma X := X \times [0, 1]/ \sim$, where $(x, t) \sim (\sigma^n x, t - n)$. The mapping class group of (X, σ), denoted by $\mathcal{M}(\sigma)$, is the group of isotopy classes of self-flow equivalences. We show there is an injection $\Psi : \mathrm{Aut}(\sigma)/\langle\sigma\rangle \to \mathcal{M}(\sigma)$, and give an example of a minimal subshift whose mapping class group is strictly larger than $\mathrm{Aut}(\sigma)\langle\sigma\rangle$. We classify the mapping class group for sturmians. (Received September 24, 2018)

1145-37-2076 **Donald Robertson*** (robertso@math.utah.edu). *Mildly mixing interval exchange transformations.*

Interval exchange transformations can be represented as symbolic systems of low complexity. We show, for an infinite family of permutations defining the exchange, that linear recurrence of the exchange implies mild mixing. (Received September 24, 2018)

1145-37-2096 **Jesse Drendel*** (drendel@math.colostate.edu). *Toric dynamical systems in population genetics.*

Toric dynamical systems make tractable models of recombination, mutation, and meiosis/fertilization, even with many loci and position effects. The longstanding global attractor conjecture, proved in 2016, says that solutions to a toric dynamical system approach a smooth connected manifold solving log-linear equations. This manifold is the linkage equilibrium of recombination models and the Hardy-Weinberg equilibrium of meiosis/fertilization models. There is an entropy-like function that increases with time for non-equilibrium solutions. The non-toric dynamics of epistatic selection can lead to linkage disequilibrium through cusp bifurcation and Hopf bifurcation of the attractor. (Received September 24, 2018)

1145-37-2128 **Federico Rodriguez Hertz**, University Park, PA 16802, and **Zhiren Wang*** (zhirenw@psu.edu), University Park, PA 16802. *Statistics of escaping trajectories in homogeneous spaces.*

Given a finite volume homogeneous space G/Γ of a higher rank semisimple Lie group of G, a point x in the space, and an unit length element a of the Cartan subgroup A, we will consider the set of directions in the tangent space at x for which the outgoing a-orbit of length T aymptotically spends at most a portion of measure ϵT near the cusp. The Hausdorff dimension of this set will be at most $e^{-C\epsilon T}$, where C is independent of the choice of a. This is a joint work with F. Rodriguez Hertz. (Received September 24, 2018)

1145-37-2259 **Lauren Lazarus*** (lauren.lazarus@trincoll.edu). *Frequency effects of various cubic resonances on a delayed oscillator.*

Limit cycle oscillations can be generated by a first-order delayed differential equation $\dot{x}(t) = -x(t-T) - x(t)^3$, which has been shown to have similar behaviors to the van der Pol oscillator and other standard models. This delayed system includes a cubic stiffening term which resonates with the linear terms and ensures that the periodic steady state is asymptotically stable when it exists. This talk will discuss some variations on the cubic term, including different combinations of delayed and instantaneous information about the system's state. Using perturbation methods and bifurcation theory, I will show that these differences affect both the natural frequency of the oscillator and its relative susceptibility to entrainment by an external periodic forcing. Parametric forcing in the form of a cubic resonance is also considered. (Received September 25, 2018)

1145-37-2309 **Stefanos Orfanos** (sorfanos@depaul.edu), **Ayse A. Sahin*** (ayse.sahin@wright.edu) and **Ilie Ugarcovici** (iugarcov@depaul.edu). *Orbit structure and orbit equivalence for actions of semi-direct product groups.* Preliminary report.

We will discuss actions of semi-direct product groups of the form $G = \mathbb{Z}^d \rtimes_A \mathbb{Z}$ where $A \in M(2,\mathbb{Z})$ with $det(A) = 1$. We discuss the interplay between continuous orbit equivalence and the geometry of the group. (Received September 25, 2018)

1145-37-2377 **Jude Dzevela Kong*** (jk1567@dimacs.rutgers.edu), 96 Frelinghuysen Road, Piscataway, NJ 08854, and **William Davis** and **Hao Wang**. *Indirect Transmitted Infectious Diseases: from Microscopic to Macroscopic Cycles.*

Many infectious diseases that spread indirectly via reservoir such as cholera remain endemic and epidemic in the world, causing thousands of deaths annually in locations that lack adequate sanitation and water infrastructures. In this talk, I will present an infectious disease transmission model that includes the dynamics of bacteriophage and bacteria, and contains an indirect infection term which accounts for the minimum infectious dose of the bacteria. Using this model, I determine what drives cyclical outbreaks of infectious diseases in endemic regions and suggest ways by which such outbreaks can be prevented. In addition, I will present a region in the parameter space of our model that leads to chaotic behaviour. This could be used to explain the irregularity in the seasonal patterns of outbreaks amongst different countries, especially if the positive relationship between bacterial proliferation and temperature is considered. (Received September 25, 2018)

1145-37-2406 **Sarah Iams***, siams@seas.harvard.edu, and **Punit Gandhi** and **Mary Silber**. *Water Transport Shapes Banded Vegetation Patterns in Dryland Ecosystems.*

In dryland ecosystems, water can be thought of as a limiting resource. In an apparent response to water scarcity, two phase mosaics of vegetation and bare ground often develop in these regions. In some locations, the mosaic forms as bands or arcs of vegetation tens of meters wide and up to a kilometer in length, separated by bare ground. Observations suggest that topography may influence the bands. In conceptual partial differential equation models of the system, inhomogeneity of the surface can lead to bands and band arcing as well as to predictions about when bands, bare soil or uniform vegetation, might appear. (Received September 25, 2018)

1145-37-2413 **Sebastian Donoso**, **Anh Ngoc Le** and **Joel Moreira***, joel.moreira@northwestern.edu, and **Wenbo Sun**. *Optimal lower bounds for multiple recurrence.*

Let $(X,\mathcal{B},\mu,T)$ be an ergodic measure preserving system, $A\in\mathcal{B}$ and $\epsilon>0$. Given functions $f_1,\ldots,f_k:\mathbb{N}\to\mathbb{Z}$, under which conditions is the set

$$S:=\left\{n\in\mathbb{N}\colon \mu(A\cap T^{-f_1(n)}A\cap T^{-f_2(n)}A\cap\ldots\cap T^{-f_k(n)}A)>\mu(A)^{k+1}-\epsilon\right\}$$

large? I will present some new results when the functions f_i involve the prime numbers, polynomials or functions of the form $f(n)=\lfloor n^{5/2}\rfloor$. I will also mention open questions even for the case when all the f_i are linear. (Received September 25, 2018)

1145-37-2534 **Jennifer N Jones-Baro*** (`jennifer.jones@cimat.mx`), **Hindy Drillick**, **Alonso Espinosa-Dominguez**, **James Leng**, **Yelena Mandelshtam** and **Cesar E. Silva**. *Models on the unit square of the Chacón, Pascal, and other cutting and stacking transformations.*

The Chacón transformation on the unit interval is an important example in ergodic theory that has been a source of many examples and counterexamples; in particular, it is a measure-preserving transformation that is weakly mixing but not mixing. Likewise, the Pascal transformation is another important transformation, but many questions about its dynamical properties still remain open. We construct transformations on the unit square that are piecewise translations on rectangles and are isomorphic to the Chacón and the Pascal transformations, and then generalize the constructions to any n-dimensional square. This construction can be used for other transformations such as rank-one transformations. Having a construction in two dimensions allows us to visualize the dynamics of the transformations, and we have constructed some animations through which some dynamical properties are observed. This allows us to make numerical estimations and new conjectures. (Received September 25, 2018)

1145-37-2554 **Diana Davis***, 500 College Avenue, Swarthmore, PA 19081. *Continued fractions for the golden L, and billiards in the pentagon.*

We give a method analogous to the continued fraction algorithm, to put a tree structure on the set of all periodic directions on the golden L. This gives us an associated tree structure on the set of periodic directions for the regular pentagon billiard table and its associated surfaces, which we use to understand the periodic trajectories. I'll show examples of many periodic billiard trajectories on the pentagon, which are strikingly beautiful, and describe some of their surprising properties. (Received September 25, 2018)

1145-37-2737 **Yelena Mandelshtam***, yelena13@stanford.edu, and **Alonso Espinosa-Dominguez**, **Hindy Drillick**, **Jennifer N. Jones-Baro**, **James Leng** and **Cesar E. Silva**. *Non-Rigid Rank-One Infinite Measures on the Circle.* Preliminary report.

Rank-one transformations have played an important role as a source of examples and counterexamples in ergodic theory. In 1976, del Junco showed that irrational rotations are rank-one, but did not give an explicit cutting and stacking construction. For a class of irrational numbers, depending on their Diophantine properties, we construct explicit rank-one transformations that are totally ergodic and not weakly mixing. We classify when the measure is finite or infinite. In the finite case they are isomorphic to irrational rotations, and we obtain explicit cutting and stacking constructions for these transformations. In addition, we extend this construction to obtain rank-one non-rigid infinite invariant measures on irrational rotations. One consequence is getting the first examples of infinite measure rank-one transformations that are totally ergodic and not weakly mixing. We also obtain nonsingular measures not admitting an invariant measure for irrational rotations. (Received September 25, 2018)

1145-37-2753 **Komi S Messan**, **Marisabel Rodriguez Messan*** (marisabel.rodriguez.messan@dartmouth.edu), **Gloria Degrandi-Hoffman** and **Yun Kang**. *The role of Varroa on the honeybee population dynamics: a modeling approach and the effect of brood-mite interaction.*

The rapid decline of honeybee population have sparked a great concern worldwide. Many field and theoretical studies have shown that the collapsing of colonies may be due to the infestation by the parasitic Varroa mite. This study investigates the population dynamics of honeybee colonies under infestation by Varroa mite. We propose a single patch brood-adult bee-mite interaction model in which the time lag from brood to adult bee is taken into account. Model parameters are estimated under constant and fluctuating seasonality. The analytical and numerical studies reveal the following: (a) Large mite mortality could drive the mite population extinct leaving the colony with healthy brood and adult bees; (b) Small brood's infestation rate could stabilize all populations at the unique interior equilibrium under constant seasonality while driving the mite population to die out when changes in seasonality is considered; (c) Large brood's infestation rate can destabilize the dynamics leading to extinction of all populations dependent on initial conditions under constant and non-constant seasonal model; (d) Sensitivity analysis indicate that the queen's egg-laying rate may have the greatest effect on colony's population size. (Received September 25, 2018)

1145-37-2759 **Sara M Clifton**, **Kaitlin Hill*** (hillk@umn.edu), **Avinash J Karamchandani**, **Eric A Autry**, **Patrick McMahon** and **Grace Sun**. *A mathematical model of gender bias and homophily in professional hierarchies.* Preliminary report.

Gender representation has been improving toward parity in the past several decades for many professions, such as mathematics, medicine, and biology. However, this representation becomes more skewed toward one gender as workers move up to higher-level positions in the professional hierarchy. Sociologists have attributed this effect to various cultural and psychological factors, such as self-segregation and bias. We present a minimal mathematical model that relates the roles of bias and homophily (self-segregation) to the progression of gender fraction through a theoretical professional hierarchy. The model consists of an $L-$dimensional system of ordinary differential equations representing different levels of a hierarchy, where individuals at each level either move up to the next or out of the system. We analyze the bifurcation structure of this system as homophily and bias vary. We identify rich dynamics, including oscillatory behavior and Takens-Bogdanov bifurcations. We validate the model by analyzing a new database of gender fractionation over time for 15 professional hierarchies. (Received September 25, 2018)

1145-37-2800 **Yunjiao Wang*** (yunjiao.wang@tsu.edu), Department of Mathematics, Texas Southern University, 3100 Cleburne Dr., Houston, TX 77004, and **Alberto Zepeda**, **Faith Grice**, **Erika Martinez**, **Susan Gonzalez** and **Julio Chavez**. *Effects of additional interactions on the dynamics of networks.* Preliminary report.

The advent of high throughput technology enables us to gather a huge amount of data pertaining to interactions among biological components. However, data accuracy due to missing and/or false interactions is often a concern. In this work, we aim to address the potential effects due to additional interactions. More specifically, based on Boolean network framework, we study possible impacts on the dynamics of three-node network systems and also consider potential effects of a sequence of interactions on the dynamics of some classes of networks. (Received September 25, 2018)

1145-37-2832 **Nick Mendler*** (nickmendler101@gmail.com). *The connectedness locus of IFS consisting of two similitudes.*

An escape time algorithm is presented for the generation and exploration of the connectedness locus of IFS which consist of 2 similitudes of the plane. The space of IFS consisting of any two similitudes of $\mathbb{C}$ is parameterized over $\mathbb{C}^4$, and while considering the locus of IFS corresponding to connected attractors the domain is compressed to $\mathbb{C}^2$. The investigated locus contains as a cross-section the 'Mandelbrot Set for pairs of linear maps' - which was introduced by Barnsley and Harrington in 1985 and subsequently related by Odlyzko and Poonen to the locus of points which are roots of complex polynomials with coefficients in $\{0, 1\}$. (Received September 25, 2018)

39 ► Difference and functional equations

1145-39-65 **Johnny Henderson*** (johnny_henderson@baylor.edu), Department of Mathematics, Baylor University, Waco, TX 76798-7328. *Existence of local solutions for a fractional difference equation with Dirichlet boundary conditions.*

For $1 < \nu \leq 2$ a real number and $T \geq 2$ a natural number, conditions are given for the existence of solutions of the νth order Atıcı-Eloe fractional difference equation, $\Delta^\nu y(t)+f(t+\nu-1, y(t+\nu-1)) = 0$, $t \in \{1, 2, \dots, T+1\}$, and satisfying the Dirichlet boundary conditions $y(\nu-2) = y(\nu+T+1) = 0$. (Received July 18, 2018)

1145-39-86 **Candace Marie Kent*** (cmkent@vcu.edu), 3510 Hanover Avenue, Richmond, VA 23221. *Heuristic Observation on the Comparison Between the Behavior of Orbits in the $3x + 1$ Problem and the $5x + 1$ Problem.* Preliminary report.

We heuristically address the $3x + 1$ Problem and the corresponding $5x + 1$ Problem. We make an observation, based on a multitude of computations, which may, in turn, lend its support of the conjectures that no orbit under the $3x + 1$ map is divergent to $+\infty$ (and so every orbit is eventually periodic as a cycle, in particular as $(1, 4, 2)$) and almost all orbits under the $5x + 1$ map are divergent to $+\infty$. Our representation of the natural numbers (which are the iterates of orbits under the $3x + 1$ and $5x + 1$ maps) is influenced by the Sharkovsky ordering of the natural numbers. (Received July 26, 2018)

1145-39-107 **Jonathan Machado*** (jomachad@uncg.edu) and **Pedro Vásquez** (pedro.vasquez1@upr.edu). *Controlling Alternans in a Discrete Cardiac Cell Model.*

In this study, we consider a condition called alternans, a period-2 heart rhythm characterized by oscillations between strong and weak heartbeats known to precede serious heart disorders. Several studies have analyzed methods to prevent or terminate alternans, but in those cases alternans occurred primarily because of instabilities in the cell membrane potential. Alternans also can arise from instabilities in intracellular calcium cycling related to contraction. Here, we use a discrete model of four coupled difference equations to examine whether suppression or complete elimination of alternans is possible using two classes of control methods, one that applied feedback terms directly to individual state variables and another that modifies the timing of heartbeats. To study alternans suppression, we use direct iteration of the model along with a linear stability analysis to provide a theoretical basis for our findings. We present results on the effectiveness of these control methods as well as the observed dependence on the instability underlying alternans. (Received July 30, 2018)

1145-39-130 **Kari E. Fowler*** (kfowler@ut.edu), 401 W. Kennedy Blvd., Tampa, FL 33606. *Nevanlinna Theory and Tropical Difference Polynomial Equations.*

There has been increasing interest in tropical mathematics in recent years, and it has grown to include applications in a wide array of disciplines. We study its application to tropical Nevanlinna theory within the context of ultra-discrete analogues of homogeneous complex differential equations. Within the setting of the one-dimensional max-plus tropical semi-ring $\mathbb{R} \cup \{-\infty\}$, we define tropical addition as $a \oplus b = \max\{a, b\}$, tropical multiplication as $a \otimes b = a + b$, and tropical exponentiation as $a^{\otimes b} = b \cdot a$, for $b \in \mathbb{R}$. Specifically, we consider growth properties of tropical meromorphic functions within the context of the interplay between coefficient and solution conditions for tropical difference polynomial equations of the form

$$P(x, f) = \bigoplus_{\lambda \in \Lambda} A_\lambda(x) \otimes \bigotimes_{j=0}^{p} f(x + c_j)^{\otimes \lambda_j} = 0.$$

(Received August 06, 2018)

1145-39-203 **M. R. S. Kulenovic***, Department of Mathematics, University of Rhode Island, Kingston, RI 02881, and **Orlando Merino**. *Invariant Curves for Planar Competitive and Cooperative Maps.*

In this talk we present results on the existence of invariant curves for planar maps that are monotone with respect to either the south-east or north-east ordering. Some of these curves are the stable or unstable manifolds of hyperbolic fixed points (saddle points) or non-hyperbolic fixed points, and are also the boundary of basins of attraction of such points. Invariant curves of maps in the form of stable, unstable and center manifolds appear in the earliest work on dynamical systems by Poincaré and Hadamard, where not only the existence but also methods for finding those manifolds were introduced. Poincaré used the method of undetermined coefficients while Hadamard used the method of successive approximations to solve locally functional equations for those manifolds in the plane. Their results were local and did not give any indications how to get the existence or an effective method of computation of global versions of these manifolds. Our results are global and provide the precise description of these manifolds. (Received August 19, 2018)

1145-39-427 **Arzu Bilgin*** (arzu.bilgin@erdogan.edu.tr), , Turkey, and **Mustafa Kulenovic**.
Global Dynamics for Discrete Models in Populations Dynamics of Single Species.

We present some basic discrete models in populations dynamics of single species with several age classes. Starting with the basic Beverton-Holt model that describes the change of single species we discuss its basic properties such as a convergence of all solutions to the equilibrium, oscillation of solutions about the equilibrium solutions, Allee's effect, Jillson's effect, etc. We consider the effect of the constant and periodic immigration and emigration on the global properties of Beverton-Holt model. We also consider the effect of the periodic environment on the global properties of Beverton-Holt model.
(Received September 06, 2018)

1145-39-540 **Ann Brett*** (ann.brett@jwu.edu). *Symmetry Methods in the Solution of Difference Equations and Discrete Dynamical Systems.* Preliminary report.

In this talk we present an introduction to symmetry in the context of mathematics and an overview of symmetric methods used in the solution of difference equations and discrete dynamical systems. (Received September 09, 2018)

1145-39-715 **Yevgeniy Kostrov** and **Zachary Kudlak*** (zachary.a.kudlak@uscga.edu), 31 Mohegan Ave Pkway, New London, CT 06320, and **Patrick Vernon**. *On a System of Rational Difference Equations with Non-constant Coefficients.*

We investigate the boundedness character of nonnegative solutions of the nonautonomous rational system

$$\begin{cases} x_{n+1} = \dfrac{\alpha_n + \gamma_n x_n}{\beta_n x_n + y_n} \\ \\ y_{n+1} = g(x_n, \dots, x_{n-k+1}, y_n, \dots, y_{n-k+1}, n) \end{cases} \quad \text{for } n = 0, 1, \dots$$

where the coefficients of the system are sequences of nonnegative numbers bounded both above and below by positive constants, the initial conditions $(x_0, y_0), (x_{-1}, y_{-1}), \dots, (x_{-k+1}, y_{-k+1})$ are positive, and g takes on only positive values for positive values of $x_n, \dots, x_{n-k+1}, y_n, y_{n-k+1}, n$. Special cases of this system, such as with periodic coefficients, are also investigated. (Received September 13, 2018)

1145-39-909 **Vlajko L. Kocic*** (vkocic@xula.edu), 4912 Elmwood Pkwy., Metairie, LA 70003. *Global asymptotic behavior of some classes of nonlinear periodically forced delay difference equations.*

WE present some results on permanence, extreme stability, and existence of periodic solutions in some classes of delay periodically forced nonlinear difference equations with applications in Population Dynamics. (Received September 17, 2018)

1145-39-1032 **Robert J Sacker*** (rsacker@usc.edu), University of Southern California, Mathematics Department KAP 104, 3620 S Vermont Ave, Los Angeles, CA 90064. *Bifurcation in the Almost Periodic Ricker Map.* Preliminary report.

It was shown in an earlier publication that the Ricker equation with Almost Periodic coefficient with finitely generated frequency module and with average value lying in $(0, 2)$ has Almost Periodic solutions lying on a torus $\mathcal{T}$ of the same dimension as the (finite) number of independent generators of the frequency module of the coefficient. The hull H of the coefficient is itself a torus homeomorphic to $\mathcal{T}$ and isomorphic to $\mathcal{T}$ as an Abelian group.

In this paper we find a bifurcation function and show that if the magnitude of the oscillatory part of the coefficient is increased and the average part is then increased above a bifurcation curve a pair of tori bifurcate, each of which is invariant under the composition of two Ricker maps in sequence and enjoys all the properties as in the pre-bifurcation case. In addition we show all the tori discussed above are C^1 smooth.

It is also surprising to notice that the stability interval $(0, 2)$ is increased as the magnitude of the oscillatory part of the coefficient is increased. Finally the case of a frequency module that is infinitely generated is treated.
(Received September 18, 2018)

1145-39-1133 **Jim Cushing*** (cushing@math.arizona.edu), Department of Mathematics, 617 N Santa Rita, University of Arizona, Tucson, AZ 85721. *Difference Equations as Models of Evolutionary Population Dynamics.*

We describe the evolutionary game theoretic methodology for extending a difference equation population dynamic model in a way so as to account for the Darwinian evolution of model coefficients. For these difference equation models, we give a general theorem that describes the transcritical bifurcation that occurs when the extinction equilibrium destabilizes. This bifurcation results in survival (positive) equilibria whose stability depends on the direction of bifurcation. We give several applications based on evolutionary versions of some classic equations, such as the discrete logistic (Beverton-Holt) and Ricker equations. In addition to illustrating our theorems, these examples also illustrate other biological phenomena, such as strong Allee effects, time dependent adaptive landscapes, and evolutionary stable strategies. (Received September 19, 2018)

1145-39-1405 **Ronald E. Mickens*** (rmickens@cau.edu), Clark Atlanta University, Atlanta, GA 30314, and **Talitha M. Washington** (talitha.washington@howard.edu), Howard University, Washington, DC 20059. *Bifurcations as the Genesis of Instabilities in the Numerical Solutions to Differential Equations.*

The discretization of differential equations by finite differences provides an important source of difference equations. However, the implementation often gives rise to numerical solutions having properties inconsistent with the expected mathematical properties of the solutions to the differential equations. These solutions are called "numerical instabilities (NI)." We demonstrate that the NI's are consequences of bifurcations related to the step-sizes which appear in the difference equations, but do not exist in the original differential equations. Further, we show how all the elementary NI's can be explicitly eliminated. This work extends the previous results of Mickens and his colleagues [1, 2, 3].

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1145-39-1415 **Paul W Eloe**, **Catherine M Kublik*** (ckublik1@udayton.edu) and **Jeffrey T Neugebauer**. *Comparison of Green's functions for a family of boundary value problems for fractional difference equations.*

In this paper, we obtain sign conditions and comparison theorems for Green's func- tions of a family of boundary value problems for a Riemann-Liouville type delta fractional difference equation. Moreover, we show that as the length of the domain diverges to infinity, each Green's function converges to a uniquely defined Green's function of a singular boundary value problem. (Received September 21, 2018)

1145-39-1544 **Alexander Y Gordon*** (aygordon@uncc.edu). *Two delocalization results for quasi-periodic Schrödinger operators.*

It has been known since 1970's that one-dimensional discrete quasi-periodic Schrödinger operators with Liouville frequencies don't have eigenvalues. The question whether this result could be extended to a multidimensional setting remained open since then. Recently, an affirmative answer was obtained (joint work with Arkadi Nemirovski). Another result extends the old statement (in a slightly and inevitably weakened form) in a different direction: to the case, where the sampling function on the torus (which, together with the vector of frequencies and a point of the torus, defines the potential) is only required to be measurable. (Received September 23, 2018)

1145-39-1641 **Ariel Setniker*** (asetniker2@unl.edu). *Sequential Nabla Fractional Differences.*

In this talk, we study the composition of nabla fractional differences, known as "sequential" nabla fractional differences, of the form $\nabla^{\nu}_{a+k+1}\nabla^{\mu}_{a}f(t)$ for $k \in \mathbb{N}_0$, in the case where $k < \mu < k+1$, $k+1 < \nu < k+2$, and $2k+1 < \mu+\nu < 2k+2$, and also in the case where $k < \mu < k+1$, $k-1 < \nu < k$, and $2k < \mu+\nu < 2k+1$. We present connections between the sign of these sequential nabla fractional differences and the monotonicity of the function $f(t)$, and further discuss fractional difference equations of the form $\nabla^{\nu}_{a+k+1}\nabla^{\mu}_{a}f(t) = h(t)$. (Received September 23, 2018)

1145-39-2370 **Saber Elaydi*** (selaydi@trinity.edu), 18806 Cierra sur, San Antonio, TX. *The structure of the omega limit sets of non-autonomous discrete dynamical systems.* Preliminary report.

In this talk we consider a non-autonomous discrete dynamical systems defined by a sequence f_n of continuous maps defined on a locally compact metric space X. First we compactify the metric space to X^* and extend the dynamical system to X^*. Next we focus on the topological structure of the omega limit set of the extended dynamical system and the origin dynamical system. (Received September 25, 2018)

1145-39-2514 **Allan Peterson*** (apeterson1@math.unl.edu), 1400 R Street, Lincoln, NE 68588-0130. *A generalized h-fractional Gronwall's inequality and its applications for nonlinear h-fractional difference systems with "maxima".*

This paper gives a generalized h-fractional Gronwall's inequality. Applying this result, we prove the uniqueness and give bounds on solutions for a nonlinear h-fractional difference system with "maxima". Finally, we give an example to illustrate one of our main results. (Received September 25, 2018)

1145-39-2605 **Feifei Du** and **Wei Hu***, wei.hu@huskers.unl.edu, and **Lynn Erbe** and **Allan Peterson**. *Some new integral inequalities on time scales.*

Feng Qi proposed the following open problem: under what conditions does the inequality

$$\int_a^b [f(x)]^t dx \geq \left[\int_a^b f(x)dx \right]^{t-1}$$

hold for $t > 1$? The inequality has been studied by various authors in the cases of q-integral inequalities, (q, h) integral inequalities on discrete time scales and time scales. In this paper, we give some generalizations of Feng-Qi type inequalities on time scales, which includes new results. (Received September 25, 2018)

1145-39-2627 **Saber Elaydi*** (selaydi@trinity.edu), 18806 Cierra sur, San Antonio, TX. *On the evolutionary dynamics of discrete-time models.* Preliminary report.

In this talk, we will investigate the dynamics of discrete-time evolutionary models of populations. In particular, we will conduct stability analysis, both local and global, using tools from non-autonomous discrete dynamical systems. (Received September 25, 2018)

1145-39-2978 **Areeba Ikram*** (aikram@mines.edu). *Solutions to Particular Discrete Fractional Equations.* Preliminary report.

We will start by presenting the necessary background for discrete fractional calculus, highlighting appropriate analogues from ordinary differential equations. We will then explore solutions to N-th order discrete fractional equations and compare these solutions to solutions in the corresponding ordinary differential equations context. In particular, we will adopt analogous counterparts to (k, N-k) boundary value problems from ordinary differential equations, and we will consider solutions to these (k, N-k) boundary value problems in the discrete fractional context. (Received September 26, 2018)

1145-39-2981 **Kevin Ahrendt*** (kahrendt@mines.edu). *Application of the Contraction Mapping Theorem for existence and uniqueness of solutions to nonlinear, fractional difference boundary value problems.*

We use the Contraction Mapping Theorem to guarantee unique solutions to the nonlinear, fractional difference equation $\nabla\nabla^{\nu}_{a*}x(t) = F(t, x(t-1))$, which is closely related to the self-adjoint differential equation. We develop a general Green's function for the corresponding homogeneous boundary value problem, and go on to find properties of the Green's function in several specific cases, including right-focal boundary conditions as well as conjugate boundary conditions. We utilize these properties with the corresponding integral equation and the Contraction Mapping Theorem to prove the existence and uniqueness of solutions to the appropriate nonlinear, fractional boundary value problems. (Received September 26, 2018)

40 ► Sequences, series, summability

1145-40-994 **Sukhdev Singh*** (singh.sukhdev01@gmail.com), Department of Mathematics, Lovely Professional University, Jalandhar-Delhi G.T Road (NH-1), Phagwara, Punjab 144411, India, and **Sanjeev Kumar** (sanjeevibs@yahoo.co.in), Department of Mathematics, IBS Khandari Campus, Dr. B. R. Ambedkar University, Agra, U.P. 282002, India. *Orlicz function and some paranormed difference $\mathbb{C}_2$-sequence spaces.* Preliminary report.

This paper deals with the results of sequence spaces extended to generalized Orlicz sequence spaces defined via double sequences. In this paper, we introduced some paranormed difference $\mathbb{C}_2$-sequence spaces by the norm on bicomplex space and the Orlicz function. We study some of their topological properties such as symmetric, solidness and completeness and some inclusion relation between these spaces are also established. (Received September 18, 2018)

1145-40-1697 **Andrzej K Brodzik*** (andrzej.k.brodzik@gmail.com). *Design of Golay sequences in Zak space.* Preliminary report.

Zak space provides a convenient framework for design of sets of polyphase sequences with good periodic correlation properties, which have many applications in radar, sonar and communications. One of such sets is the set of periodic Golay sequences. In this work a special case of periodic Golay sequence set is considered, where each of the sequences in the set has compact support in Zak space, an optimal zero auto correlation zone, and any two sequences in the set have an all-zero crosscorrelation. Sequences with compact support in Zak space are, in general, more difficult to compute and identify, which can be advantageous when used in covert applications. (Received September 24, 2018)

41 ► *Approximations and expansions*

1145-41-147 **George A Anastassiou*** (ganastss@memphis.edu), 3725 Norriswood St, Department of Mathematical Sciences, University of Memphis, Memphis, TN 38016. *Multivariate and Convex Approximation by Choquet integrals.*

Here we consider the quantitative approximation of positive sublinear operators to the unit operator. These are given a precise Choquet integral interpretation. Initially we start with the study of the rate of the convergence of the well-known Bernstein-Kantorovich-Choquet and Bernstein-Durrweyer-Choquet polynomial Choquet-integral operators. We introduce also their multivariate analogs. Then we study the very general comonotonic positive sublinear operators based on the representation theorem of Schmeidler (1986). We finish with the approximation by the very general direct Choquet-integral form positive sublinear operators. All approximations are given via inequalities involving the modulus of continuity of the approximated function or its higher order derivative. We derive univariate and multivariate results without or with convexity assumptions. In the latter case estimates become very elegant and brief. (Received August 09, 2018)

1145-41-148 **George A Anastassiou***, 3725 Norriswood st, Department of Mathematical Sciences, University of Memphis, Memphis, TN 38016. *Caputo and Canavati fractional Approximation by Choquet integrals.*

Here we consider the quantitative Caputo and Canavati fractional ap- proximation of positive sublinear operators to the unit operator. These are given a precise Choquet integral interpretation. Initially we start with the study of the fractional rate of the convergence of the well-known Bernstein-Kantorovich-Choquet and Bernstein-Durrweyer-Choquet poly- nomial Choquet-integral operators. Then we study the very general comonotonic positive sublinear operators based on the representation theorem of Schmeidler (1986). We finish with the approximation by the very general direct Choquet-integral form positive sublinear operators. All fractional approximations are given via inequalities involving the modulus of continuity of the approximated function fractional order derivative. (Received August 09, 2018)

1145-41-263 **Ratikanta Behera*** (ratikanta@iiserkol.ac.in), Department of Mathematics and Statistics, IISER Kolkata, Mohanpur, west Bengal, 741246, India. *Multilevel wavelet approximation on the sphere.*

The dynamically adaptive multilevel approximation on the sphere is necessary to solve problems with localized structures or sharp transitions. Here we will discuss, how well a function is approximated by a multilevel wavelet expansion. In the fact that it requires very less number of wavelet coefficients to represent general functions accurately. The basic idea behind the multilevel wavelet approximation is that a function can be approximated as a linear combination of wavelets having different scales and locations. This allows compression and efficient computations. The accuracy and computational efficiency of the technique are demonstrated for an approximation of the differential operators on an adaptive spherical geodesic grid. The strength of the technique is that it can be extended easily to other curved manifolds by considering appropriate coarse approximations to the desired manifold. (Received August 27, 2018)

1145-41-514 **Rene Vidal*** (rvidal@cis.jhu.edu), 302B Clark Hall, 3400 N Charles St., Baltimore, MD 21218. *Dropout as a Low-Rank Regularizer for Matrix Factorization.*

Dropout is a simple yet effective regularization technique that has been applied to various machine learning tasks, including linear classification, matrix factorization (MF) and deep learning. However, the theoretical properties of dropout as a regularizer remain quite elusive. This talk will present a theoretical analysis of dropout for MF, where Bernoulli random variables are used to drop columns of the factors. We demonstrate the equivalence between dropout and a fully deterministic model for MF in which the factors are regularized by the sum of the product of squared Euclidean norms of the columns. Additionally, we investigate the case of a variable sized factorization and we prove that dropout is equivalent to a convex approximation problem with (squared) nuclear norm regularization. As a consequence, we conclude that dropout induces a low-rank regularizer that results in a data dependent singular-value thresholding. (Received September 08, 2018)

1145-41-568 **Shiping Cao*** (sc2873@cornell.edu), Malott Hall, room 105, Cornell University, Ithaca, NY 14853, and **Hua Qiu** (huaqiu@nju.edu.cn), Nanjing, Jiangsu 210093, Peoples Rep of China. *Boundary value problems on domains in Sierpinski gaskets.*

We study boundary value problems for the Laplacians on subdomains of the Sierpinski gaskets. First, we consider the left half Ω of the Sierpinski gasket $\mathcal{SG}$, whose boundary X is a countable set. For a two-parameter family of Laplacians on $\mathcal{SG}$ that are symmetric and self-similar, we give an explicit analogue of the Poisson integral formula to recover harmonic functions on Ω from their boundary values on X, and characterize functions of finite energy in terms of boundary values. We investigate the exact trace spaces on X of the L^2 and L^∞ domains of the Laplacians on $\mathcal{SG}$, and extend the trace result to general Sobolev type spaces $L^2_\sigma(\mathcal{SG})$. A consistent form of the trace spaces for real order σ is given. Second, we extend the consideration to certain subdomains in the level-l Sierpinski gaskets $\mathcal{SG}_l(l \geq 2)$ whose boundaries are discrete sets or Cantor sets. Three types of domains, the left half of $\mathcal{SG}_l$ and the upper and lower parts generated by horizontal cuts of $\mathcal{SG}_l$ are considered at present. We show that the arguments for Dirichlet problems for harmonic functions can be extended to these domains. (Received September 10, 2018)

1145-41-1693 **Verónica Becher*** (vbecher@dc.uba.ar), Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Pabellon I, Ciudad Universitaria, 1428 Buenos Aires, Argentina. *Normal numbers with digit dependencies.*

We give metric theorems for the property of Borel normality for real numbers under the assumption of digit dependencies in their expansion in a given integer base. We quantify precisely how much digit dependence can be allowed such that, still, almost all real numbers are normal. Our theorem states that almost all real numbers are normal when at least slightly more than $\log\log n$ consecutive digits with indices starting at position n are independent. As the main application, we consider the Toeplitz set T_P, which is the set of all sequences $a_1a_2\dots$ of symbols from $\{0,\dots,b-1\}$ such that a_n is equal to a_{pn}, for every p in P and $n = 1, 2, \dots$. Here b is an integer base and P is a finite set of prime numbers. We show that almost every real number whose base b expansion is in T_P is normal to base b. In the case when P is the singleton set $\{2\}$ we prove that more is true: almost every real number whose base b expansion is in T_P is normal to all integer bases.

This is joint work between Christoph Aistleitner, Verónica Becher and Olivier Carton. (Received September 23, 2018)

1145-41-1715 **Philipp Christian Petersen*** (pc.petersen.pp@gmail.com). *Expressivity and structure of neural network spaces.*

Novel machine learning techniques based on deep learning have reported remarkable results in many areas such as image classification, game intelligence, or speech recognition. In this talk, we will demonstrate that neural networks are immensely powerful approximators, but this implies massive theoretical problems in the optimisation.

One intriguing aspect of the underlying neural network architecture is that it facilitates the representation of complex functions using considerably fewer parameters than more classical approximation methods. Moreover, neural networks have been shown to possess the flexibility to adapt to unknown low dimensional structures. We will present some novel results of neural network approximation with a focus on dimension reduction. It is conceivable that the high expressivity of neural networks increases the complexity of optimising over this set. We analyse certain topological aspects of this set and will, indeed, observe that the set of neural networks is not particularly suitable for optimisation. Precisely, we will observe that the set of neural networks is not convex, not closed and cannot be stably parametrised for all practically relevant activation functions. (Received September 24, 2018)

1145-41-1748 **Soeren Dittmer*** (soeren.dittmer@gmail.com). *Singular Values for ReLU layers.* Preliminary report.

Singular values are one of the most important tools in linear algebra; we extend their definition to a class of non-linear operators which includes ReLU layers in artificial neural networks. We show how this inspires a new type of low-rank layer and explains the success of linear bottlenecks in networks. We will also discuss Gaussian mean width and its relation to data processed by neural networks. (Received September 24, 2018)

1145-41-1927 **Emily J King***, king@math.uni-bremen.de, and **Nate Strawn** and **Soledad Villar**.
Introduction to Low Complexity Models in Data Analysis and Machine Learning.

The pertinent structure of real-world data, in particular in high dimensional ambient space, is often significantly simpler than the ambient dimension would suggest. Low complexity models capturing this simpler structure are essential for computational applications in high-dimensional estimation of model parameters as well as tasks like detecting the boundaries of a region of interest in an image, ascertaining trends in time-series data, and uncovering latent variables and the non-linear but dependent relationships between them. For high-dimensional inverse problems, low complexity models are often used to make problems well-posed and result in regularized solutions. Such low complexity models can take the form of union-of-subspaces models (e.g., sparsity or low-rank assumptions) or have non-linear structure (e.g., low dimensional manifolds) and may involve statistical elements. Further, generative models represented by trained neural networks have also recently proven to be powerful low complexity models. This talk will cover the basic theory and applications of low complexity models and serve as the introduction to the Special Session on Low Complexity Models in Data Analysis and Machine Learning (SS 55). (Received September 24, 2018)

1145-41-1979 **Jacob D Austin*** (`jacob.austin@my.simpson.edu`), 701 N C Street, Unit 3056, Indianola, IA 50125, **Katlyn V York** (`katlyn.york@my.simpson.edu`), 701 N C Street, Unit 4140, Indianola, IA 50125, and **Kaylee R Grabarkewitz** (`kaylee.grabarkewitz@my.simpson.edu`), 701 N C Street, Unit 3305, Indianola, IA 50125.
Theoretical Nanoparticle Light Scattering.

We present an experimental method to dynamically determine the composition, in terms of shape and size, of a mixture of nanoparticles suspended in water. This method is based on the use of the Discrete Dipole Approximation (DDA) to predict the scattering pattern of light incident on the sample. In this report we present a general background to light scattering, including Maxwell's equations, Stokes vectors, and cross sections. The theory of the DDA is reviewed and applied to shapes constructed of silver nanocubes and gold nanospheres. We give examples of the application of this method to various sample types and discuss applications and limitations. Theoretical results are then compared to experimental data. (Received September 24, 2018)

1145-41-2538 **Barbara Zwicknagl*** (`zwicknagl@math.tu-berlin.de`). *Multiscale function reconstruction based on reproducing kernels.*

In this talk, I shall discuss variational problems arising from function reconstruction. Given function values at scattered discrete locations, one often computes an approximation to the unknown function from a Hilbert space by minimizing a functional which consists of a fidelity term and a regularising term involving the Hilbert space norm. It is well-known that for a large class of such functionals, minimizers lie in a finite dimensional space spanned by translates of the reproducing kernel of the Hilbert space.

Such reproducing kernels often have an intrinsic multiscale structure and they are typically not given in a closed form expression. Hence, to work practically with such multiscale kernels, a careful approximation of the kernel function is required, which does not spoil the good approximation properties. In this talk, I will discuss some quantitative approximation and stability properties of reconstruction processes in generalized Besov spaces based on properly approximated kernel functions.

This talk is based on joint work with Michael Griebel and Christian Rieger (both University of Bonn). (Received September 25, 2018)

1145-41-2622 **Catherine Payne***, payneca@wssu.edu, and **R. Fabiano**. *Semidiscrete approximation of linear neutral delay differential equations.*

We consider semidiscrete approximation of a linear 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 appropriate initial data. 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. We reformulate the neutral equation as an abstract Cauchy problem $\dot{z}(t) = \mathcal{A}z(t)$ and describe a spline-based approximation scheme. The approximation scheme we use converges for both the solution semigroup and its adjoint, which gives better results than related schemes in applications involving control problems. We will finish with some examples to show that this scheme can be used in problems with both continuous and discontinuous initial data. (Received September 25, 2018)

1145-41-2795 **Anna Aboud*** (`acseitz@iastate.edu`). *A Dual Kaczmarz Algorithm.* Preliminary report.

The Kaczmarz algorithm is an iterative method for solving a system of linear equations. It can be extended so as to reconstruct a vector x in a (separable) Hilbert space from the inner-products $\langle x, \phi_n\rangle$. This extension uses the sequence $\{\phi_n\}$ in the reconstruction from the sequence $\langle x, \phi_n \rangle$, but only succeeds when the sequence is *effective*. We dualize the Kaczmarz algorithm so that the reconstruction of x can be obtained from $\langle x, \phi_n \rangle$ by using a second sequence $\{\psi_n\}$ in the reconstruction. This allows for the reconstruction of x even when the sequence $\{\phi_n\}$ is not effective; in particular, our dualization yields a reconstruction when the sequence $\{\phi_n\}$ is *almost effective*. We also obtain some partial results characterizing when the reconstruction of x from $\langle x, \phi_n \rangle$ using $\{\psi_n\}$ succeeds, which we call an *effective pair*. (Received September 25, 2018)

42 ► Fourier analysis

1145-42-222 **Robert S. Strichartz*** (str@math.cornell.edu), Math Dept, Malott Hall, Ithaca, NY 14853. *Two fun snapshots from classical harmonic analysis.*

First: Suppose Fejer had been lazy, and instead of averaging all the partial sums of a Fourier series from 0 to N, he had averaged from a prescribed sparse collection of partial sums. Would uniform convergence still hold? In joint work with Ethan Goolish we found the answer to be sometimes yes, sometimes no, and in a lot of cases to be "most likely" with experimental evidence (nice pictures). Second: What do the eigenfunctions of the Laplacian on a regular polyhedron look like? In joint work with Evn Greif, Daniel Kaplan and Samuel Wiese, we found some beautiful pictures of them. It turns out that there are nonsingular ones that are smooth at vertices, extend periodically to the plane, and are represented by trigonometric polynomials. There are also singular ones that are none of the above. The tetrahedron is boring because they are all nonsingular and lift to a double covering by a hexagonal torus. The octahedron is especially interesting because some nonsingular eigenfunctions can be rotated and dilated so that the eigenvalue is multiplied by 1/3. (Received August 21, 2018)

1145-42-273 **Kevin O'Neill***, oneill@math.berkeley.edu. *A Sharpened Inequality for Twisted Convolution.*

Consider the trilinear form for twisted convolution on $\mathbb{R}^{2d}$:

$$\mathcal{T}_t(\mathbf{f}) := \iint f_1(x) f_2(y) f_3(x+y) e^{it\sigma(x,y)} dx dy,$$

where σ is a symplectic form and t is a real-valued parameter. It is known that in the case $t \neq 0$ the optimal constant for twisted convolution is the same as that for convolution, though no extremizers exist. Expanding about the manifold of triples of maximizers and $t = 0$ we prove a sharpened inequality for twisted convolution with an arbitrary antisymmetric form in place of σ. (Received August 27, 2018)

1145-42-487 **Ruixiang Zhang*** (ruixiang@math.wisc.edu), 451 W WILSON ST, MADISON, WI 53703, and **Shaoming Guo**. *Studying Parsell-Vinogradov Systems via Decoupling.*

We will talk about our recent proof of a sharp upper bound on the number of integer solutions of the Parsell-Vinogradov system in every dimension via the method of decoupling (joint with Shaoming Guo). (Received September 07, 2018)

1145-42-1024 **Philip T Gressman***, Mathematics Department, David Rittenhouse Lab, 209 South 33rd Street, Philadelphia, PA 19104. *Geometric problems related to Fourier restriction and decoupling.*

In this talk, I will discuss recent developments related to the problem of characterizing well-curved geometries of submanifolds of Euclidean space as dictated by model Fourier restriction and decoupling problems. The work incorporates ideas old and new from representation theory and geometric invariant theory and has the potential to bring clarity to a number of other challenging, geometrically-connected problems in harmonic analysis as well, including L^p-improving and linear and nonlinear variants of the Brascamp-Lieb inequalities. (Received September 18, 2018)

1145-42-1083 **Zane Kun Li*** (zkli@math.ucla.edu). *Decoupling for the moment curve in $\mathbb{R}^3$ inspired from efficient congruencing.* Preliminary report.

Wooley and Bourgain, Demeter, and Guth were both able to prove Vinogradov's mean value theorem. The former used methods from number theory while the latter used methods from harmonic analysis. Similarities have been observed but no direct dictionary between the two methods has been written. We sketch some ideas for proving decoupling for the moment curve in 3D using ideas inspired from efficient congruencing. Our proof is a bilinear proof while Bourgain-Demeter-Guth's proof of decoupling for the moment curve is a trilinear proof. We mention some bilinear Kakeya phenomena that we have observed. This is work in progress joint with Kirsti Biggs and Sarah Peluse. (Received September 18, 2018)

1145-42-1186 **Wencai Liu***, 410 P, Rowland Hall, IRVINE, CA 92697. *WKB and absence of the singular continuous spectrum for perturbed periodic Schrödinger operators.*

In this talk, we consider the Schrödinger operator,

$$Hu = -u'' + (V_0(x) + V(x))u,$$

where $V_0(x)$ is 1-periodic and $V(x)$ is a decaying perturbation. We show that if the perturbed potential $V \in \ell^p(L^1)$ for some $1 \leq p < 2$, then an essential support of the absolutely continuous spectrum equals the spectral bands. Moreover, if the potential V belongs to $\ell^p(L^1)$ with respect to a weight $|x|^\gamma$ with $\gamma > 0$, the optimal upper bound of the Hausdorff dimension of the singular component of the spectral measure is established. By additional spectral analysis, we show that $\sigma_{sc}(H) = \emptyset$ if $\limsup_{x\to\infty} x|V(x)| < \infty$. (Received September 19, 2018)

1145-42-1258 **Congzhi Xia*** (xia@clarkson.edu), 8 Clarkson Ave., CU Box 5815, Potsdam, NY 13699. *Reconstruction of piece-wise smooth functions from non-uniform Fourier data.* Preliminary report.

Non-uniform Fourier data are routinely collected in applications such as magnetic resonance imaging, synthetic aperture radar, and synthetic imaging in radio astronomy. However, reconstructing piece-wise smooth functions from Fourier measurements suffers from the Gibbs phenomenon (O(1) oscillations in the neighborhood of the edges). The popular filter/mollifier method could alleviate the Gibbs phenomenon and improve the accuracy away from the edges. We will introduce in this talk a hybrid filter-extrapolation method to further improve the accuracy around the edges. (Received September 20, 2018)

1145-42-1290 **Almaz Butaev** and **Galia Dafni*** (galia.dafni@concordia.ca), Department of Mathematics and Statistics, 1455 de Maisonneuve Blvd. West, Montreal, Quebec H3G 1M8, Canada. *Extension of functions of vanishing mean oscillation in a domain.*

We prove an analogue for VMO of the extension theorem of P. Jones, which gives a necessary and sufficient condition on a domain in $\mathbb{R}^n$ in order for functions of bounded mean oscillation in the domain to be extendable to functions in BMO($\mathbb{R}^n$). The construction of the extension follows the work of Jones and Brezis-Nirenberg. (Received September 20, 2018)

1145-42-1456 **Larry Guth**, **AlexI Iosevich**, **Yumeng Ou** and **Hong Wang*** (hongwang@mit.edu), 143 Albany Street 339, Cambridge, MA 02139. *Falconer problem in $\mathbb{R}^2$.*

We show that if E is a set of dimension at least $\frac{5}{4}$ on the plane, then its distance set $\Delta(E) = \{|x-y|, x \in E, y \in E\}$ has positive Lebesgue measure. This improves upon Wolff's theorem for $\dim E > \frac{4}{3}$. (Received September 22, 2018)

1145-42-1499 **Francisco Marques Dos Santos Vieira** and **Benjamin Steinhurst*** (bsteinhurst@mcdaniel.edu), 2 College Hill, Math. CS Department, McDaniel College, Westminster, MD 21157. *Spectral Segmentation on Nearly-Self-Similar Laakso Spaces.* Preliminary report.

Laakso spaces serve as a convenient family of fractal spaces on which to study a the spectrum of a natural self-adjoint Laplacian. This is because unlike most other fractals the spectrum of a natural Laplacian can be computing explicitly including multiplicities. Laakso spaces are generated using a sequence of integers, when the sequence is periodic the resulting space is self-similar. When the sequence is is a periodic sequence plus a "small" perturbation we say it is "nearly-self-similar." In this talk we consider the spectral zeta function associated to the Laplacians on a sequence of nearly-self-similar Laakso spaces. We will consider numerical data on the location and residues of the poles of the zeta function and the implications this has for the oscillations in the eigenvalue counting functions. We will also consider the convergence of the spectral zeta functions along some Gromov-Hausdorff convergent sequences of Laakso spaces. (Received September 22, 2018)

1145-42-1549 **Dominique Maldague*** (dmaldague@berkeley.edu), **Dong Dong** and **Dominick Villano**. *Special cases of multilinear oscillatory integrals.* Preliminary report.

We use tools from the multilinear oscillatory integral program developed by Christ, Li, Thiele, and Tao to treat special cases which are not covered by existing theory. Consideration of special cases leads to two theorems which extend the examples for which we know λ-power decay holds. (Received September 23, 2018)

1145-42-1672 **Zhen Zeng***, 209 South 33rd St., Philadelphia, PA 19104. *Decay property of multilinear oscillatory integrals.*

In the breakthrough paper of Christ, Li, Tao and Thiele, they initial the study of the conditions on the polynomial phase P and the projections $\{\pi_i\}$ to ensure the power decay estimate of the corresponding multilinear oscillatory integrals. It turns out that λ-uniformity introduced by Christ, Li, Tao and Thiele can be generalized to a more general splitting lemma which is developed by Christ. In this talk, I will extend their results and tools to a more general trilinear case. (Received September 23, 2018)

1145-42-1689 **Virginia Naibo** and **Alex Thomson*** (thomson521@ksu.edu), Cardwell Hall 138, 1228 N. 17th Street, Manhattan, KS 66506. *Coifman–Meyer multipliers: Leibniz-type rules and applications to scattering of solutions to PDEs.*

Leibniz-type rules for Coifman–Meyer multiplier operators are studied in the settings of Triebel–Lizorkin and Besov spaces associated to weights in the Muckenhoupt classes. Even in the unweighted case, improvements on the currently known estimates are obtained. The flexibility of the methods of proofs allows us to prove Leibniz-type rules in a variety of function spaces that include Triebel–Lizorkin and Besov spaces based on weighted Lebesgue, Lorentz and Morrey spaces as well as variable-exponent Lebesgue spaces. Applications to scattering properties of solutions to certain systems of partial differential equations involving fractional powers of the Laplacian are presented. (Received September 23, 2018)

1145-42-1825 **Maxim Gilula***, 619 Red Cedar Rd, East Lansing, MI 48824. *Oscillatory Loomis-Whitney.* Preliminary report.

I will discuss recent progress on multilinear oscillatory integral operator estimates. Significant progress in higher dimensions was made by Phong-Stein-Sturm for the case where the operator, L, acts on a tensor product of L_p functions of one variable for a certain range of p's, where the phase function is any polynomial. Christ-Li-Tao-Thiele showed that for a large family of phases, L decays in the oscillatory variable for much more general inputs than tensor products of L_p functions. Recent progress by Xiaochun Li has reawakened interest in these operators in the case that the input functions have variables in common. I will discuss recent progress in the Loomis-Whitney case (inputs of L are functions $f_i(x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_d)$ – please pardon the abuse of notation) with an oscillatory factor. This research is based off of unpublished work of Gressman-Xiao. (Received September 24, 2018)

1145-42-1891 **Calvin F Hotchkiss*** (hotchkis@udel.edu). *Fourier Bases on the Skewed Sierpinski Gasket.*

We consider a certain iterated function system, whose invariant set is a skewed Sierpinski gasket, $S = \{(x, y) \in R2 : x \in C_3, y \in C_3, x + y \in C_3\}$, where C_3 is the standard middle-thirds Cantor set. We show the existence of several sequences of exponentials which form orthonormal bases on $L^2(S)$, and discuss similar results for related fractals. (Received September 24, 2018)

1145-42-2023 **Chandan Biswas*** (chandan.biswas@uc.edu) and **Leonid Slavin**. *On the Bellman function for the Hardy operator and Hardy-Littlewood Maximal operator in $\mathbb{R}$.*

We find the Bellman function for the Hardy operator and discuss it's connection to the Bellman function for the Hardy-Littlewood Maximal operator in $\mathbb{R}$. The absence of a "dyadic structure" in these operators makes it different from the previously known Bellman function for the "dyadic Hardy-Littlewood Maximal operator". (Received September 24, 2018)

1145-42-2034 **Xiumin Du**, **Larry Guth**, **Yumeng Ou**, **Hong Wang**, **Bobby Wilson*** (blwilson@uw.edu) and **Ruixiang Zhang**. *The Falconer Distance Set Problem.*

We will discuss the improvement of the results for the Falconer distance set problem in dimensions three and higher using weighted Fourier restriction estimates. (Received September 24, 2018)

1145-42-2140 **Divyang Bhimani**, College Park, MD , and **Kasso Okoudjou*** (kasso@mit.edu), MIT, Department of Mathematics, Cambridge, MA. *Gabor Frames with arbitrary redundancy and Wilson tight frames in $L^2(\mathbb{R})$.* Preliminary report.

Given a Gabor system $\mathcal{G}(\varphi, \alpha, \beta)$ with general lattice parameters $\alpha, \beta > 0$, we propose a Wilson system $\mathcal{W}(\varphi, \alpha, \beta)$. Under mild conditions on φ, we show that the Gabor system $\mathcal{G}(\varphi, \alpha, \beta)$ is a tight frame with redundancy β^{-1} if and only if the Wilson system $\mathcal{W}(\varphi, \alpha, \beta)$ is a Parseval frame for $L^2(\mathbb{R})$. Examples of smooth rapidly decaying generators φ for these Wilson systems are given. (Received September 24, 2018)

1145-42-2156 **Michael Christ***, Department of Mathematics, University of California, Berkeley, CA 94708, and **Dominique Maldague**. *A symmetrization inequality shorn of symmetry.* Preliminary report.

An inequality of Brascamp-Lieb-Luttinger and Rogers concerns functionals $\int_{R^D} \prod_{j \in J} \mathbf{1}_{E_j}(L_j(x))\, dx$ where $E_j \subset R^d$ and $L_j : R^D \to R^d$ are surjective linear mappings. If D is a multiple of d and if there is a diagonal action of

$O(d)$ that is a symmetry of the functional, the inequality states that among sets of specified Lebesgue measures, the functional attains its maximum value when E_j are balls centered at the origin.

We investigate a more general class of tuples of linear mappings L_j, with $d = 2$, for which the symmetry hypothesis does not hold. A definition of admissibility is formulated. Maximizing tuples that are Steiner symmetric with respect to both coordinate axes with respect are shown to exist. When the mappings are small perturbations of a tuple satisfying the symmetry hypothesis, such Steiner symmetric maximizers are shown to be domains with smooth boundaries, and to be small perturbations of ellipsoids. The proof of smoothness might be described as a bootsrapping argument for a coupled system of free boundary problems. (Received September 24, 2018)

1145-42-2281 **Fernando Gama**, **Alejandro Ribeiro*** (aribeiro@seas.upenn.edu) and **Joan Bruna**.
Graph Neural Networks and Graph Scattering Transforms.

Convolutional Neural Networks (CNN) are layered information processing architectures in which each of the layers is itself the composition of a convolution operation with a pointwise nonlinearity. Graph Neural Networks (GNNs) replace the regular convolution operation with a graph convolution operation. We will discuss graph convolutions, their use in building GNN architectures, and explore stability of GNN operators. The stability results establish that a GNN is stable to graph deformations that are close to permutations. (Received September 25, 2018)

1145-42-2557 **Joris Roos*** (jroos@math.wisc.edu), **Shaoming Guo** and **Po-Lam Yung**.
Variation-norm estimates for certain singular oscillatory integrals.

In this talk we discuss variation-norm estimates for certain oscillatory integrals related to Carleson's theorem. Corresponding maximal operators were first studied by Stein and Wainger. Our estimates are sharp in the range of exponents, up to endpoints. The proof relies on square function estimates for a family of Schrödinger-like equations due to Lee, Rogers and Seeger and local smoothing estimates for these equations. This is a joint work with Shaoming Guo and Po-Lam Yung. Our variational estimates can be combined with certain number-theoretic estimates and an argument in the spirit of Bourgain's multi-frequency maximal lemma to prove bounds for discrete analogues of the Stein-Wainger maximal operator (cf. recent work of Ben Krause). (Received September 25, 2018)

1145-42-2602 **Jeremy Schwend*** (jschwend@math.wisc.edu), 2921 Fish Hatchery Rd Apt 214, Fitchburg, WI 53713. *Optimal $L^p \to L^q$ Estimates for Euclidean Averages Over Prototypical Hypersurfaces in $\mathbb{R}^3$.*

We find the precise range of $(\frac{1}{p}, \frac{1}{q})$ for which local averages along graphs of a class of two-variable polynomials in $\mathbb{R}^3$ are bounded (at least in the restricted-weak sense) from L^p to L^q, given the hypersurfaces have Euclidean measure. We derive these results using positive, geometric methods, for a model class of polynomials bearing a strong connection to the general real-analytic case. (Received September 25, 2018)

1145-42-2706 **Nina Zubrilina*** (nina57@stanford.edu), 531 Lasuen Mall, P.O.17601, Stanford, CA 94305. *Zeros of Optimal Functions in the Cohn-Elkies Sphere Packing Theorem.*

Recent breakthroughs by Viazovska et al. have provided solutions to the sphere packing problem in $\mathbb{R}^8$ and $\mathbb{R}^{24}$ by exhibiting an explicit optimal function, arising from the theory of modular forms, for the Cohn-Elkies linear program in those dimensions. These functions have roots exactly at the lengths of elements of the respective optimal lattices: $\{\sqrt{2n}\}_{n\geq 1}$ for the E_8 lattice, and $\{\sqrt{2n}\}_{n\geq 2}$, for the Leech lattice. But what are the roots of optimal functions in other dimensions? We prove that the number of sizes up to X of roots of an optimal function grows at least linearly in X for $n \geq 1$ and that the distances between the sizes of the roots are not bounded from below for $n \geq 2$. (Received September 25, 2018)

43 ► *Abstract harmonic analysis*

1145-43-2056 **Marina Iliopoulou*** (m.iliopoulou@berkeley.edu), Evans Hall, Berkeley, CA 94720, and **Larry Guth** and **Jonathan Hickman**. *Sharp estimates for Hörmander-type oscillatory integral operators according to the signature of the phase function.*

At the heart of harmonic analysis lies the restriction problem: the study of Fourier transforms of functions that are defined on curved surfaces. The problem came to life in the late 60s, when Stein observed that such Fourier transforms have better behaviour than if the surfaces were flat. Soon after, Hörmander conjectured that oscillatory integral operators with more general phase functions should also demonstrate similar agreeable behaviour. Surprisingly, 20 years later Bourgain disproved Hörmander's conjecture. In this talk, we present sharp estimates for such operators, according to the signature of the phase function. This is joint work with Jonathan Hickman, continuing our joint work with Larry Guth. (Received September 24, 2018)

1145-43-2294 **John E Haga*** (hagaj@wit.edu), 550 Huntington Ave, Department of Applied Mathematics, Wentworth Institute of Technology, Boston, MA 02115. *Levy Processes in the Cartan Group.* Preliminary report.

The infinitesimal generators of Lévy processes in Euclidean space are pseudo-differential operators with symbols given by the Lévy-Khintchine formula. This classical result relies heavily on Fourier theory which in the case when the state space is a Lie group involves abstract harmonic analysis requiring a formulation of the dual group of unitary irreducible representations. The notion of pseudo-differential operators can be extended to connected, simply connected nilpotent Lie groups by employing the Weyl functional calculus. In 2013 we demonstrated that the generators of Lévy processes in the 4 dimensional Engel group G_E are pseudo-differential operators which admit $C_c(G_E)$ as its core. Here we present an extension of these results to the 5 dimensional step 3 nilpotent Cartan group. (Received September 25, 2018)

1145-43-2561 **Norbert N Youmbi*** (nyoumbi@francis.edu), 117 Evergreen Dr, Loretto, PA 15931. *The Algebraic Structure of a Topological Semihypergroups.*

The theory of semihypergroup, is studied in both an algebraic and topological approach. Unlike in the group case, a topological semihypergroup, is not defined, by associating a topology to an existing algebraic structure. In the contrary, there is no algebraic structure assumed on the base space of a topological semihypergroup. In this paper, we use the convolution of measures defined on the vector space of Radon measures of a topological semihypergroup, to define an algebraic structure on the base space. We establish the fact that a topological semihypergroup is actually an algebraic semihypergroup, and establish some interesting algebraic results that could ease research on a topological semihypergroup. (Received September 25, 2018)

44 ► Integral transforms, operational calculus

1145-44-686 **Florin Catrina*** (catrinaf@stjohns.edu) and **Aurel I. Stan**. *On the hypercontractivity of a convolution operator.*

We discuss a convolution operator which appears as an integral representation of the Wick product on $L^p(\mathbb{R}, \mu)$ spaces where the probability measure μ has a Gamma distribution. The hypercontractivity of this operator is tightly connected to inequalities of Brascamp-Lieb type. (Received September 12, 2018)

1145-44-2628 **Lance Nielsen*** (lnielsen@creighton.edu), Department of Mathematics, Creighton University, 2500 California Plaza, Omaha, NE 68178. *Incorporating Unbounded Operators into Feynman's Operational Calculus.* Preliminary report.

We will illustrate a method of incorporating unbounded operators into Feynman's operational calculus, the forming of functions of several not necessarily commuting operators. In particular, the functional calculus introduced by A. E. Taylor in his 1951 paper *Spectral theory of closed distributive operators* is applied to the abstract setting of Feynman's operational calculus to enable the use of unbounded operators. This extension to unbounded operators enables us to make a connection with a type of Feynman integral, the "modified Feynman integral." (Received September 25, 2018)

45 ► Integral equations

1145-45-335 **Fanhui Xu*** (fanhuixu@usc.edu), KAP 104, Department of Mathematics, University of Southern California, 3620 S. Vermont Ave., Los Angeles, CA 90089-2532, and **Remigijus Mikulevicius**, KAP 104, Department of Mathematics, University of Southern California, 3620 S. Vermont Ave., Los Angeles, CA 90089-2532. *On the Cauchy Problem for Integro-Differential Equations in the Scale of Generalized Hölder Spaces.*

A Cauchy problem of parabolic integro-differential equations is considered in the scale of Hölder spaces of functions whose regularity is defined by a radially O-regularly varying Lévy measure. Existence and uniqueness of a solution is proved by using probabilistic representations and deriving a priori estimates. (Received September 02, 2018)

1145-45-388 **Kapil Kant*** (sahukapil8@gmail.com), Department of Mathematics, Indian Institute of technology, Kharagpur, India, Kharagpur, W.B. 721302, India, and **Gnaneshwar Nelakanti** (gnanesh@maths.iitkgp.ac.in), Department of Mathematics, Indian Institute of Technology, Kharagpur, India, Kharagpur, W.B. 721302, India. *Superconvergence of Jacobi spectral methods for Weakly singular Volterra Integral Equations.*

In this article, a Jacobi spectral Galerkin method is developed for weakly singular Volterra integral equations of the second kind. To obtain the Superconvergence results, we transform the domain of integration of Volterra integral equation to the standard interval $[-1, 1]$ by using variable transformation and function transformation. We obtain the convergence rates in both in infinity and weighted L^2- norm. We prove that the Jacobi spectral iterated Galerkin method improves over Jacobi spectral Galerkin method. We improve these results further by considering the Jacobi spectral iterated multi-Galerkin method. Theoretical results are justified by the numerical results. (Received September 05, 2018)

1145-45-537 **Paul W Eloe** and **Jeffrey T Neugebauer***, jeffrey.neugebauer@eku.edu. *An Avery Fixed Point Theorem applied to a Hammerstein Integral Equation.*

We apply a recent Avery *et al.* fixed point theorem to a Hammerstein integral equation

$$x(t) = \int_{T_1}^{T_2} G(t,s)f(x(s))\mathrm{d}s, \quad t \in [T_1, T_2].$$

Under certain conditions on G, we show the existence of positive solutions and the existence of positive symmetric solutions. The function G is related to Green's functions for different boundary value problems. The existence of positive solutions of these boundary value problems is obtained. (Received September 09, 2018)

1145-45-598 **Mathew Gluck*** (mgluck@towson.edu), Department of Mathematics, Towson University, 8000 York Rd., Towson, MD 21252. *Embedding Inequalities for a Family of Integral Operators and Applications.*

In this talk embedding inequalities for a family of integral operators $E_{\alpha,\beta} : L^p(\partial\mathbb{R}^n_+) \to L^q(\mathbb{R}^n_+)$ that include the classical Poisson extension operator and a Riesz potential type operator will be discussed. For the conformally invariant parameters the extremal functions are classified and the value of the optimal embedding constant is computed. As an application, for certain parameters we prove the embedding inequalities for bounded subdomains $\Omega \subset \mathbb{R}^n$ and show that if the optimal embedding constant for Ω is strictly larger than the optimal embedding constant for the unit ball, then the optimal constant is attained. We show that this criterion is satisfied by an annular domain whose hole is sufficiently small. Motivated by this fact we prove the existence of a domain Ω equipped scalar-flat metric g in the conformal class of the Euclidean metric whose isoperimetric constant is strictly larger than that of the Euclidean ball. (Received September 11, 2018)

1145-45-660 **Ke Chen** and **Qin Li*** (qinli@math.wisc.edu), 480 Lincoln Dr., Madison, WI 52706, and **Steve Wright**. *Low rankness in forward and inverse kinetic theory.*

Multi-scale kinetic equations can be compressed: in certain regimes, the Boltzmann equation is close to the Euler, and the radiative transfer equation is close to the diffusion equation. While passing to the limits, a lot of detailed information is lost. In linear algebra language it is equivalent to low-rankness. I will discuss such transition and how it affects the computation: mainly, it greatly advances the forward solvers, but the inverse problem is significantly harder. (Received September 12, 2018)

1145-45-1073 **John R. Graef*** (john-graef@utc.edu), Department of Mathematics, University of Tennessee at Chattanooga, 615 McCallie Ave., Chattanooga, TN 37403, and **Said R. Grace**. *Asymptotic behavior of solutions of a forced third order integro-differential equation with δ-Laplacian.*

The asymptotic behavior of solutions of a certain forced third order integro-differential equation with a δ-Laplacian is studied. The goal is to investigate whether nonoscillatory solutions behave at infinity like certain nontrivial nonlinear functions. The proofs involve applications of Young's, Hölder's, and Gronwall's inequalities. (Received September 18, 2018)

1145-45-1388 **Qingyang Zhang*** (qyy816321@outlook.com), 1920 South 3rd street,Unit #39, Waco, TX 76706, and **Shuhuang Xiang** (xiangsh@csu.edu.cn), School of Mathematics and Statistics, Central South University, No.932 South Lushan Road, Changsha, Hunan 410083, Peoples Rep of China. *On fast multipole methods for Volterra integral equations with highly oscillatory kernels.*

This paper explores the fast multipole methods (FMMs) to accelerate the approximation for weakly singular Volterra integral equations with highly oscillatory trigonometric kernels. By constructing the fast translation

path, the FMM is utilized to speed up the iterative method, which reduces the complexity from $O(N^2)$ to $O(N)$. Especially, we use the collocation method to discretize the Volterra integral equation with constants and linear elements respectively, then apply the GMRES to solve the dense and non-symmetric linear system. In addition, the highly oscillatory integrals derived from the algorithm are calculated effectively by the steepest descent method. The proposed method shows that the numerical solutions become more accurate as the frequency increases. Both of the optimal convergence rates of truncation and the error bounds analysis are represented in the end. (Received September 21, 2018)

1145-45-1742 **Samiran Chakraborty*** (samiranchakraborty@iitkgp.ac.in), Department of Mathematics, IIT Kharagpur, Kharagpur, 721302, India, and **Gnaneshwar Nelakanti** (gnanesh@maths.iitkgp.ac.in), Department of Mathematics, IIT Kharagpur, India. *Convergence Results of Newton Iteration Method for nonlinear Fredholm Hammerstein Integral Equations.*

In this paper we consider Newton-iteration scheme based on Galerkin, iterated Galerkin and multi-Galerkin operator for solving non-linear integral equations of Fredholm-Hammerstein type for both smooth and weakly singular kernels. If $\mathbb{X}_n$ is a space of piecewise polynomial subspace of degree $\leq m-1$, we show that for a smooth kernel, Galerkin, iterated Galerkin and multi-Galerkin solution in the k-th Newton-iteration scheme converges with the orders $\mathcal{O}(h^{(k+1)m})$, $\mathcal{O}(h^{(k+2)m})$ and $\mathcal{O}(h^{2(k+1)m})$, respectively, where h is the norm of the partition. For weakly singular kernels, we show that the Galerkin solution in the k-th Newton-iteration scheme converges with the order $\mathcal{O}(h^{(k+1)(1-\alpha)})$, $0<\alpha<1$ for algebraic kernal and $\mathcal{O}(h^{k+1}(\log h)^{k+1})$ for logarithmic kernel. Also the iterated Galerkin and multi-Galerkin solution in the k-th Newton-iteration scheme converges with the order $\mathcal{O}(h^{m+(k+1)(1-\alpha)})$ for algebraic kernel and with the order $\mathcal{O}(h^{m+k+1}(\log h)^{k+1})$ for logarithmic kernel. Similar results are also proved for collocation, iterated collocation and multi-collocation operators. (Received September 24, 2018)

1145-45-1905 **Alan Dyson*** (acd313@lehigh.edu). *Existence of Traveling Fronts and Pulses in Lateral Inhibition Neuronal Networks with Sigmoidal Firing Rate Functions.*

Electrode recordings have revealed the existence of traveling waves (in terms of voltage) that propagate across the mammalian cortex following the presence of certain stimuli. Considering experimental findings and known properties of neurons, a common mathematical, population-level approach to encapsulating such behavior is to coarse grain time and space in the form of neural field models and attempt to study the existence, uniqueness, and stability of such waves.

In this talk, we discuss the role of the implicit function theorem on Banach spaces in proving the existence of traveling fronts when synaptic coupling kernels model nonlocal, lateral inhibition. Our results are inspired by the seminal study of monotone traveling fronts in neural field models (Ermentrout and McLeod, 1993). We also discuss techniques for proving the existence of traveling pulses in singularly perturbed systems using the theory of invariant stable and unstable manifolds in dynamical systems. (Received September 24, 2018)

1145-45-1999 **Ying Zhou*** (zhouyi@lafayette.edu). *A periodic spatial model for population dynamics under seasonal changes.*

Seasonal changes in the habitat affect the population dynamics of its residents. These changes can be in the location, size, and quality of the habitat. In this talk, I will present a periodic integrodifference-equation model to discuss the e effects of these seasonal changes on the resident population. (Received September 24, 2018)

1145-45-2725 **M Rahman***, 1 UNF Drive, Jacksonville, FL 32224. *Stochastic approximations of Fredholm Volterra Integro-differential equation arising in mathematical neuroscience.* Preliminary report.

This paper extends the results of synaptically generated wave propagation through a network of connected excitatory neurons to a continuous model, defined by a Fredholm Volterra integro-differential equation, which includes memory effects of the past as well as parametric noise in the system. Stochastic approximation and numerical simulations are discussed. (Received September 25, 2018)

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1145-46-365 **Marius V Ionescu*** (ionescu@usna.edu) and **Thomas L Savage**. *The "Hot Spots" Conjecture on the Vicsek Set.*

In this talk we present a proof of the hot spot conjecture on the Vicsek Set. Specifically, we will show that every eigenfunction of the second smallest eigenvalue of the Neumann Laplacian on the Vicsek set attains its maximum and minimum on the boundary. (Received September 04, 2018)

1145-46-366 **Jin Liang*** (jinliang@sjtu.edu.cn), 800 Dongchuan RD., Minhang District, Shanghai, Shanghai 200240, Peoples Rep of China. *Properties of operator semigroups.* Preliminary report.

In this talk, we are concerned with some basic properties of operator semigroups in Banach spaces. We first talk about some important theorems on the uniformly continuous semigroups and strongly continuous semigroups in Banach spaces as well as the wellposedness of the Cauchy problem for related evolution equations in Banach spaces. Then we introduce something about the Cauchy problem for nonautonomous evolution equations and higher order differential equations in Banach spaces. Finally, we present some recent research results on the norm continuity of strongly continuous semigroups. (Received September 04, 2018)

1145-46-367 **Ti-Jun Xiao*** (tjxiao@fudan.edu.cn), 220 Handan Rd., Yangpu District, Shanghai, Shanghai 200433, Peoples Rep of China. *Coupled systems of second order evolution equations in Hilbert spaces.* Preliminary report.

This talk concerns a class of coupled systems, which consist of second order evolution equations in a Hilbert space with indirect memory-damping. Based on the theory of hyperbolic type evolution equations, we investigate the stability of the coupled systems through the coupling and memory effects. The integrability for the energy of the system over $(0, +\infty)$ is obtained, which implies that the energy tends to zero at infinity. For reasonable memory kernels, we obtain uniform exponential stability of the energy. Moreover, we give an application of our general theorems to the Timoshenko system. (Received September 04, 2018)

1145-46-443 **Igor V. Nikolaev*** (igor.v.nikolaev@gmail.com), Department of Mathematics, St. John's University, 8000 Utopia Parkway, New York, NY 11439. *Quantum dynamics of elliptic curves.*

We calculate the K-theory of a crossed product C^*-algebra $\mathcal{A}_{RM} \rtimes \mathcal{E}(K)$, where $\mathcal{A}_{RM}$ is the noncommutative torus with real multiplication and $\mathcal{E}(K)$ is an elliptic curve over the number field K. We use this result to evaluate the rank and the Shafarevich-Tate group of $\mathcal{E}(K)$. Reference: arXiv:1808.03493 (Received September 06, 2018)

1145-46-644 **Alexandru Aleman**, **Michael Hartz*** (michael.hartz@fernuni-hagen.de), **John E. McCarthy** and **Stefan Richter**. *Weak products of complete Pick spaces.*

The weak product of a Hilbert function space plays the role that is played by H^1 in the theory of Hardy spaces. I will talk about several aspects of weak products of complete Pick spaces, including duality, invariant subspaces and the relationship to the Smirnov class. (Received September 12, 2018)

1145-46-719 **Aqeeb A Sabree*** (aqeeb-sabree@uiowa.edu), 14 MacLean Hall, Iowa City, IA 52246. *Factorizations of Positive Definite Kernels.*

From the Moore-Aronszajn theorem, we have an explicit correspondence between reproducing kernel Hilbert spaces (RKHS) and reproducing kernel functions—also called positive definite kernels or positive definite functions. This presentation will focus on the duality between positive definite functions and their boundary spaces. We will define these notions and cover a brief overview of the subject area. A major focus of this presentation will be placed on the idea of reproducing positive definite kernels with boundary functions. It is known that every reproducing kernel Hilbert space has an associated generalized boundary probability space. We will investigate this concept with different examples and aspects of my dissertation. These RKHSs have numerous applications to areas such as complex analysis, harmonic analysis, stochastic analysis, information theory, and machine learning. (Received September 13, 2018)

1145-46-734 **Trubee Hodgman Davison*** (trubee.davison@colorado.edu), University of Colorado, Campus Box 395, Boulder, CO 80309. *An Operator-Valued Kantorovich Metric on Complete Metric Spaces.*

The Kantorovich metric provides a way of measuring the distance between two Borel probability measures on a metric space. This metric has a broad range of applications from bioinformatics to image processing, and is commonly linked to the optimal transport problem in computer science. Noteworthy to this paper will be the role of the Kantorovich metric in the study of iterated function systems, which are families of contractive mappings on a complete metric space. When the underlying metric space is compact, it is well known that the space of Borel probability measures on this metric space, equipped with the Kantorovich metric, constitutes a compact, and thus complete metric space. In previous work, we generalized the Kantorovich metric to operator-valued measures for a compact underlying metric space, and applied this generalized metric to the setting of iterated function systems. We note that the work of P. Jorgensen, K. Shuman, and K. Kornelson provided the framework for our application to this setting. The situation when the underlying metric space is complete, but not necessarily compact, has been studied by A. Kravchenko. In this paper, we extend the results of Kravchenko to the generalized Kantorovich metric on operator-valued measures. (Received September 13, 2018)

1145-46-738 **Michael Anshelevich*** (manshel@math.tamu.edu). *Möbius inversion, Wick products, and product formulas.* Preliminary report.

I will explain how inversion formulas for Wick products come from the Möbius inversion on posets. Then I will introduce a general product formula on posets, which leads to product formulas for Wick products. The Wick products for which these techniques work so far correspond to Hermite, Charlier, Laguerre, Chebyshev, and free Charlier polynomials. (Received September 13, 2018)

1145-46-755 **Yasuyuki Kawahigashi*** (yasuyuki@ms.u-tokyo.ac.jp), Department of Mathematical Sciences, the University of Tokyo, 3-8-1 Komaba, Tokyo, 153-8914, Japan. *Topological phases of matter and subfactors.*

A topological phase of matter is described with a modular tensor category where an anyon corresponds to an irreducible object. In this way, we study various problems such as gapped domain walls and boundary-bulk duality in terms of subfactors and get applications to condensed matter physics. In particular, we present relative versions of boundary-bulk duality and the Verlinde formula. (Received September 14, 2018)

1145-46-863 **Rolando de Santiago*** (rdesantiago@math.ucla.edu), CA, and **Ionut Chifan** and **Wanchalerm Sucpikarnon**. *Tensor product decompositions of II_1 factors arising from extensions of amalgamated free product groups.*

We introduce a new family of groups Γ which satisfy the following product rigidity phenomenon: all tensor product decompositions of the II_1 factor $L(\Gamma)$ arise only from the canonical direct product decompositions of the underlying group Γ. Our groups are assembled from certain amalgamated free products and include many remarkable groups studied throughout mathematics such as graph product groups, Burger-Mozes groups, Higman group, various integral two-dimensional Cremona groups, etc. As a consequence, we obtain several new examples of groups that give rise to prime factors. (Received September 16, 2018)

1145-46-987 **Florin Catrina*** (catrinaf@stjohns.edu) and **Mikhail I Ostrovskii**. *Nowhere differentiable Lipschitz maps of $[0,1]$ into $L_1[0,1]$.*

We construct examples of Lipschitz maps F from $[0,1] \subset \mathbb{R}$ into $L_1[0,1]$ which are nowhere differentiable. The novelty of these constructions lies in the fact that for any $t \in [0,1]$, the image $F(t) \in L_1[0,1]$ is arbitrarily smooth. (Received September 18, 2018)

1145-46-1050 **Don Hadwin** and **Weihua Li*** (wli@colum.edu), 45 Northgate Rd, Riverside, IL 60546, and **Wenjing Liu** and **Junhao Shen**. *A characterization of tracially nuclear C*-algebras.* Preliminary report.

We give two characterizations of tracially nuclear C*-algebras. The first is that the finite summand of the second dual is hyperfinite. The second is in terms of a variant of the weak* uniqueness property. The necessary condition holds for all tracially nuclear C*-algebras. When the algebra is separable, we prove the sufficiency. (Received September 18, 2018)

1145-46-1054 **Igor Klep*** (igor.klep@auckland.ac.nz), The University of Auckland, Department of Mathematics, Private Bag 92019, Auckland, 1142, New Zealand. *Noncommutative polynomials describing convex sets.*

The seminal 2012 theorem of Helton and McCullough states that every semialgebraic matrix convex set is given by a linear matrix inequality (LMI). The purpose of this talk is two-fold. First, we prove that every irreducible polynomial f with convex semialgebraic set D_f must be of degree at most 2 and concave. Second, we present effective algorithms for (a) checking whether D_f is convex; (b) finding an LMI representation $D_f = D_L$ for convex D_f. Techniques employed include realization theory, noncommutative algebra and semidefinite programming.

This is joint work with Bill Helton, Scott McCullough, and Jurij Volčič. (Received September 18, 2018)

1145-46-1130 **Gaston M N'Guerekata*** (gaston.n'guerekata@morgan.edu), 1700 E Cold Spring Ln, Baltimore, MD 21251. *Eberlein-weakly almost periodic (in Stepanov - like sense) functions and applications.* Preliminary report.

In this talk, we prove a number of properties concerning a (new) class of (Stepanov - like) Eberlein-weakly almost periodic (S^P-E.w. a. p.) functions with values in a Banach space. We use the results obtained to study the asymptotic behavior of solutions to the evolution equation :

$$u(t) = \int_{-\infty}^{t} a(t-s)[Au(s) + f(s)]\, ds,\ t \in \mathbb{R},$$

where A is the generator of an integral resolvent family in a Banach space $\mathbb{X}$, $a \in L^1(\mathbb{R})$, and f is a given $\mathbb{X}-$valued function on $\mathbb{R}$. The objective is to deduce Eberlein-weak almost periodicity (in Stepanov - like sense) of the solution u from corresponding properties on the part f. (Received September 19, 2018)

1145-46-1165 **Alexander A. Katz*** (katza@stjohns.edu), 8000 Utopia Parkway, SJH-334-G, Queens, NY 11439. *Local Structure in Jordan-Lie Banach algebras.*

We introduce projective limits of projective families of JLB-algebras and investigate how they are related to locally C*-algebras. (Received September 19, 2018)

1145-46-1269 **Edward S. Sichel*** (edsichel@mail.fresnostate.edu), Department of Mathematics, California State University, Fresno, 5245 North Backer Avenue, M/S PB108, Fresno, CA 93740-8001. *On the Nature of Expansions on Compact and Totally Bounded Metric Spaces and More.* Preliminary report.

When proving a known result describing expansive mappings on compact metric spaces as isometric surjections, we observe that relaxing the condition of compactness to total boundedness preserves the isometry property, and nearly so that of surjectivity.

While a counterexample is found showing that the converse to the above descriptions do not hold, we are able to characterize boundedness in terms of a certain specific type of expansions we call *anticontractions.* (Received September 20, 2018)

1145-46-1305 **Terje Hõim*** (thoim@fau.edu), Dept. of Mathematics, Wilkes Honors College, Florida Atlantic University, Jupiter, FL 33458, and **D. A. Robbins** (david.robbins@trincoll.edu). *Irreducible representations of some vector-valued function algebras.*

Let $\pi : \mathcal{E} \to X$ be a bundle of Banach algebras, where X is a completely regular Hausdorff space. We identify the sets of irreducible representations of several topological subalgebras of $\Gamma(\pi)$, the space of continuous sections of π. These subalgebras include: $\Gamma_b(\pi)$, the space of bounded sections of π; and $\Gamma_b^{cs}(\pi, \mathcal{D})$, the space of sections bounded on each set of a cover $\mathcal{D}$ of X, under the cover-strict topology determined by $\mathcal{D}$; and $\Gamma_b^{c}(\pi, \mathcal{D})$, the space of sections bounded on each set of a cover $\mathcal{D}$ of X by C_b-embedded sets. The results unify recent and older work of various authors regarding representations on algebra-valued function spaces. (Received September 20, 2018)

1145-46-1323 **Mujahid Abbas*** (abbas.mujahid@gmail.com), Department of Mathematics, Government College University, Lahore, Punjab 54000, Pakistan. *Stability of fixed point of mappings in generalized cone metric spaces.*

We define the stability of a sequence of fixed points of mappings that satisfying certain generalized contractive conditions in the setup of generalized cone metric space. We also define the new convergence criteria and properties for convergence in generalized cone metric spaces. Our obtained results unify, strengthen and generalize various fixed point results and stability results in the existing literature. (Received September 21, 2018)

1145-46-1329 **Maria Angeles Japon*** (japon@us.es), Departamento de Análisis Matemático, Facultad de Matemáticas. C. Tarfia s.n., 41012 Sevilla, Spain. *Some Geometric Properties characterized by Fixed Point Theorems.*

In this talk we will explain how some fixed point theorems can be applied to characterize certain geometric properties of the domain where the mappings are defined, or even some properties of the environment where the domain is included. Some recent results on the Banach space of continuous functions $C(K)$ obtained by the author will be included. (Received September 21, 2018)

1145-46-1351 **Stephen J Dilworth*** (dilworth@math.sc.edu), Department of Mathematics, University of South Carolina, Columbia, SC 29208, and **Denka Kutzarova** and **Mikhail I Ostrovskii**. *Lipschitz Free Spaces on Finite Metric Spaces.*

Main results of the paper:

(1) For any finite metric space M the Lipschitz free space on M contains a large well-complemented subspace which is close to ℓ_1^n.

(2) Lipschitz free spaces on large classes of recursively defined sequences of graphs are not uniformly isomorphic to ℓ_1^n of the corresponding dimensions. These classes contain well-known families of diamond graphs and Laakso graphs.

Interesting features of our approach are: (a) We consider averages over groups of cycle-preserving bijections of graphs which are not necessarily graph automorphisms; (b) In the case of such recursive families of graphs as Laakso graphs we use the well-known approach of Grünbaum (1960) and Rudin (1962) for estimating projection constants in the case where invariant projections are not unique. (Received September 21, 2018)

1145-46-1442 **Hua Qiu*** (huaqiu@nju.edu.cn), Dept. of Maths, Nanjing University, Nanjing, Jiangsu 210093, Peoples Rep of China. *Metrics on fractals with symmetry and applications to sub-Gaussian heat kernel bounds.*

We prove that for a large class of self-similar sets with certain symmetry, including the nested fractals and the generalized Sierpinski carpets, the time changed Brownian motion via a symmetric self-similar measure enjoys two sided sub-Gaussian heat kernel estimates. The proof relies on that for a given symmetric self-similar measure, we can construct an intrinsic metric which is adapted to the weights given by the self-similar measure and satisfies the chain condition. We then illustrate our result by using the snow flake and the standard Sierpinski carpet as examples. Conversely, we show that on the standard Sierpinski carpet, if the symmetry of the self-similar measure is loosened, we can construct the metric but the chain condition fails. This is a joint work with Qingsong Gu, Kasing Lau and Huojun Ruan. (Received September 21, 2018)

1145-46-1479 **Sofya S Masharipova*** (ssm57@pitt.edu), Dept. of Mathematics, Krebs Hall, 450 Schoolhouse Road, University of Pittsburg-Johnstown, Johnstown, PA 15904, and **Shukhrat M Usmanov** (shukhrat.usmanov@waldorf.edu), Dept. of Mathematics, Waldorf University, 106 South 6th Street, Forest City, IA 50436. *Positive functionals on operator algebras on Pontryagin space Pi_1.* Preliminary report.

In the work we define and study positive linear functionals on symmetric algebras of bounded linear operators on Pontryagin space Π_1. Finite and infinite normal trace are considered. For normal states and normal traces on such algebras of some V. S. Shulman's types the theorems of Radon-Nikodym type are proven. Connection with V. S. Shulman's types of such algebras is described (see Math. Sbornik, 1972, No 2). (Received September 22, 2018)

1145-46-1535 **Adam Stawski*** (acs192@pitt.edu), 4720 Centre Ave, Pittsburgh, PA 15213. *Results in the Theory of Fixed Point Free Mappings.*

In this survey talk, we will briefly discuss some results in the theory of fixed point free nonexpansive and contractive mappings in Banach Spaces. (Received September 23, 2018)

1145-46-1643 **Joseph A Ball*** (joball@math.vt.edu). *Reproducing kernel Hilbert spaces: the free noncommutative and Hilbert module settings.*

The classical result of Aronszajn gives the connection between positive kernels and reproducing kernel Hilbert spaces. Extension of this formalism to the case of operator-valued kernels and reproducing kernel Hilbert spaces consisting of vector-valued functions is well known. Recent work of Ball-Marx-Vinnikov (Journal of Functional Analysis 2016) introduced the notion of completely positive noncommutative kernel and its associated free noncommutative reproducing kernel Hilbert space whose elements consist of free noncommutative functions in the sense of Kaliuzhnyi-Verbovetskyi–Vinnikov (AMS Mathematical Surveys and Monographs 199, 2014). The talk will review this background and discuss the next layer of generalization originating the 2016 Virginia Tech dissertation of Gregory Marx, namely: the setting where Hilbert spaces are replaced by Hilbert C^*- modules or (for more complete results) Hilbert W^*-modules, thereby extending to the free noncommutative setting results of Kasparov, Murphy, and Szafraniec. (Received September 23, 2018)

1145-46-1699 **Joseph Eisner** and **Daniel Freeman*** (daniel.freeman@slu.edu). *Continuous Schauder frames for Banach spaces.*

Given a Banach space X, a sequence of pairs $(x_j, f_j)_{j\in N}$ is called a Schauder frame of X if

$$x = \sum_{j\in N} f_j(x)x_j \quad \text{for all } x \in X.$$

Instead of using a discrete representation with a series, continuous Schauder frames give a reconstruction formula using an integral. That is, if (M,μ) is a σ-finite measure space and $t \to (x_t, f_t)$ is a measurable map from M to $X \times X^*$ then we say that $(x_t, f_t)_{t\in M}$ is a continuous Schauder frame of X if

$$x = \int_{t\in M} f_t(x)x_t \quad \text{for all } x \in X.$$

We prove that the properties shrinking and boundedly complete may be extended to continuous Schauder frames. Furthermore, every unconditional wavelet for $L_p(R)$ gives rise to a continuous wavelet transform where $1 < p < \infty$. (Received September 24, 2018)

1145-46-1800 **Amy Elizabeth Peterson*** (amy.peterson@uconn.edu). *The Gaussian limit of High Dimensional Spherical Means.*

Given a function f we can associate to an affine subspace A the integral of f over A. For A, an affine subspace in l^2 of finite codimension and A_N its intersection with $\mathbb{R}^N$, we create a circle S_{A_N} which is the intersection of A_N with the sphere $S^{N-1}(\sqrt{N})$. We show that, in the large-N limit, the spherical integral of f over S_{A_N} converges to a Gaussian integral of f in infinite dimensions. (Received September 24, 2018)

1145-46-1828 **Oleg Friedman*** (friedman001@yahoo.com), Department of Mathematics, Lander College for Men / Touro College, 75-31 150th Street, Flushing, NY 11367, and **Alexander A. Katz** (katza@stjohns.edu), Department of Math & CS, SJC of LAS, St. John's University, 8000 Utopia Parkway, SJH-334-G, Queens, NY 11439. *On Jordan-Sherman-Takeda-Grothendieck type theorem for real locally C*-algebras.*

For real locally C*-algebras which are projective limits of projective families of real C*-algebras, a Jordan-Sherman-Takeda-Grothendieck type theorem is established, i.e. it is shown that each continuous Hermitian functional on such algebras can be uniquely decomposed into a difference of two continuous positive functionals. (Received September 24, 2018)

1145-46-1840 **Cleon S. Barroso*** (cleonbar@mat.ufc.br), Av Humberto Monte S/N, Campus do Pici, Department of Mathematics, Bl 914, CEP 60455-360, Fortaleza, CEARA 60455360, Brazil. *Existence of shift basic sequences and its implications in metric fixed point theory.*

Basic sequences with shift property are very useful in metric fixed point theory. In this talk I will discuss the existence and non-existence of shift basic sequences in Banach spaces. I also plain to introduce a related property which generalizes the so-called Pelczynski property (u). The quoted property will be referred as "property (su)". As an instance, while it is well-known that James's space fails property (u) we will see that it fulfills property (su). More generally, I will sketch the proof that every Banach space with spreading basis has property (su). As will be clear in the talk, this result implies that weak compactness can be characterized in term of the generic fixed point property for bi-Lipschitz affine maps in every Banach space with a spreading basis. (Received September 24, 2018)

1145-46-1857 **Roxana Popescu*** (rop42@pitt.edu), Pittsburgh, PA 15260. *Grothendieck Operators and Weakly p-summable series.*

We will discuss a result of A. Pełczynski and W. Szlenk regarding the natural embedding of the Banach space ℓ_1 into ℓ_p as a Grothendieck operator for $p \geq 2$. As a corollary, we will see that a more general result holds for weakly unconditionally convergent series in an arbitrary Banach space X. However, it turns out that this is no longer true when we move to the case of weakly p-summable and unconditionally p-summable series for $p > 1$. (Received September 24, 2018)

1145-46-1863 **Zhengwei Liu*** (zhengweiliu@fas.harvard.edu), 17 Oxford Street, Cambridge, MA 02138. *Classification of subfactors by skein theory.*

We propose a program on the classification of subfactors and planar algebras by skein theory. We will talk about some recent classification results for various skein theories. They include local skein theories, such as commute relations, exchange relations, popping-triangle relations; and global skein theories, such as Yang-Baxter relations, Thurston relations. We discovered a new one-parameter family of planar algebras in the skein theoretic classification program. (Received September 24, 2018)

1145-46-2040 **Danny Crytser*** (dcrytser@stlawu.edu), 118 Valentine Hall, St Lawrence University, Canton, NY 13617. *Unique extension and expectation properties for graph and groupoid C^*-algebras.* Preliminary report.

We consider the problem of when an inclusion $A \subset B$ has a variety of largeness properties, such as unique extension of pure states or unique (conditional or pseudo-) expectation, using previous work of Pitts and Zarikian. In the case of groupoid C^*-algebras, some of these are related to previously-understood properties of groupoids. In particular, we show that $C_0(G^{(0)}) \subset C^*(\mathrm{Iso}^\circ(G))$ has unique conditional expectation if and only if G is topologically principal. We consider similar problems for graph and k-graph C^*-algebras. (Received September 24, 2018)

1145-46-2177 **Pamela I. Delgado*** (pid2@pitt.edu). *Weak Compactness and the Fixed Point Property.*

We will give a survey of various results studying the relation between weak compactness and the Fixed Point Property in different Banach Spaces. In particular we will contrast the spaces c_0 and c. In the former, weak compactness is equivalent to the Fixed Point Property, while in the latter this is no longer true. (Received September 24, 2018)

1145-46-2369 **Cameron Louis Williams*** (williacl@potsdam.edu), **Nikhil N Pandya**, **Donald J Kouri** and **Bernhard G Bodmann**. *Coupled Supersymmetries and Associated Fourier-Like Transforms: New Generalizations of the Quantum Harmonic Oscillator and Fourier Transform.*

Coupled supersymmetry is a specific subclass of supersymmetries that more accurately reflect the properties of the harmonic oscillator. Coupled supersymmetries have exactly solvable eigenfunctions and eigenvalues, uncertainty principles, and coherent states. The harmonic oscillator eigenfunctions, eigenvalues, uncertainty principles, and coherent states may be realized as special cases. Additionally, there exist associated Fourier-like transforms for coupled supersymmetries. In this talk, I will develop coupled supersymmetry and establish some of the basic results therein, including eigenfunctions, eigenvalues, uncertainty principles, and their associated Fourier-like transforms. (Received September 25, 2018)

1145-46-2513 **Edward Voskanian*** (voskanian@math.ucr.edu), 7020 Estepa Drive, Tujunga, CA 91042. *Mathematical Diffraction and the Complex Roots of a Nonlattice Dirichlet Polynomial.* Preliminary report.

The discovery of quasicrystals established a new theory of solid state physics, and motivated by the desire to model these new structures also gave rise to the theory of mathematical quasicrystals. The set of complex roots of a nonlattice Dirichlet polynomial are approximated by the roots of a sequence of lattice Dirichlet polynomials determined by a sequence of simultaneous Diophantine approximations. This procedure, developed by Lapidus and van Frankenhuijsen, shows that the complex roots of a nonlattice Dirichlet polynomial have a quasiperiodic structure. The paper "Model Sets: A Survey" by Robert V. Moody suggests that aperiodicity and diffractivity are among the properties considered representative of mathematical quasicrystals, a term not universally defined. In this paper we give a survey of an open problem stated by Lapidus and van Frankenhuijsen asking if the set of complex roots of a nonlattice Dirichlet polynomial can be understood in terms of a suitable generalized mathematical quasicrystal. And, using a measure theoretic idealization of kinematic diffraction developed by A. Hof, a formula for the diffraction measure of a lattice Dirichlet polynomial satisfying a kind of regularity condition is given. (Received September 25, 2018)

1145-46-2595 **Katie Elliott*** (katie_elliott@baylor.edu). *A Self-Adjoint Operator Generated by the Krall Differential Expression with the Krall Polynomials as Eigenfunctions.*

We construct the self-adjoint operator generated by the sixth-order Lagrangian symmetric Krall differential equation in the extended Hilbert space $L^2(-1,1) \oplus \mathbb{C}^2$ which as the Krall polynomials as (orthogonal) eigenfunctions. The theory we use to create this self-adjoint operator was developed recently by L. L. Littlejohn and R. Wellman as an application of the general Glazman-Krein-Naimark (GKN) Theorem discovered by W. N. Everitt and L. Markus using complex sympletic geometry. In order to explicitly construct this operator, we use properties of functions in the maximal domain in $L^2(-1,1)$ of the Krall expression that were previously established by S. M. Loveland. As we will see, continuity, as a boundary condition, is forced by our construction of this self-adjoint operator. (Received September 25, 2018)

1145-46-2669 **Douglas Mupasiri*** (mupasiri@uni.edu). *Some recent results on Mackey duals of Banach spaces.*

For a Banach space X with dual space X*, the Mackey topology is the topology on X* of uniform convergence on the collection of all absolutely convex weakly compact subsets of X. The talk will focus on some recent results on the Mackey dual topology which give information about the structure of the underlying Banach space X. (Received September 25, 2018)

1145-46-2714 **Swarup N. Ghosh*** (swarup.ghosh@swosu.edu), 100 Campus Drive, Weatherford, OK 73096. *A conjecture of Andrew Gleason for uniform algebras on smooth manifolds.* Preliminary report.

In 1957, Andrew Gleason conjectured that if A is a uniform algebra on its maximal ideal space X and every point of X is a one-point Gleason part for A, then A must contain all continuous functions on X. Gleason's conjecture was disproved by Brian Cole in 1968. In this talk, we will establish a strengthened form of Gleason's conjecture for uniform algebras generated by real-analytic functions on compact subsets of real-analytic three-dimensional manifolds. (Received September 25, 2018)

1145-46-2717 **Laszlo Zsido*** (zsido@axp.mat.uniroma2.it), Departimento di Matematica, Universita di Roma "Tor Vergata", Via Della Ricerca Scientifica 1, 00133 Roma, Italy. *A quantitative BT-theorem and applications.*

The classical "BT-Theorem" of Murray and von Neumann states that if M is a von Neumann algebra on a Hilbert space H, and ξ, η are vectors in H such that η belongs to the closure of $M\xi$, then $\eta = bT\xi$ where $b \in M$ and T is a densely defined, closed linear operator affiliated to M. It can be extended to sequences in $\overline{M\xi}$ as follows:

If $(\eta_k)_{k\geq 1}$ *is a sequence in* $\overline{M\xi}$ *such that*

$$\sum_{k=1}^{\infty} \|\eta_k\|^2 < +\infty\,,$$

then

$$\eta_k = b_k T\xi\,, \qquad k \geq 1$$

where T *is a densely defined, closed linear operator affiliated to* M *and* $b_k \in M$ *can be chosen such that* $\lim\limits_{k\to\infty} \|b_k\| = 0\,.$

The above extended "BT-Theorem" can be applied to the proof of automatic continuity results in fairly general situations.

This talk is based upon joint work with Francesco Fidaleo. (Received September 25, 2018)

1145-46-2786 **Genady Grabarnik*** (grabarng@stjohns.edu), St John's University, Queens, NY 11439. *Recent results in ergodic therems in von Neuman Algebras.*

We provide a survey of the recent results in the ergodic theorems in the function spaces associated with von Neumann Algebras (Received September 25, 2018)

47 ► Operator theory

1145-47-28 **Claudio Cioffi-Revilla*** (ccioffi@gmu.edu). *The nabladot operator for integrated calculus of hybrid functions with continuous and discrete variables.*

Science equations sometimes consist of hybrid functions containing both continuous and discrete variables; i.e., so-called "concrete" multivariate functions, in the sense of D. Knuth. Examples include fundamental probability functions for compound events, the binomial probability formula, graph geodesic distance, Amdahl's law, Zipf's law, and various quantum equations, among others. Traditional gradient-based operators from classical multivariate differential calculus and sensitivity analysis are not strictly applicable to a broad class of such functions due to the presence of discrete variables and relatively low-range integer values, such as small cardinalities in the neighborhood of Miller's number, 7 ± 2. The "nabladot" operator for hybrid concrete functions of continuous and discrete variables is proposed and illustrated with examples from diverse domains in the natural, social, and engineering sciences. Results show new features previously unavailable through extant classical analysis and continuous approximations. (Received June 21, 2018)

1145-47-162 **Yuri Latushkin*** (latushkiny@missouri.edu). *The Maslov index and spectra of differential operators.*

We will discuss applications in spectral theory of differential operators of a topological invariant, the Maslov index, that counts the number of signed intersections of a path of Lagrangian subspaces with a fixed subspace. (Received August 13, 2018)

1145-47-186 **Ajda Fosner** and **Wu Jing*** (wjing@uncfsu.edu), Department of Mathematics & Computer Science, Fayetteville State University, Fayetteville, NC 28301. *Lie centralizers on triangular rings and nest algebras.*

We introduce the definition of Lie centralizers and investigate the additivity of Lie centralizers on triangular rings. We also present characterizations of both centralizers and Lie centralizers on triangular rings and nest algebras. (Received August 16, 2018)

1145-47-329 **Grigoriy Blekherman** and **Lawrence Fialkow*** (fialkowl@newpaltz.edu). *The core variety and representing measures in the truncated moment problem.*

The classical Truncated Moment Problem asks for necessary and sufficient conditions so that a linear functional L on $\mathcal{P}_d$, the vector space of real n-variable polynomials of degree at most d, can be written as integration with respect to a positive Borel measure μ on $\mathbb{R}^n$. We work in a more general setting, where L is a linear functional acting on a finite dimensional vector space V of Borel-measurable functions defined on a T_1 topological space S. Using an iterative geometric construction, we associate to L a subset of S called the *core variety*, $CV(L)$. The main result is that L has a representing measure μ if and only if $CV(L)$ is nonempty. In this case, L has a finitely atomic representing measure , and the union of supports of all such measures is precisely $CV(L)$. We also prove a version of the Truncated Riesz-Haviland Theorem in this general setting, and use this to solve the generalized Truncated Moment Problem in terms of positive extensions of L. These results are adapted to derive a Riesz-Haviland Theorem for a generalized Full Moment Problem and to obtain a core variety theorem for the latter problem. (Received September 01, 2018)

1145-47-346 **Orr Moshe Shalit*** (oshalit@technion.ac.il), Department of Mathematics, 3200000 Haifa, Israel. *Noncommutative varieties and the classification of some universal operator algebras.*

In this talk, we consider the universal norm-closed operator algebra generated by a row contraction satisfying some homogeneous polynomial identities. The isomorphism problem was solved, for the case where the ideal of identities was radical and commutative, almost ten years ago by Davidson-Ramsey-Shalit and Hartz. Over the years, progress has been made in generalizing this result in several different directions. In this talk I will discuss some of the recent results as well as several open questions that arise in this quest, putting an emphasis on the role of noncommutative varieties. (Received September 03, 2018)

1145-47-370 **Victor Vinnikov*** (vinnikov@math.bgu.ac.il), P.O.B. 653, 8410501 Beer Sheva, Israel. *Rings of germs of nc functions.* Preliminary report.

The noncommutative (nc) space over a vector space $\mathcal{V}$ is the disjoint union of square matrices of all sizes over $\mathcal{V}$. This work is part of the extensive ongoing study by many authors of free nc functions, that is functions whose domain and range are subsets of nc spaces, that are graded (they preserve the matrix size), and that respect direct sums and similarities. Here, we are interested in local theory of nc functions around a given centre $Y \in \mathcal{V}^{s\times s}$, in either the algebraic setting where we consider nc functions on the "nilpotent ball" around Y, or the analytic setting where we consider germs of nc functions that are bounded in various topologies. Some of our key results are the construction of the skew field of germs of meromorphic nc functions around a scalar centre; a proof that the ring of germs of analytic nc functions around a matrix (irreducible) centre is not a domain; and a proof that the ring of nc functions on the nilpotent ball around an irreducible centre Y is the completion of the free algebra with respect to the ideal of functions vanishing at Y (which is a consequence of a Hermite type interpolation theorem for nc polynomials). This is a joint work, in progress, with Igor Klep and Jurij Volcic. (Received September 04, 2018)

1145-47-441 **Bryan Goldberg*** (bgoldberg@albany.edu), bgoldberg@albany.edu, and **Rongwei Yang**. *Complex Dynamics on the Projective Spectrum of the Infinite Dihedral Group.*

Using the self-similarity of the infinite dihedral group (D_∞) in *Joint Spectrum and the Infinite Dihedral Group*, Grigorchuk and Yang defined a mapping $F : \mathbb{C}^3 \to \mathbb{C}^3$ where $F(z) = \big(z_0(z_0^2 - z_1^2 - z_2^2), z_1^2 z_2, z_2(z_0^2 - z_2^2)\big)$. After establishing some background on $F(z)$ we'll use complex dynamics to establish some properties of this mapping. We'll use equivalent projective space and look at $F : \mathbb{P}^2 \to \mathbb{P}^2$ to discuss some results including the Fatou and Julia sets of $F(z)$ restricted to the projective spectrum. We'll conclude by examing connections between spectral theory and dynamics in this particular situation. This is joint work with Rongwei Yang. (Received September 20, 2018)

1145-47-512 **Ji Eun Lee*** (jieunlee7@sejong.ac.kr), 209, Neungdong-ro, Gwangjin-gu, Sejong University, Seoul, 05006, South Korea, **Robin Harte** (hartere@gmail.com), , Ireland, and **Eungil Ko** (eiko@ewha.ac.kr), Seoul, South Korea. *Operator matrices with Hankel and Toeplitz entries.*

Hankel and Toeplitz operators are the compressions of Laurent and bilateral Hankel operators, which in turn can be presented as 2×2 operator matrices A with Toeplitz and Hankel entries. In particular, we invesigate spectral relations between Laurent operators A and their entries. Moreover, we examine self-adjointness, normality, or hyponormality of Laurent operators A. (Received September 08, 2018)

1145-47-538 **Kelly Bickel*** (kelly.bickel@bucknell.edu), **James Eldred Pascoe** and **Alan Sola**. *Portraits of Rational Inner Functions.*

This talk focuses on two-variable rational inner functions ϕ with singularities on the two-torus $\mathbb{T}^2$. Such ϕ always possess well-behaved unimodular level sets whose analytic properties imply information about the zero set of ϕ and the fine numerical stability of ϕ near its singularities. Such results will be illustrated via pictures of key unimodular level sets. (Received September 09, 2018)

1145-47-541 **Scott Mccullough*** (sam@ufl.edu). *Free bianalytic maps between spectraballs.* Preliminary report.

A free spectrahedron is the fully matricial analog of the notion of a spectrahedron from convex geometry. A spectraball is a fully matricial analog of a spectrahedron with circular symmetry. This talk will focus on recent progress - joint with Meric Augat, Bill Helton, Igor Klep, and Jurij Volcic - on characterizing free bianalytic mappings from one spectraball to another and from a spectraball to a free spectrahedron. The evidence indicates there are few such maps and they have a highly algebraic structure. (Received September 09, 2018)

1145-47-549 **Jake Fillman*** (fillman@vt.edu), Mathematics (MC0123), 225 Stanger Street, Blacksburg, VA 24061. *Ballistic motion for limit-periodic Schrödinger operators.*

We study Schrödinger operators that are uniformly approximated by periodic operators. We show that if the rate of approximation is sufficiently rapid, then the associated quantum dynamics are ballistic in the sense that the position observable converges (on a linear scale) to an observable having trivial kernel. This may be used to establish a lower bound on the Lieb–Robinson velocity for an XY spin chain on the integers with limit-periodic coefficients. (Received September 09, 2018)

1145-47-573 **Benjamin P Russo*** (russobp@farmingdale.edu) and **Arthur Parzygnat** (arthur.parzygnat@uconn.edu). *C^*-algebras and the Category of Stochastic Maps.*

Stochastic maps are a generalization of functions in that they assign to each point in the domain a probability measure of on the codomain. In this talk we will discuss the category of stochastic maps. In particular, we will explore some generalizations of probabilistic concepts resulting from the existence of a contravariant functor from the category of stochastic maps into the category of C^*-algebras. This is joint work with Arthur Parzygnat (UConn). (Received September 10, 2018)

1145-47-579 **Arthur J Parzygnat*** (arthur.parzygnat@uconn.edu), 341 Mansfield Road U-1009, Storrs, CT 06269-1009, and **Benjamin P Russo**. *Non-commutative disintegration.*

The notion of a disintegration of positive measures can be formulated diagrammatically in a category of transition kernels. Combining this with the functor relating transition kernels and positive operators, a notion of non-commutative disintegration can be made for certain C*-algebras and von Neumann algebras in terms of positive operators. While a certain degree of uniqueness holds as in the classical measure-theoretic case, existence of such disintegrations is not guaranteed even on finite-dimensional matrix algebras. Such disintegrations are closely related to reversible processes in quantum information theory and conditional probabilities in non-commutative probability. This is joint work with Benjamin P. Russo (Farmingdale State College SUNY). (Received September 10, 2018)

1145-47-580 **Raphael Clouatre*** (raphael.clouatre@umanitoba.ca) and **Edward Timko** (edward.timko@umanitoba.ca). *Classifying cyclic row contractions.*

Pure commuting row contractions that are “almost co-isometric” can be classified up to unitary equivalence by compressions of the Drury–Arveson shift. Although very fine, this classification is restricted to row contractions with one-dimensional defect spaces. We explain how the defect condition can be relaxed to a more flexible cyclicity condition, upon settling for a coarser classification. Interestingly, our proof takes us out of the commutative world, as it hinges on tools that are genuinely non-commutative. New multivariate pathologies are encountered when aiming for higher multiplicities, and we exhibit some purely algebraic obstructions to the existence of cyclic decompositions for nilpotent tuples. This comes as a bit of a surprise, since such decompositions always exist in the classical univariate case. (Received September 10, 2018)

1145-47-828 **Greg Knese*** (geknese@wustl.edu), Washington University in St. Louis, One Brookings Dr, Campus Box 1146, St. Louis, MO 63130. *The Polya class in several variables.* Preliminary report.

The Polya class consists of entire functions which are local uniform limits of stable polynomials, those with no zeros in the upper half plane (in the case of one variable) or in the product of upper half planes (in several variables). We will discuss how determinantal representations in two variables can be used to prove global bounds on stable polynomials which extend to the Polya class. We will also discuss progress on representing Polya class functions in two variables via infinite dimensional determinants. (Received September 15, 2018)

1145-47-845 **Raul E Curto*** (raul-curto@uiowa.edu), Department of Mathematics, The University of Iowa, Iowa City, IA 52242. *Limits of iterates of spherical Aluthge transforms.* Preliminary report.

Let $\mathbf{T} \equiv (T_1, T_2)$ be a commuting pair of Hilbert space operators, and let $P := \sqrt{T_1^* T_2 + T_1^* T_2}$ be the positive factor in the (joint) polar decomposition of $\mathbf{T}$, i.e., $T_i = V_i P$ $(i = 1, 2)$. The spherical Aluthge transform of $\mathbf{T}$ is the (necessarily commuting) pair $\widehat{\mathbf{T}} := (\sqrt{P} V_1 \sqrt{P}, \sqrt{P} V_1 \sqrt{P})$. We study the iterates of the spherical Aluthge transform, that is, the commuting pairs given by $\widehat{\mathbf{T}}^{(1)} := \widehat{\mathbf{T}}$ and $\widehat{\mathbf{T}}^{(n)} := \widehat{\widehat{\mathbf{T}}^{(n-1)}}$ $(n \geq 2)$.

In this talk, we will focus on the asymptotic behavior of the sequence $\{\widehat{\mathbf{T}}^{(n)}\}_{n \geq 1}$ as $n \to \infty$. In those cases when the limit exists, the limit pair is a fixed point for the spherical Aluthge transform, that is, a spherically quasinormal pair. For large suitable classes of 2-variable weighted shifts we will establish the convergence of the sequence of iterates in the weak operator topology.

The talk is based on joint work with Chafiq Benhida (Université de Lille, Lille, France) and Jasang Yoon (The University of Texas Rio Grande Valley, Edinburg, Texas, USA). (Received September 16, 2018)

1145-47-846 **Maxim Derevyagin*** (maksym.derevyagin@uconn.edu), CT. *Two-parameter eigenvalue problems for Jacobi matrices.*

A number of questions in analysis and probability leads to an eigenvalue problem of the form

$$(J + sH - xI)y = 0,$$

where J, H are Jacobi matrices, s and x are spectral parameters (one of which is usually fixed), and y is a vector to be found. Clearly, the elements of y should be polynomials in x and, at the same time, they should be rational functions in s.

At first, we will discuss the questions that induce such eigenvalue problems and then a few concrete examples of J and H will be considered. Also, a basic ideology of Darboux transformations for the eigenvalue problems in question will be presented. (Received September 16, 2018)

1145-47-888 **David P Kimsey*** (kimsey@ncl.ac.uk). *On a minimal solution of the indefinite multidimensional truncated moment problem.*

We will consider the the indefinite multidimensional truncated moment problem. Necessary and sufficient conditions for a given truncated multisequence to have a signed representing measure μ with $\operatorname{card}\operatorname{supp}\mu$ as small as possible are given by the existence of a rank preserving extension of a multivariate Hankel matrix built from the given truncated multisequence such that the corresponding polynomial ideal is real radical. This result is a special case of a more general characterisation of truncated multisequences with a minimal complex representing measure whose support is symmetric about the real axis (which we will call *quasi-complex*). One motivation for our results is the fact that positive semidefinite truncated multisequence need not have a positive representing measure. Thus, our main result gives the potential for computing a signed representing measure $\mu = \mu_+ - \mu_-$, where $\operatorname{card}\operatorname{supp}\mu_-$ is potentially small. We will illustrate this point on concrete examples. (Received September 17, 2018)

1145-47-992 **William M. Higdon*** (whigdon314@comcast.net). *Let $\varphi(z) = 1/4(1+z)^2$ be a self-mapping of the unit disk. Does the composition operator C_φ lie within a strongly-continuous semigroup of composition operators on $H^2(\mathbf{D})$?* Preliminary report.

Let $\varphi(z) = 1/4(1+z)^2$ be a self-mapping on the unit disk $\mathbf{D}$ in the complex plane. Let C_φ be the induced composition operator on the Hardy space $H^2(\mathbf{D})$. The question has been posed to some interested parties: "Does C_φ lie within a strongly-continuous semigroup of composition operators?". We provide the answer to the question in the context of a more general result. (Received September 18, 2018)

1145-47-1052 **Matthew A Fury*** (maf44@psu.edu), Penn State Abington, 1600 Woodland Road, Abington, PA 19001. *Logarithmic approximation of ill-posed problems associated with generators of holomorphic semigroups.*

The backward heat equation, one of the most widely studied ill-posed problems, has been treated with several regularization methods including the quasi-reversibility method and numerical methods, especially in Hilbert space. In Banach space, one approach is by the theory of semigroups of linear operators as $-\Delta$ generates a holomorphic semigroup of angle $\pi/2$ on $L^p(\mathbb{R}^n)$, $1 < p < \infty$. In this case, we apply a logarithmic approximation introduced by Boussetila and Rebbani, and applied by Huang, in order to prove continuous dependence on modeling for the backward heat equation, and more generally for ill-posed problems associated with strongly elliptic differential operators of even order in Banach space. (Received September 18, 2018)

1145-47-1086 **Don Hadwin** (don@unh.edu) and **Mahtab Lak*** (lak.mahtab@gmail.com). *A general view of reflexivitgy for absolutely convex sets.* Preliminary report.

Suppose (X, Y) is a dual pair over the field $\mathbb{F}$ (either the real or complex numbers), and suppose $E \subset Y$ separates the points of Y and is closed under scalar multiplication. Then (X, Y, E) is a *reflexivity triple* introduced by D. Hadwin in 1994. Hadwin, using annihilators, used reflexivity triples to introduce a very general notion of reflexivity for linear subspaces of X. We replace annihilators with polars and study a more general notion of reflexivity for absolutely convex subsets of X. The notions of hyperreflexivity and direct integrals in this setting require a completely new definition, but we are able to extend many of Hadwin's results and we obtain a result on hyperreflexivity that in new even in the original Hilbert space setting. (Received September 18, 2018)

1145-47-1097 **Wenjing Liu*** (wbs4@wildcats.unh.edu) and **Don Hadwin**. *A Generalized Voiculescu Theorem of AH-algebras into Semifinite von Neumann Algebras.* Preliminary report.

In this talk, we extend the result of Don Hadwin for approximate summands of representations from AH algebras into von Nuemann algebras. We also will discuss a necessary and sufficient condition for two unital $*$-homorphisms of AH algebras into semifinite von Neumann algebras to be approximate equivalent is that they are approximate equivalent relative to compact operators. (Received September 25, 2018)

1145-47-1243 **Marat V. Markin*** (mmarkin@csufresno.edu), Department of Mathematics, California State University, Fresno, 5245 North Backer Avenue, M/S PB108, Fresno, CA 93740-8001. *On the Smoothness of Weak Solutions of an Abstract Evolution Equation with a Scalar Type Spectral Operator on the Real Axis.* Preliminary report.

Given the abstract evolution equation

$$y'(t) = Ay(t),\ t \in \mathbb{R},$$

with *scalar type spectral operator* A in a complex Banach space, found are conditions *necessary and sufficient* for all *weak solutions* of the equation, which a priori need not be strongly differentiable, to be *strongly infinite differentiable* or *strongly Gevrey ultradifferentiable* of order $\beta \geq 1$, in particular *analytic* or *entire*, on $\mathbb{R}$. Also, revealed are certain interesting inherent smoothness improvement effects. The important case of the equation with a *normal operator* A in a complex Hilbert space is immediately obtained as a particular one. (Received September 20, 2018)

1145-47-1276 **Victor Kaftal*** (kaftalv@ucmail.uc.edu). *Diagonals of positive operators - an alternative approach.*

Finding which sequence $\{\xi_i\}$ can be the diagonal of a given positive bounded operator A has been the focus of much research starting with the classic Schur-Horn theorem and including the more recent Kadison Pythagorean theorem. Recognizing that this problem is equivalent to finding the coefficients in the decomposition of $A = \sum_j \xi_j P_j$ where P_j are rank-one projections, provides an additional, sometimes easier, approach. An illustration of this fact is the new proof of the sufficiency condition in the Kadison Pythagorean theorem (when A is a projection) and its extension to the case when A is a sum of (not necessarily mutually orthogonal) projections.

The talk is based on joint work with David Larson and is dedicated to the memory of Richard Kadison. (Received September 20, 2018)

1145-47-1531 **Dhruba R Adhikari*** (dadhikar@kennesaw.edu). *Topological degrees for quasibounded multivalued $(\widetilde{S_+})$-perturbations of maximal monotone operators.*

Let X be an infinite dimensional real reflexive Banach space with dual space X^* and $G \subset X$ open and bounded. Let $T : X \supset D(T) \to 2^{X^*}$ be a maximal monotone operator with $0 \in D(T)$ and $0 \in T(0)$, and let $C : X \supset D(C) \to 2^{X^*}$ be densely defined strongly quasibounded and of type $(\widetilde{S}_+)$. A new topological degree theory is introduced for the sum $T + C$ with a degree mapping $\mathrm{d}(T + C, G, 0)$ defined eventually in terms of the Ma degree for multivalued compact operators. Unlike single-valued operators considered by Kartsatos and

Skrypnik, the operator C here is multivalued so that the multivalued generalized pseudomonotone operators considered by Browder and Hess include such C and even $T+C$. Consequently, the main existence results of Browder and Hess are obtained via the new degree theory and some of their existence results are extended. An application of the theory to elliptic partial differential inclusions in general divergence form is also given. (Received September 23, 2018)

1145-47-1552 **Flavia Colonna**, Fairfax, VA 22030, and **Shams Alyusof*** (salyusof@gmu.edu). *Weighted Composition Operators from Analytic Function Spaces into Zygmund-Type Spaces.*

In this work, we characterize the bounded and compact weighted composition operators from a large class of Banach space X of analytic functions on the open unit disk into Zygmund-type spaces. Under more restrictive conditions, we provide an approximation of the essential norm of such operators. We apply our results to the cases when X is the Hardy space H^p and the weighted Bergman space A^p_α for $\alpha > -1$ and $p > 1$. Also, we disscuss the case of the space $S^p, p > 1$ where our results are not applicable. (Received September 23, 2018)

1145-47-1583 **Gabriel Prajitura***, 350 New Campus Drive, Brockport, 14420, and **Ruhan Zhao** and **Jasbir Singh Manhas**. *Frame - preserving operators.* Preliminary report.

We will discuss operators that take frames into frames and will determine under what conditions composition operators have this property. (Received September 23, 2018)

1145-47-1634 **Andrey Glubokov***, Ave Maria University, FL , and **Igor Nikolaev**, St. John's University. *Cluster Algebra or rank 2 and Jones Index Theorem.*

We apply the properties of the cluster algebras to give another proof of the Jones Index Theorem. The talk is based on a joint work with Pr. Igor Nikolaev. (Received September 23, 2018)

1145-47-1657 **Jake Fillman** and **Rui Han***, School of Mathematics, Georgia Tech, 686 Cherry St., Atlanta, GA 30332, and **Svetlanta Jitomirskaya**. *Discrete Bethe-Sommerfeld Conjecture.*

We will talk about discrete versions of the Bethe-Sommerfeld conjecture. Namely, we study the spectra of multi-dimensional periodic Schrödinger operators on various discrete lattices with sufficiently small potentials. In particular, we provide sharp bounds on the number of gaps that may perturbatively open, we characterize those energies at which gaps may open, and we give sharp arithmetic criteria on the periods that ensure no gaps open. We will also provide examples that open the maximal number of gaps and estimate the scaling behavior of the gap lengths as the coupling constant goes to zero. This talk is based on a joint work with Svetlana Jitomirskaya and another work with Jake Fillman. (Received September 23, 2018)

1145-47-1662 **Rui Han**, **Svetlana Jitomirskaya** and **Fan Yang***, School of Math, Georgia Tech, 686 Cherry St., Atlanta, GA 30332. *Universal hierarchical structure of eigenfunctions of the Maryland model.*

We will talk about the universal hierarchical structure of eigenfunctions of the Maryland model: $(Hu)_n = u_{n+1}+u_{n-1}+\lambda\tan(\pi(\theta+n\alpha))u_n$. We will give exact exponential asymptotics of eigenfunctions for all frequencies and phases in the localization regime. This talk is based on a joint work with Rui Han and Svetlana Jitomirskaya. (Received September 23, 2018)

1145-47-1673 **Brian C Lins*** (blins@hsc.edu), Midlothian, VA 23112-1535, and **Ilya M. Spitkovsky** (imspitkovsky@gmail.com). *Inverse continuity of the numerical range map for Hilbert space operators.*

We describe continuity properties of the multivalued inverse of the numerical range map $f_A : x \mapsto \langle Ax, x\rangle$ associated with a linear operator A defined on a complex Hilbert space $\mathcal{H}$. We prove in particular that f_A^{-1} is strongly continuous at all points of the interior of the numerical range $W(A)$. We give examples where strong and weak continuity fail on the boundary and address special cases such as normal and compact operators. (Received September 23, 2018)

1145-47-1809 **Rachael M. Norton*** (rachael.norton@northwestern.edu). *A Nevanlinna-Pick theorem in the context of the weighted Hardy algebra over a W^*-correspondence.*

Since the original proof of the Nevanlinna-Pick theorem in 1915, many noncommutative generalizations have arisen and two proof strategies have emerged: via a commutant lifting theorem or via a displacement equation. In this talk, we present a generalized Nevanlinna-Pick theorem in the setting of the weighted Hardy algebra over a W^*-correspondence, which generalizes a theorem proved by the author in 2017. The proof hinges on a displacement equation and avoids commutant lifting. Time permitting, we compare our result with a similar theorem proved by Good in 2017 via her weighted commutant lifting theorem. (Received September 24, 2018)

1145-47-1874 **Masayoshi Kaneda*** (masayoshi.kaneda@mathematik.uni-goettingen.de), Mathematisches Institut, Georg-August-Universität Göttingen, D-37073 Göttingen, NI, Germany, and **Thomas Schick** (thomas.schick@mathematik.uni-goettingen.de), Mathematisches Institut, Georg-August-Universität Göttingen, D-37073 Göttingen, NI, Germany. *Open projections and Murray-von Neumann equivalence.*

We identify the class of C^*-algebras for which openness of projections is stable under Murray-von Neumann equivalence. The C^*-algebras for which all projections in their second duals are open are examples of such C^*-algebras, and they are precisely those C^*-algebras which are ideals in their second duals. We also show that any C^*-algebra for which the closure of every open projection in its second dual is again open has the largest essential ideal which is a c_0-direct sum of AW^*-algebras. (Received September 24, 2018)

1145-47-2290 **Mai Tran*** (mttran@albany.edu), 1400 Washington Avenue, Albany, NY 12222, and **Rongwei Yang** (ryang@albany.edu), 1400 Washington Avenue, Albany, NY 12222. *Non-Euclidean Metrics on the Resolvent Set.*

For a bounded linear operator A on a complex Hilbert space $\mathcal{H}$, the functions $g_x(z) = \|(A-z)^{-1}x\|^2$, where $x \in \mathcal{H}$ with $\|x\| = 1$, defines a family of non-Euclidean metrics on the resolvent set $\rho(A)$. Thus the arc length of a fixed circle $C \subset \rho(A)$ with respect to the metric g_x is dependent on the choice of x. This paper derives an integral equation for the extremal values of the arc length. If there exists a solution to the extremal equation, x, then it can be shown to have particular properties relating to A. In the case A is the unilateral shift operator on the Hardy space $\mathbf{H}^2(\mathbb{D})$, the paper proves that the arc length of C is maximal if and only if x is an inner function. This is the joint work with Rongwei Yang. (Received September 25, 2018)

1145-47-2373 **M Akram*** (mua961@psu.edu), Department of Computer Science and Mathematic, School of Science, Engineering,and Technology, Penn State Harrisburg, Middletown, PA 17057, and **Nosheen Zakariya**. *Common Fixed Point Theorems for $\psi-$Expansive Mappings in $G-$Metric Spaces.*

In this paper, we introduced ψ-expansive mappings on G-metric spaces and proved several fixed point theorems for a class of ψ-expansive mappings in the setting of G-metric spaces. Our results are the generalization of several results from metric spaces set up to the generalized metric spaces set up in the existing literature. (Received September 25, 2018)

1145-47-2601 **Mitch Hamidi*** (mhamidi@huskers.unl.edu). *Admissibility of C*-Covers and Crossed Products of Operator Algebras.*

Let $(\mathcal{A}, G, \alpha)$ be an operator algebra dynamical system, where $\alpha : G \curvearrowright \mathcal{A}$ is the action of G on $\mathcal{A}$ by completely isometric automorphisms. We say a C*-cover for $\mathcal{A}$ is *α-admissible* if α extends to an action of G on the C*-cover which yields a C*-dynamical system with an appropriate equivariance property. We discuss new examples of C*-covers that fail to be admissible for a given dynamical system and provide a new characterization for α-admissibility in terms of a C*-cover's boundary ideal structure. We then consider ways to extend the dynamics using a partial crossed product construction. (Received September 25, 2018)

1145-47-2670 **Torrey M Gallagher*** (tmg012@bucknell.edu). *Recent results for mean nonexpansive mappings.*

Mean nonexpansive mappings were introduced by Goebel and Japon Pineda in 2007 as a generalization to the usual notion of a nonexpansivity. There have been many results pertaining both to the general, operator-theoretic behavior of mean nonexpansive mappings as well as their fixed point properties. We will present an overview of these results, including basic fixed point theorems, a classification of mean isometries, a demiclosedness principle, and a generalization of the definition with open questions highlighted throughout the presentation. (Received September 25, 2018)

1145-47-2709 **Cong Zhou*** (zhouco@iu.edu), Department of Mathematics, Indiana University, Bloomington, IN 47408. *Limit laws for R-diagonals.*

In this talk we determine the distribution behavior of the sum of *-free identically distributed R-diagonal random variables. The theory is shown to parallel the free probability theory of free random variables, though the limit laws of the tracial case and non-tracial case are entirelyLimit laws for R-diagonals different. We show the convergence in moments of the sum of *-free, R-diagonal identically distributed random variable is R-diagonal and free additive convolution-infinitely divisible, which is previously known parametrizable by a pair of compactly supported Borel probability measures on the positive real axis. In particular, we determine the domains of attraction of those parameters in the free theory. (Received September 25, 2018)

1145-47-2788 **Ali Zarringhalam*** (ali.zaringhalam@gmail.com), 33 Academic Way, Math Dept UNH, Durham, NH 03824. *Invariant Operator Ranges in von Neumann Algebras.* Preliminary report.

Suppose $\mathcal{M}$ is a von Neumann algebra. An *operator range in* $\mathcal{M}$ is the range of an operator in $\mathcal{M}$. When $\mathcal{M} = B(H)$, the algebra of operators on a Hilbert space H, R. Douglas and C. Foiaş proved that if $S, T \in B(H)$, and T is not algebraic, and if S leaves invariant every T-invariant operator range, then $S = f(T)$ for some entire function f. I am investigating this result when $B(H)$ is replaced with a factor von Neumann algebra $\mathcal{M}$. (Received September 25, 2018)

1145-47-2798 **Aaron Thomas Welters*** (awelters@fit.edu). *On the field recursion method for two-component composites.*

I will discuss an abstract version of the field equation recursion method for two-component composites with isotropic phases. A derivation of the method, based on the abstract theory of composites and Fredholm operator theory, will be given with a focus on the necessary and sufficient conditions for the recursion to hold at each step. In this approach, the effective tensor $\mathbf{L}_*$ can be interpreted as the Z-operator on a certain orthogonal $Z(2)$ subspace collection. The base case of the recursion starts with an orthogonal $Z(2)$ subspace collection on a Hilbert space $\mathcal{H}$, the Z-problem, and the associated Y-problem. We provide some new conditions for the solvability of both these problems and give explicit representations of the associated operators, namely, the Z-operator and Y-operator, respectively. An iterative method is then developed from a hierarchy of subspace collections and their associated operators which leads to a continued fraction representation of the initial effective tensor $\mathbf{L}_*$. This is joint work with Graeme Milton (Univ. of Utah) and Maxence Cassier (Institut Fresnel). (Received September 25, 2018)

49 ► Calculus of variations and optimal control; optimization

1145-49-80 **S. Melike Aydogan*** (aydogansm@itu.edu.tr), Istanbul Technical University, Department of Mathematics, Maslak, 34467 Sarıyer/Istanbul, 34467 Istanbul, Turkey. *On Two Fractional q-Derivative Inclusions.* Preliminary report.

There are a lot of works on fractional differential equation. One of the fractional derivations is q-difference type. On the other hand, fractional differential inclusions are strong generalization for fractional differential equations. In this talk, we investigate the existence of solution for two fractional q-derivative inclusions. (Received July 24, 2018)

1145-49-389 **Jinlu Li*** (jli@shawnee.edu), Department of Mathematics, Shawnee State University, Portsmouth, OH 45662. *Fixed Point Theorems on Partially Ordered Banach Spaces and Their Applications.*

In this talk, we will present several fixed point theorems on partially ordered sets and on partially ordered Banach spaces. We will show that in these fixed point theorems, the considered mappings are not required to satisfy any continuity conditions but they satisfy some order monotonic conditions. Meanwhile, in these theorems, the order properties of the set of fixed points are also provided. Finally, we will present some applications of these fixed point results to game theory with incomplete utilities, ordered variational inequalities, ordered optimization problems, and integral equations. (Received September 05, 2018)

1145-49-510 **Gisèle Mophou*** (gisele.mophou@univ-antilles.fr), AIms-Cameroon, P.O. Box 608, Limbe, Cameroon, **Romario Tiomela Foko** (romario.foko@aims-cameroon.org), AIMS-Cameroon, P.O. Box 608, Limbe, Cameroon, and **Ali Seibou** (alichaibou10@gmail.com), Université Ouaga 3S, Ouagadougou, Burkina Faso. *Optimal control of averaged state of a parabolic equation with missing boundary condition.*

We consider the optimal control of general heat governed by an operator depend on an unknown parameter and with missing boundary condition. Using the notion of no-regret and low-regret control we prove that we can bring the average of the state of our model to a desired state. Then by means of Euler-Lagrange first order optimality condition, we expressed the optimal control in term of average of an appropriate adjoint state that we characterize by an optimality system. The main tools are the Lebesgue dominated convergence theorem and an appropriate Hilbert space endowed with a norm containing the average of the state. (Received September 08, 2018)

1145-49-605 **Ugur G Abdulla** (abdulla@fit.edu) and **Evan Cosgrove*** (ecosgrove2011@my.fit.edu). *On the Optimal Control of the Multiphase Free Boundary Problems for Nonlinear Parabolic Equations.* Preliminary report.

We consider the inverse Stefan type multiphase free boundary problem, in which information on the boundary heat flux is missing, and must be found along with the temperature. We generalize the method developed in *Abdulla and Poggi, Applied Mathematics and Optimization, 2018* to pursue optimal control framework where control vector consists of the heat flux, and the cost functional is the L_2-norm declination of the trace of temperature at the final moment of time to the measured data. We pursue discretization of the problem, and prove convergence of the discrete problem to the original problem with respect to both control and functional.
(Received September 11, 2018)

1145-49-611 **Ugur Abdulla**, **Vladislav Bukshtynov** and **Saleheh Seif*** (sseif2014@my.fit.edu), 316 Georgetown avenue, Melbourne, FL 32901. *Breast Cancer Detection through Electrical Impedance Tomography and Optimal Control Theory: Theoretical and Computational Analysis.*

The Inverse Electrical Impedance Tomography (EIT) problem on recovering electrical conductivity tensor and potential in the body based on the measurement of the boundary voltages on the electrodes for a given electrode current is analyzed. A PDE constrained optimal control framework in Besov space is pursued, where the electrical conductivity tensor and boundary voltages are control parameters, and the cost functional is the norm declinations of the boundary electrode current from the given current pattern and boundary electrode voltages from the measurements. The state vector is a solution of the second order elliptic PDE in divergence form with bounded measurable coefficients under mixed Neumann/Robin type boundary condition. Existence of the optimal control and Fréchet differentiability in the Besov space setting is proved. The formula for the Fréchet gradient and optimality condition is derived. Extensive numerical analysis is pursued in the 2D case by implementing the projective gradient method, re-parameterization via principal component analysis (PCA) and Tikhonov regularization. (Received September 11, 2018)

1145-49-643 **Irene Fonseca*** (fonseca@andrew.cmu.edu), 221 Conover Road, Pittsburgh, PA 15208, and **Riccardo Cristoferi**, **Adrian Hagerty** and **Cristina Popovici**. *A Homogenization Result in the Gradient Theory of Phase Transitions.*

A variational model in the context of the gradient theory for fluid-fluid phase transition with small scale heterogeneity is studied. In particular, the case where the scale of the small homogeneities is of the same order of the scale governing the phase transition is considered. In the limit, as the parameter scale tends to zero, there is an interaction between the homogenization and the phase transition process. (Received September 12, 2018)

1145-49-657 **Filippo Cagnetti*** (f.cagnetti@sussex.ac.uk). *Stochastic Homogenisation of Free-Discontinuity Problems.*

Free-discontinuity problems were introduced by Ennio De Giorgi and Luigi Ambrosio in 1988. These are variational problems where the energy to be minimised involves both volume and surface terms. The expression “Free-Discontinuity” refers to the fact that the set where the surface energy is concentrated is not a priori fixed, and can be described as the discontinuity set of a function. We will discuss the stochastic homogenisation of free-discontinuity functionals. Assuming stationarity for the random volume and surface integrands, we prove the existence of a homogenised functional, whose volume and surface integrands are characterised by asymptotic formulas involving minimisation problems on larger and larger cubes with special boundary conditions. In the proof we combine a recent deterministic Gamma-convergence result for free-discontinuity functionals with the Subadditive Ergodic Theorem by Akcoglu and Krengel. This is a joint work in collaboration with Gianni Dal Maso (SISSA), Lucia Scardia (Heriot-Watt University), and Caterina Zeppieri (University of Münster).
(Received September 12, 2018)

1145-49-697 **Lorenzo Freddi**, **Peter Hornung**, **Maria Giovanna Mora*** (mariagiovanna.mora@unipv.it) and **Roberto Paroni**. *A corrected Sadowsky functional for inextensible elastic ribbons.*

In 1930 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 made of 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 the Sadowsky energy, depends on the curvature and torsion of the centerline of the band and it is singular at points with zero curvature. In this talk we will re-examine the

derivation of the Sadowsky energy using Γ-convergence. The energy deduced in this way generalizes and corrects the classical Sadowsky functional. (Received September 13, 2018)

1145-49-762 **Ryan Murray*** (rwm22@psu.edu), The Pennsylvania State University, McAllister building, State College, PA 16802. *Second-order Gamma-convergence for Cahn-Hilliard energies.*

The Cahn-Hilliard model is a classical model for microscopic phase transitions in materials, which serves as an important prototype of many phase transition problems in continuum mechanics. I will discuss some recent results regarding second-order Gamma-convergence of these models using a novel rearrangement technique. I will also discuss applications of these results to the study of metastable states for the Allen-Cahn equation, and current work extending these results to more physically realistic energies. This is joint work with Giovanni Leoni and Matteo Rinaldi. (Received September 14, 2018)

1145-49-772 **Mohsen Razzaghi*** (razzaghi@math.msstate.edu), Mississippi State University, Mississippi State, MS 39762. *An approximate method for solving variational problems.*

Orthogonal functions may be widely classified into three families. The first includes sets of piecewise constant basis functions (PCBFs), (e.g., block-pulse, Haar, etc.). The second consists of sets of orthogonal polynomials (e.g., Chebyshev, Legendre, etc.). The third are widely used sets of sine-cosine functions in the Fourier series. While orthogonal polynomials and sine-cosine functions together form a class of continuous basis functions, PCBFs have discontinuities or jumps. For several problems in science and engineering, images often have properties that vary continuously in some regions and discontinuously in others. In recent years, the hybrid functions consisting of the combination of block-pulse functions with orthogonal polynomials have been shown to be a mathematical power tool for discretization of selected problems. In this talk, the hybrid of block-pulse and Legendre polynomials is used to find the numerical solution of variational problems. Numerical examples are included to demonstrate the validity and applicability of the proposed method and comparison is made with existing results. (Received September 14, 2018)

1145-49-1134 **Christina Joy Edholm*** (cedholm@utk.edu), **Chris Guiver**, **Brigitte Tenhumberg**, **Stuart Townley** and **Richard Rebarber**. *Comparison of adaptive and optimal control illustrated with pest management.* Preliminary report.

To determine effective management strategies for controlling invasive species, we compare implementing adaptive and optimal control. Both methods are used to determine how much control to apply at each time step. Adaptive control is a feedback control which uses observations of part of state to update the amount of control. In contrast, when using optimal control the choice of control minimizes a cost functional, assuming that the initial population state and the population dynamics are completely known. We model the invasive species with a stage structured discrete time linear population projection model, and assume that the control increases one of the mortality rates. As a case study we use the invasive insect species *Diaprepes abbreviatus*, and consider the robustness and resulting cost of each control scheme. (Received September 19, 2018)

1145-49-1272 **Carolin Kreisbeck*** (c.kreisbeck@uu.nl), Mathematisch Instituut, Universiteit Utrecht, Postbus 80010, 3508TA Utrecht, Netherlands, and **Elvira Zappale**, D.I.In., Universita degli studi di Salerno, Via Giovanni Paolo II 132, 84084 Fisciano, Italy. *Relaxation of nonlocal supremal functionals.*

Nonlocal functionals in the form of double integrals appear naturally in models of peridynamics. In the homogeneous case, separate convexity of the integrands has recently been identified as a necessary and sufficient condition for weak lower semicontinuity. When it comes to relaxation, though, a characterization of the weak lower semicontinuous envelopes is still largely open. It is in particular unclear whether they can be represented as double integrals.

Motivated by these interesting developments, this talk addresses a related question by discussing homogeneous supremal functionals in the nonlocal setting. We show that weak* lower semicontinuity holds if and only if the level sets of a symmetrized and suitably diagonalized version of the supremand are separately convex. It turns out that, unlike for double integrals, the supremal structure of the functionals we consider here is guaranteed to be preserved in the process of relaxation. The proof of this statement relies on the connection between supremal and indicator functionals, which reduces the problem to studying weak* closures of a class of nonlocal inclusions. We give examples of explicit relaxation formulas for different multi-well functions. (Received September 20, 2018)

1145-49-1374 **Daniel Bienstock** and **Yuri Faenza***, yf2414@columbia.edu, and **Igor Malinovic**, **Monaldo Mastrolilli**, **Ola Svensson** and **Mark Zuckerberg**. *Bounded pitch inequalities for min knapsack: approximate separation and integrality gaps.*

The pitch of a (valid) inequality for the min knapsack polytope is the minimum integer k such that, if any k variables from its support are set to 1, then the inequality is satisfied. Bounded pitch inequalities came to prominence for their connections with the Chvàtal-Gomory and Bienstock-Zuckerberg operators.

In this talk, we investigate the strength of bounded pitch inequalities, proving bounds on the integrality gap when they are added to the natural LP relaxation (possibly, in conjunction with other inequalities), and we discuss algorithms for approximately separating them. (Received September 21, 2018)

1145-49-1469 **Gayatri Pany*** (gayatripany@gmail.com), Singapore University of Technology and Design, Singapore, 487372, Singapore. *Equilibrium structure for a spatial economy: effects of automated transport modes.*

Our study relates to potential games, i.e., the study of games where the equilibria can be derived from the optimization of a potential. A potential is a functional in terms of some distribution related to the underlying game, for example it may be action distribution or spatial distribution, depending on the framework of the game. Adoption of variational approach enables to find the equilibria effectively. It has been observed that urban forms are affected by the continuous development of the transport modes. Several case studies are available in literature. Motivated by these works, we study equilibrium structure for a spatial economy ($\mathcal{S}$) based on, before and after the introduction of automated modes of transport. In this work we adopt the variational approach. The first step towards applying the variational approach will be to build up an utility functional in terms of distribution of commuters (λ). Critical points of this functional will represent the equilibria for the spatial economy. Our study is at the exploratory stage. Consequently we will study the conditions for the existence and uniqueness of the equilibria. (Received September 22, 2018)

1145-49-1476 **David Shoup*** (david.shoup@alvernia.edu). *Optimizing Compositions of Popular Pharmaceutical Drugs.* Preliminary report.

Pharmaceutical companies constantly seek to improve the efficacy of their drugs while subject to various constraints such as friability, size, and overall cost. Because the compositions of many popular drugs are widely promulgated, researchers can use optimization techniques to improve overall drug design and thus will provide the industry with a more efficient and effective product. (Received September 22, 2018)

1145-49-1534 **Christina Knox*** (knox@math.ucr.edu) and **Amir Moradifam**. *Electrical Networks with Prescribed Current.*

In this talk, we will investigate the inverse problem of recovering the conductivities of an electrical network from the knowledge of the magnitude of the current along the edges coupled with either the voltage on the boundary of the network or the current flowing in or out of the network. This problem corresponds to finding the minimizers of a l^1 minimization problem. Additionally, we show that while the conductivities are not determined uniquely the flow of the current is uniquely determined. We will also present a convergent numerical algorithm for solving these problems along with basic numerical simulations. Lastly, we will discuss some applications of this inverse problem. (Received September 23, 2018)

1145-49-1536 **Elvira Zappale*** (ezappale@unisa.it), Dipartimento di Ingegneria Industriale, Università degli Studi di Salerno, via Giovanni Paolo II, 132, 84084 Fisciano (Salerno), Italy. *Relaxation of Nonlocal Energies in the context of structured deformations.* Preliminary report.

An extension of the variational formulation obtained in [1] for free energies dealing with structured deformations (SD) is proposed. SD have been introduced in [2] to give a unified macroscopic description of bodies with microstructures, dislocations, cracks, and voids. The classical model takes into account the fact that a part of the energy which, in the approximating sequences, is carried on the deformation jumps is transferred to the bulk term in the limit. Here, with the aim at incorporating and describing better the nonlinear behaviour of disarrangements in the resulting energy, a nonlocal (averaged) term due to contribution of separation and slips, is added (see [3]). The results have been obtained in collaboration with José Matias (IST LIsbon, Portugal), Marco Morandotti (Politecnico di Torino, Italy), and David Owen (CMU, Pittsburgh (PA)).

[1] R. Choksi and I. Fonseca: Bulk and interfacial energy densities for structured deformations of continua. Arch. Rational Mech. Anal., 138 (1997), 37-103. [2] G. Del Piero and D. R. Owen: Structured deformations of continua. Arch. Rational Mech. Anal. 124, (1993), 99-155. [3] G. Del Piero and D. Owen: Structured

Deformations: Part Two. Quaderni dell'INdAM, Gruppo Nazionale di Fisica Matematica, no. 58 (2000), 1-62. (Received September 23, 2018)

1145-49-1593 **Melissa Meinert*** (mmeinert@math.uni-bielefeld.de). *Sobolev spaces and calculus of variations on fractals.*

In this talk, we will review $p-$energies and $(1,p)-$Sobolev spaces for fractals and metric measure spaces that carry a local Dirichlet form. These Sobolev spaces are then used to generalize some basic results from the calculus of variations, such as the existence of minimizers of convex functionals.

Under certain conditions, we will present regularity results for weak solutions of nonlinear equations and systems that do not need any continuity of coefficients.

This talk is based on joint work with Dorina Koch and Michael Hinz. (Received September 23, 2018)

1145-49-1650 **Nicolas Charon***, Clark Hall, office 317B, 3400 N. Charles Street, Baltimore, MD 21218, and **Hsi-Wei Hsieh** (c76068@gmail.com), AMS Department, Johns Hopkins University, 3400 N Charles Street, Baltimore, MD 21218. *Diffeomorphic registration of discrete varifolds.* Preliminary report.

We propose a new framework and algorithm pipeline to address the problem of diffeomorphic registration of a large class of geometric objects that can be described as discrete distributions of local direction vectors called varifolds. It builds, on the one hand, on the large deformation diffeomorphic metric mapping (LDDMM) model to generate deformation groups and metrics on those groups as well as the idea of representing shapes as oriented varifolds. However, unlike previous approaches in which varifold representations are primarily used as surrogates to define and evaluate fidelity terms, the specificity of this work is to directly express the dynamical system corresponding to deformations of discrete varifolds . We then show that the registration problem can be formulated as a finite-dimensional optimal control problem which we numerically solve through a geodesic shooting strategy. In addition, we introduce and analyze a projection-based approach in order to reduce the size of varifold representations and accelerate the registration pipeline. (Received September 23, 2018)

1145-49-1775 **Pawan K Gupta*** (gupta.pawan@knights.ucf.edu) and **Marianna Pensky** (marianna.pensky@ucf.edu). *Solution of ill-posed linear inverse problems using over-complete dictionaries under non-gaussian noise.*

There has been a great amount of effort to solve ill-posed linear inverse problems under gaussian noise. Moreover, other noise scenarios did not receive an equal amount of attention. In the present paper, we consider solutions of ill-posed linear inverse problems using over-complete dictionaries under the diverse noise scenarios. (Received September 24, 2018)

1145-49-2007 **Babhru Joshi*** (babhru.joshi@rice.edu), **Paul Hand**, **Ali Ahmed** and **Alireza Aghasi**. *A convex program for bilinear inversion of sparse vectors.*

We consider the bilinear inverse problem of recovering two vectors, $\boldsymbol{x} \in \mathbb{R}^L$ and $\boldsymbol{w} \in \mathbb{R}^L$, from their entrywise product. We consider the case where $\boldsymbol{x}$ and $\boldsymbol{w}$ have known signs and are sparse with respect to known dictionaries of size K and N, respectively. Here, K and N may be larger than, smaller than, or equal to L. We introduce ℓ_1-BranchHull, which is a convex program posed in the natural parameter space and does not require an approximate solution or initialization in order to be stated or solved. We study the case where $\boldsymbol{x}$ and $\boldsymbol{w}$ are S_1- and S_2 -sparse with respect to a random dictionary and present a recovery guarantee that only depends on the number of measurements as $L \geq \Omega(S_1 + S_2)\log^2(K+N)$. We also introduce a variant of ℓ_1-BranchHull for the purpose of tolerating noise and outliers and show it can recover piecewise constant behavior from real images. (Received September 24, 2018)

1145-49-2111 **Selim Esedoglu** and **Tiago Salvador*** (saldanha@umich.edu), Department of Mathematics, University of Michigan, 530 Church St., Ann Arbor, MI 48105. *Γ-convergence of threshold dynamics algorithms.*

I will report on recent developments in a class of algorithms, known as threshold dynamics, for computing the motion of interfaces by mean curvature. These algorithms try to generate the desired interfacial motion by alternating two very simple operations: convolution, and thresholding. I will present a simplified version of the threshold dynamics algorithm given in the work of Esedoglu and Otto (2015) for the isotropic multiphase case that does not require the use of retardation functions. I will discuss the stability and convergence of the proposed algorithm, and threshold dynamics in general, which rely heavily on the positivity of the convolution kernel and its Fourier transform. Some counterexamples in which Γ-convergence fails in the very simple isotropic, multiphase case will also be presented. Finally, I will discuss recent results on Γ-convergence of the two phase, anisotropic case for sign changing kernels. Our contribution, which will also be discussed, is enlarging the class of admissible sign changing kernels since it is possible to construct interesting anisotropies not covered by the previous work. Joint work with Selim Esedoglu. (Received September 25, 2018)

1145-49-2201 **Nabin Kumar Sahu*** (nabin6582@gmail.com). *A system of multivariate variational inequalities and the existence of its solutions in Banach spaces.*

In this paper we study a system of multivariate variational inequalities in a uniformly convex smooth Banach space by using the unique semi-inner product structure equipped in it. We consider the following problem: Let X be a uniformly convex smooth Banach space with a unique semi-inner product $[.,.]$. Let K be a nonempty closed convex bounded subset of X. Let A_1,A_2,.....,A_N be $N-$variables monotone demi-continuous mappings from K^N into X. We discuss the existence solution of the following system of multivariate variational inequalities:

$$[A_1(x_1, x_2, ..., x_N),\ y_1 - x_1] \geq 0,\ \forall y_1 \in K$$
$$[A_2(x_1, x_2, ..., x_N),\ y_2 - x_2] \geq 0,\ \forall y_2 \in K$$
$$- - - - - - - - - - - - - - - - - - - -$$
$$- - - - - - - - - - - - - - - - - - - -$$
$$[A_N(x_1, x_2, ..., x_N),\ y_N - x_N] \geq 0,\ \forall y_N \in K$$

We also prove that the solutions set of the above system of multivariate variational inequalities is closed convex in K^N. Moreover we show that if $A_1, A_2, ..., A_N$ are strictly monotone, then the above system has a unique solution. (Received September 25, 2018)

1145-49-2240 **Sabyasachi Pani*** (spani@iitbbs.ac.in), Dr. Sabyasaci Pani, School of Basic Sciences, Indian Institute of Technology Bhubaneswar, Bhubaneswar, Orissa 752050, India. *Some Results on Nonlinear Mixed Variational-like Inequalities.*

In this paper We define generalized weakly relaxed $\eta - \alpha$ pseudomonotonicity and strictly $\eta - \alpha$ quasimonotonicity with respect to a bi-function f. Using KKM technique, we prove some existence results for nonlinear mixed variational-like inequalities with generalized weakly relaxed $\eta - \alpha$ pseudomonotone and strictly $\eta - \alpha$ quasimonotone operators. In addition, some results on Generalized Strongly Nonlinear Mixed Variational-like inequality with respect to weakly relaxed $\eta - \alpha$ monotone mappings in Banach space settings are discussed. (Received September 25, 2018)

1145-49-2283 **Reecha Upadhyay***, rupadhya@svsu.edu, and **Arundhati Bagchi Misra**, abmisra@svsu.edu. *Optimization of Student Loans using Euler-Lagrange Equation.* Preliminary report.

The researchers work on the application of Euler-Lagrange equation on dynamic optimization problems and mainly replicate The Career Decisions of Young Men and The Effect of Parental Transfers and Borrowing Constraints on Educational Attainment published by Keane and Wolpin in 1997 and 2001 respectively. In the papers, Keane and Wolpin solved the optimization problems of student loans using the Bellman principle of optimization and, the researchers plan to do so by applying Euler-Lagrange equation using MATLAB. The Bellman Principle of Optimality by Ioanid Rosu links Euler-Lagrange principle to the Bellman principle and the researcher's work is informed by Rosu's paper. While Wolpin's papers comprised of numerous parameters, the researchers seek to obtain the same solutions with fewer parameters initially. The researchers follow the solution method described in the paper The Solution and Estimation of Discrete Choice Dynamic Programming Models by Simulation and Interpolation: Monte Carlo Evidence by Keane Wolpin in 1994. (Received September 25, 2018)

1145-49-2302 **Samir Chowdhury*** (chowdhury.57@osu.edu) and **Facundo Mémoli** (memoli@math.osu.edu). *Gromov-Wasserstein distances: Fast network comparison via entropy regularized optimal transport.*

When faced with a weighted, directed network represented as a square matrix of real-valued entries (e.g. as produced by some gene regulatory network inference algorithms), further analysis is often performed by first thresholding/symmetrizing the network at some user-specified level. This is wasteful for certain tasks.

For performing retrieval, classification, or clustering on a database of networks, one implicitly needs a ground metric for comparing the networks at all threshold levels. We consider such a metric based on principles of optimal transport. A key feature of this metric is that it accounts for the significance of each node, meaning that it is robust to outliers. We provide a suite of approximate algorithms for computing this metric via entropy regularized optimal transport. These methods involve essentially only matrix-vector products, and can be easily implemented on GPU architectures for scalable, parallelized computation.

We exemplify these tools by applying them to unsupervised clustering tasks on databases of real-world and simulated networks. For the simulations, we define a generative model for random networks based on the stochastic block model that may be of independent interest. (Received September 25, 2018)

1145-49-2466 **Boris Mordukhovich**, **Ebrahim Sarabi** and **Hong Do*** (fq0828@wayne.edu), 641 Prentis St, apt 207, Detroit, MI 48201. *Critical multipliers via second-order generalized differentiation of a subclass of piecewise linear-quadratic functions.* Preliminary report.

It has been well recognized that critical multipliers, the notion of which developed by Izmailov and Solodov for classical Karush-Kuhn-Tucker (KKT) systems, are largely responsible for slow convergence of major primal-dual algorithms of optimization. Recently their notion has been extended to a general framework of constrained optimization including composite optimization, minimax problems, etc. This talk concerns the critical multipliers for variational systems of a major subclass of piecewise linear-quadratic functions. Implementing a comprehensive second-order study of this class, we obtain complete characterizations of critical and noncritical multipliers via the problem data. It is shown that noncriticality is equivalent to a certain calmness property of a perturbed variational system. These results can be applied to study the vanishment of critical multipliers under the fulfilment of the full stability of local minimizers in problems of composite optimization. (Received September 25, 2018)

1145-49-2850 **Michael Barg** and **Amanda J Mangum*** (amangum@niagara.edu). *Examining the Relative Density of Two Lipid Types to Determine if Solutions to a Phase Separation Problem Are Geodesic Disks.*

We analyze numerical solutions to a phase minimization problem on a discretized Cassinian oval. We minimize a Landau-type free energy of a phase function, ϕ, representing the relative density of one of two types of lipids. For segregation problems where the solution consists of two disjoint sets of lipids on a membrane, it has been shown that for certain surfaces, the minority lipids will tend to form a geodesic disk-like shape roughly centered at a point of maximum Gauss curvature on the membrane. We find that for large enough minority patches, the shape may no longer be classified as a geodesic disk. We examine the ϕ value of the nodes that violate the expected geodesic disk shape for various sizes of strongly separated solutions and present an example of a minority patch that does not conform to the expected geodesic disk-like solution. (Received September 25, 2018)

1145-49-2865 **Michael C. Barg*** (mbarg@niagara.edu) and **Amanda J. Mangum**. *Using Numerical Solutions of the Geodesic Equations to Determine Sizes and Shapes of Strongly Separated Lipid Patches in Equilibrium.*

We study a two-phase separation problem on a lipid membrane treated as a surface. By minimizing an appropriate free energy functional subject to a conservation constraint, strongly separated solutions can be obtained for some values of the parameters. Numerically, the solution patch shape and location depends on a number of factors, including the grid size, a diffusion coefficient, a conservation parameter, and the initial phase distribution. For strongly separated numerical solutions, one must make a decision in order to determine the boundary of the patch. In this talk, I will discuss how solutions of the geodesic equations can be used in a decision algorithm to select the radius of an equilibrium patch in addition to providing a way of measuring the deviation of the patch from a comparably-sized geodesic disk. Subsequent patch area computations offer an approach for determining parameter values which lead to solutions that are nearly geodesic disks in the traditional sense. (Received September 25, 2018)

1145-49-2889 **Ugur Abdulla**, 150 W. University Blvd, Mathematical Sciences Department, Melbourne, FL 32901, and **Jonathan Goldfarb***, 150 W. University Blvd, Mathematical Sciences Department, Melbourne, FL 32901. *Optimal Control of One-Phase Free Boundary Problems in Multiple Space Dimensions.*

We consider an inverse one-phase Stefan-type free boundary problem (ISP) for the second order parabolic PDE

$$\Delta u + a \cdot \nabla u + a_0 u - \frac{\partial u}{\partial t} = f \text{ in } \Omega = D_1 \times (0,T) \cup \{(x,t):\ x \in D,\ \eta(x) < t < T,\}$$

A new variational formulation developed in *U. G. Abdulla, Inverse Problems and Imaging, 7, 2(2013), 307–340; 10, 4 (2016), 869-898* is extended to many space variables. We pursue optimal control framework in Besov spaces framework, where free boundary and the density of the sources are control vector components and the cost functional consists of the L_2-norm declination of the traces of the temperature at the final moment and free boundary from available measurements. The existence of the optimal control is proved and the convergence of the sequence of the discrete optimal control problems to continuous optimal control problem is analyzed. (Received September 25, 2018)

1145-49-2920 **Amir Ali Ahmadi*** (a_a_a@princeton.edu), Princeton, NJ 08540, and **Bachir El Khadir** (bkhadir@exchange.princeton.edu), Princeton, NJ 08540. *Time-varying semidefinite optimization.*

We study time-varying semidefinite programs (TV-SDPs), which are semidefinite programs whose data (and solutions) are functions of time. Our focus is on the setting where the data varies polynomially with time. We show that under a strict feasibility assumption, restricting the solutions to also be polynomial functions of time does not change the optimal value of the TV-SDP. Moreover, by using a Positivstellensatz on univariate polynomial matrices, we show that the best polynomial solution of a given degree to a TV-SDP can be found by solving a semidefinite program of tractable size. We also provide a sequence of dual problems which can be cast as SDPs and that give upper bounds on the optimal value of a TV-SDP (in maximization form). We prove that under a boundedness assumption, this sequence of upper bounds converges to the optimal value of the TV-SDP. Under the same assumption, we also show that the optimal value of the TV-SDP is attained. We demonstrate the efficacy of our algorithms on a maximum-flow problem with time-varying edge capacities, a wireless coverage problem with time-varying coverage requirements, and on bi-objective semidefinite optimization where the goal is to approximate the Pareto curve in one shot. Joint work with Bachir El Khadir (Princeton). (Received September 25, 2018)

1145-49-2932 **Tiziana Giorgi**, **Sookyung Joo** and **Lidia Mrad*** (lmrad@math.arizona.edu). *Switching Dynamics in Liquid Crystals.*

One of the important applications of liquid crystal materials is their use in optical and display devices. There are several phases of liquid crystals, some of which promise more efficient and less expensive optical devices than others. A recently discovered phase is made up of bow-shaped molecules, a characteristic that endows them with spontaneous ferroelectricity. Under the effect of an applied electric field, two competing mechanisms of switching can be detected in the tilted structure of these materials. To understand which mechanism emerges under certain physical conditions, one can carry out dynamical analysis starting with a free energy and constructing a gradient flow. The challenge in writing the corresponding weak Euler-Lagrange equations is the orthogonality constraint on the two variables of the model. We illustrate how this challenge can be overcome and explain how the continuous gradient flow can be obtained from the discrete-in-time one. (Received September 25, 2018)

51 ► Geometry

1145-51-138 **Facundo Memoli** and **Osman Berat Okutan*** (okutan.1@osu.edu). *Approximating length spaces with metric graphs of bounded first Betti number.*

A metric graph is a length space which is homeomorphic to a topological graph. It is known that every length space can be Gromov-Hausdorff approximated with metric graphs. In this talk, we investigate how good an approximation can be guaranteed given an upper bound on the first Betti number of approximating graphs. (Received August 08, 2018)

1145-51-159 **Rebekah Chase*** (chas11713599@evangel.edu), **Carl Hammarsten**, **Ryan A Mike** and **Laura J Seaberg**. *Intersections of Shortest Taxicab Paths in the Sierpiński Carpet.* Preliminary report.

In recent work, Berkove and Smith have developed an algorithm to construct shortest taxicab paths in the Sierpiński carpet and some of its higher-dimensional generalizations. We consider an extension of this problem examining minimal area surfaces bound by shortest taxicab paths in higher-dimensional fractals. Such a minimal surface will have zero area if and only if the associated shortest paths have non-empty common intersection. Specifically, we give a set of necessary and sufficient conditions on the relative positions for three points in the carpet which characterize when the pairwise shortest taxicab paths have non-empty triple intersection. Finally, we indicate how our work might generalize to higher dimensions. (Received August 13, 2018)

1145-51-205 **Yizhen Chen*** (johnson.chen@prismsus.org). *The behavior of iterations of compositions of inversions preserving a circle.*

Let $\mathcal{C}$ be a circle, and $\mathcal{E}$ be a conic. Let $f_{\mathcal{E}} : \mathcal{C} \to \mathcal{C}$ be a homeomorphism such that line $xf(x)$ is always tangent to $\mathcal{E}$ for $x \in \mathcal{C}$. Poncelet's porism states that if f^n has a fixed point, then f^n is the identity. We replace $\mathcal{E}$ by a polygon, and study the behavior of a composition of inversions $f_A : \mathcal{C} \to \mathcal{C}$ where A is a point and line $xf_A(x)$ always passes through A for $x \in \mathcal{C}$. We found two different ways to convert a composition f of several inversions into a composition of two inversions. When f has no fixed points, we give a simple condition that f^n has a fixed point ($n > 1$), which is also equivalent to that f^n is the identity. When f has fixed points, one of the fixed points P has the property that $\lim_{n\to\infty} f^n(x) = P$ for every $x \in \mathcal{C}$ except the other fixed point. We found a simple criterion to determine which fixed point has this property for a composition f of m inversions f_{A_k}. For $f = f_C \circ f_B \circ f_A$ we have another simple criterion when all of A, B, and C are inside $\mathcal{C}$. Lastly, there is a conic $\mathcal{E}(A, B)$ such that $f_C \circ f_B \circ f_A$ has no fixed points if and only if C is inside it. We found several interesting properties of $\mathcal{E}(A, B)$. (Received August 19, 2018)

1145-51-232 **Marshall A Whittlesey*** (mwhittle@csusm.edu), Department of Mathematics, California State University San Marcos, San Marcos, CA 92096. *Using quaternions to prove theorems in spherical geometry.*

The quaternions have long been known to be useful for describing rotations and reflections in 3 dimensional Euclidean space. We show how to use the quaternions as a tool to prove theorems in spherical geometry. (Received August 23, 2018)

1145-51-259 **Michal Adamaszek**, **Henry Adams*** (henry.adams@colostate.edu) and **Florian Frick**. *Metric reconstruction via optimal transport.*

Given a sample of points X in a metric space M and a scale $r > 0$, the Vietoris–Rips simplicial complex $\mathrm{VR}(X; r)$ is a standard construction to attempt to recover M from X up to homotopy type. A deficiency of this approach is that the Vietoris–Rips complex $\mathrm{VR}(X; r)$ is not metrizable if it is not locally finite, and thus cannot recover metric information about the metric space M. Even worse, the inclusion map $X \hookrightarrow \mathrm{VR}(X; r)$ need not always be continuous! We attempt to remedy these shortcomings by defining a metric space thickening of X, which we call the *Vietoris–Rips thickening* $\mathrm{VR}^m(X; r)$, via the theory of optimal transport. When M is a complete Riemannian manifold, we show that the the Vietoris–Rips thickening satisfies Hausmann's theorem ($\mathrm{VR}^m(M; r) \simeq M$ for r sufficiently small) with a simpler proof: homotopy equivalence $\mathrm{VR}^m(M; r) \to M$ is canonically defined as a center of mass map, and its homotopy inverse is the (now continuous) inclusion map $M \hookrightarrow \mathrm{VR}^m(M; r)$. Furthermore, we describe the homotopy type of the Vietoris–Rips thickening of the n-sphere at the first positive scale parameter r where the homotopy type changes. (Received September 25, 2018)

1145-51-305 **Elene Karangozishvili*** (karangoe@lafayette.edu). *Investigating shortest paths in generalizations of the Cantor Set.* Preliminary report.

The Sierpiński carpet and Menger sponge are well-studied generalizations of the Cantor set to higher dimensions, but they are only two of a doubly-infinite family of fractals that naturally generalize the Cantor set. Most of these higher-dimensional fractals are connected sets, so we study each with a goal of better understanding different types of paths that join two arbitrary points and stay in the fractal. In particular we determine the shortest taxicab distance between any two points in the fractal and construct an explicit path which realizes it. This allows us to compare the taxicab metric in the fractal with the standard Euclidean metric. (Received August 29, 2018)

1145-51-615 **Will Traves*** (traves@usna.edu). *Binomial proofs of fundamental results in geometry.*

T.S. Michael and I often talked about problems in elementary geometry. He knew a lot and I had much to learn. In this talk I'll present some algebraic proofs of elementary results in Euclidean geometry. The surprise is that many of these results admit an interpretation in projective geometry – even though they involve lengths and distances – a development that I think T.S. would have liked. (Received September 11, 2018)

1145-51-843 **Ajeet S Gary*** (agary@terpmail.umd.edu). *Dynamics on the Character Variety of the Fricke Spaces of Surfaces on Two Generators.*

We are interested in the Fricke spaces of certain orientable surfaces with fundamental group rank two. They can be expressed using character varieties, representations as triples that comprise a certain family of cubic surfaces. We investigate the dynamics of the mapping class group action on the Fricke space as polynomial automorphisms of the surface, specifically ergodicity and a particularly interesting wandering domain. (Received September 16, 2018)

1145-51-1459 **Florian Frick*** (frick@cmu.edu). *Splitting Loops: Variants of the Square Peg Problem.*

In 1911 Toeplitz conjectured that any simple closed curve in the plane inscribes a square. A less famous variant of this problem is Hadwiger's 1971 conjecture that any simple closed curve in 3-space inscribes a parallelogram. Both conjectures have been resolved under some smoothness condition on the curve. We resolve Hadwiger's conjecture in full generality by relating it to partition results for real-valued functions.

This is joint work with Jai Aslam, Shujian Chen, Sam Saloff-Coste, Linus Setiabrata, and Hugh Thomas. (Received September 22, 2018)

1145-51-1701 **Xinghua Gao*** (xgao29@illinois.edu). *Orderability of Dehn Fillings.*
Boyer, Gordon, and Watson conjectured that an irreducible rational homology 3-sphere is not an L-space if and only if its fundamental group is left-orderable. In a recent work, Culler and Dunfield showed how to encode information of elliptic $\widetilde{PSL_2\mathbb{R}}$ representations of a one-cusped 3 manifold in the translation extension locus and use it to construct orders on intervals of Dehn fillings. In this talk, I will show how to construct the holonomy extension locus from hyperbolic $\widetilde{PSL_2\mathbb{R}}$ representations and use it to construct orders on some other Dehn fillings. (Received September 24, 2018)

1145-51-1812 **David M Bronicki*** (bronickd@mail.gvsu.edu). *Exploring the foundations of Symplectic Geometry.*
In this talk, we explore symplectic geometry, a relatively new alternative to other geometries. We will give a description of a proof of the nonsqueezing theorem, a foundational theorem in symplectic geometry. To do so, we will explore basic properties of symplectic spaces and describe the function of J-holomorphic curves. (Received September 24, 2018)

1145-51-1862 **Alice H Mark*** (alice.mark@rutgers.edu). *Presentations for cusped arithmetic hyperbolic lattices.*
I will describe a method by which we obtained presentations for certain complex and quaternion hyperbolic lattices. We applied a classical theorem of Macbeath to invariant horoball covers of the complex and quaternion hyperbolic planes. In the talk, I will use the well-understood and easy-to-draw example of $PSL_2\mathbb{Z}$ acting on the real hyperbolic plane to make sense, by analogy, of the higher-dimensional picture that you get for certain lattices in $PU(2,1)$ and $PSp(2,1)$. This is joint work with Julien Paupert. (Received September 24, 2018)

1145-51-1941 **Andrea Heald***, amheald@uw.edu, and **Rebekah Palmer**. *Finding nonsimple geodesics in Hyperbolic 3-manifolds.* Preliminary report.
Let Γ be a Kleinian group such that $M = \mathbb{H}^3/Gamma$ is a hyperbolic 3-manifold with invariant quaternion algebra $A\Gamma$. A theorem of Chinburg and Reid states that if M has a non simple geodesic then $A\Gamma \cong (\frac{\alpha,\beta}{K\Gamma})$ where $\beta \in K\Gamma \cap \mathbb{R}$. In this talk we will prove the converse when Γ is arithmetic. (Received September 24, 2018)

1145-51-1974 **Elise A. Weir*** (eweir@utk.edu). *Zariski dense surface subgroups in $SL(5,Z)$ and the restricted Hitchin component for triangle groups.*
A hyperbolic triangle group $T(p,q,r)$ is the group of orientation-preserving isometries of a tiling of the hyperbolic plane H^2 by geodesic triangles with angles π/p, π/q, and π/r. The quotient of H^2 by this group action produces a spherical orbifold with cone points of orders p, q, and r. Our setting consists of representations of triangle groups in the Hitchin component, a component of the representation variety where representations are always discrete and faithful. The Hitchin component serves as a higher-dimensional generalization of Teichmüller space, and relates to deformation spaces of hyperbolic structures on orbifolds.

In particular, we produce a formula for the dimension of the Hitchin component for representations of each hyperbolic triangle group $T(p,q,r)$ to either $Sp(2m)$ or $SO(m,m+1)$, and for any $m \geq 1$. To better understand the benefit of considering a symplectic or special orthogonal codomain (as opposed to special linear), we will discuss connections to the pursuit of finding infinite families of representations $\tau_k : T(3,3,4) \to SL(5,Z)$ with images that are Zariski dense in $SL(5,R)$ and which can be used to generate infinitely many pairwise non-conjugate surface subgroups in $SL(5,Z)$. (Received September 24, 2018)

1145-51-1983 **Christian Millichap** (christian.millichap@furman.edu), **Bakul Sathaye*** (sathaybv@wfu.edu) and **Salman Siddiqi** (siddiqis@umich.edu). *Does the primitive length spectrum fully characterize arithmetic surfaces?* Preliminary report.
Given a smooth Riemannian manifold (M,g), the primitive length spectrum is the collection of all lengths of primitive closed geodesics counted with multiplicity. Recently, Lafont and McReynolds showed that the primitive length spectrum of arithmetic hyperbolic 2- and 3-manifolds contain arbitrarily long arithmetic progressions. Further, they conjecture that this is in fact a characterization of arithmeticity of M. In this talk, we discuss to what extent this property of arithmetic progressions characterizes arithmeticity in the case of closed hyperbolic surfaces. The goal is to show that there are only finitely many hyperbolic structures on a surface for which this property holds and I will discuss progress made towards this goal. This is joint work with Christian Millichap and Salman Siddiqi. (Received September 24, 2018)

1145-51-1997 **Derek Smith*** (smithder@lafayette.edu), Math Department, Lafayette College, Easton, PA 18042, and **Ethan Berkove** (berkovee@lafayette.edu), Math Department, Lafayette College, Easton, PA 18042. *Short Paths in the Sierpiński Carpet and Menger Sponge.*

The two-dimensional Sierpiński carpet S^2 and three-dimensional Menger sponge S^3 are two fractals that have been studied from many points of view. In this talk we address questions related to moving from one point to another within these two fractals and also within members of a family $\{S^n\}$ of higher-dimensional generalizations. Inspired by Cristea's study of path distances in the Sierpiński carpet, we determine the shortest taxicab distance $d_T(s, f)$ between any two points $s, f \in S^n$, and we study its relationship to the Euclidean distance between these points. As an application, we then determine the diameter of the Sierpiński carpet. (Received September 24, 2018)

52 ► Convex and discrete geometry

1145-52-527 **Emily Barranca*** (ebarran1@swarthmore.edu), 14 Crystal Ln, Delmar, NY 12054, and **Clara Buck** and **Lauren Hartmann**. *Special Sets of Vertices in Paley Graphs.* Preliminary report.

Strongly regular graphs have three distinct eigenvalues that give bounds on the average degree of an induced subgraph. Tight sets are sets of vertices that induce a subgraph with as many or as few edges as possible relative to the parameters and eigenvalues of the graph. A particular family of examples of strongly regular graphs is the Paley Graph P(q), which has the finite field of size q $\equiv$ 1 mod 4 as its vertex set, where two vertices are adjacent when their difference is a nonzero perfect square in the considered field.

Motivated by a 1984 result by Blockhuis, we consider the connection between Paley graphs $P(q^2)$ and finite affine planes. In this model, each line of the affine plane represents either a clique or an independent set in the graph. Selecting only those lines which correspond to cliques, we construct a partial affine plane in which two vertices are adjacent in the graph if and only if they are on the same line in the affine plane. This allows us to examine tight sets of $P(q^2)$ in a geometric context. We work towards classifying the tight sets which are not the disjoint union of smaller tight sets. (Received September 08, 2018)

1145-52-620 **Kristin DeSplinter**, **Satyan Devadoss*** (devadoss@sandiego.edu), **Jordan Readyhough** and **Bryce Wimberly**. *Cube unfoldings never overlap.*

The open problem of constructing a net (a connected edge-unfolding without overlap) for every convex polyhedron can be traced back 500 years to Albrecht Dürer. We explore nets for cubes by developing a visual algorithm. This is used to show that any unfolding of an n-cube is without overlap, with elegant relationships to integer partitions and chord diagrams. (Received September 11, 2018)

1145-52-1117 **Kyle Meyer** and **Ivan Soprunov*** (i.soprunov@csuohio.edu), Cleveland, OH 44115, and **Jenya Soprunova**. *On the maximum number of $\mathbb{F}_q$-zeroes of polynomials with a given Newton polytope.* Preliminary report.

Let $\mathbb{F}_q$ be a finite field. We are interested in estimating the largest number of $\mathbb{F}_q$-zeroes a polynomial f with given Newton polytope may have. For large enough q, we provide such an estimate in the case of 3-variate polynomials in terms of some geometric invariants of the polytope. Our approach is based on analysing collections of 3-dimensional lattice polytopes appearing as the Newton polytopes of absolutely irreducible factors of f. The result has an application to minimum distance estimation for 3-dimensional toric codes. (Received September 19, 2018)

1145-52-1608 **Anthea Monod*** (am4691@cumc.columbia.edu). *Tropical Statistics & Geometry of Phylogenetic Tree Space.* Preliminary report.

Phylogenetic trees are the fundamental representation of evolutionary processes, and are particularly essential in modeling many important and diverse biological phenomena, such as speciation, the spread of pathogens, and the evolution of cancer. Trees may be compared with one another in a moduli space, whose geometry is determined by a metric. The classical representation of this space is the BHV tree space, endowed with the geodesic metric. In this talk, I will discuss an alternative distance function, known as the tropical metric. I will present a comparison of geometric and topological properties of tree spaces under the two metrics that are particularly relevant for statistical analysis. I will make the case that the tropical moduli space of phylogenetic trees is a natural setting for probability and statistics, because it allows for a tropical interpretation of linear algebra, which is the basis of classical statistical analysis. This is joint work with Bo Lin and Ruriko Yoshida. (Received September 23, 2018)

1145-52-1638 **Thomas C. Hull*** (thull@wne.edu), Western New England University, 1215 Wilbraham Road, Springfield, MA, MA 01119. *Higher dimensional flat origami and non-crossing conditions.*

In flat origami theory, an *isometric folding* is map $f : S \to \mathbb{R}^2$ whose domain S is a bounded region of the plane and where f is a continuous piecewise isometry. The set $\Sigma(f) \subset S$ of all points where f is non-differentiable is called the *crease pattern* of f. One can prove that $\Sigma(S)$ will be a planar graph. Two basic theorems of flat origami are *Maekawa's Theorem* (a combinatorial theorem on the parity of creases around a vertex in $\Sigma(f)$) and *Kawasaki's Theorem* (a necessary and sufficient condition for a vertex in $\Sigma(f)$ to, locally, be an isometric folding). However, it turns out that isometric foldings in arbitrary dimension were studied by Robertson (1977) and Lawrence & Spingarn (1989). Both proved a generalized Kawasaki's Theorem, but neither considered Maekawa nor the sufficient direction of Kawasaki. In this talk we prove a version of Maekawa in arbitrary dimension, which requires us to develop a partial ordering (which we call a *layer ordering*) of regions in the compliment of $\Sigma(f)$. This in turn allows us to define what it means for n-dimensional paper to *self-intersect* (similar to self-intersection in 2D paper) and thus establish a full version of Kawasaki in arbitrary dimension. (Received September 23, 2018)

1145-52-1792 **Raman Sanyal** and **Josephine Yu*** (jyu@math.gatech.edu), School of Mathematics, Georgia Tech, 686 Cherry St, Skiles Building, Atlanta, GA 30332. *Deformation dimension of zonotopes.* Preliminary report.

Given a polytope, we consider *deformations* obtained by moving the facets in parallel directions while preserving the edges. The space of such deformations is a polyhedral cone, and its dimension, after quotienting out translations, is called the **deformation dimension** of the polytope. In general, the deformation dimension depends not only on the face poset but also on the geometric realization of the polytope. In this talk we will explore the question of whether the deformation dimension of a zonotope is a combinatorial invariant. We give a formula for the deformation dimension when the matroid of the dual hyperplane arrangement of the zonotope is a graphical matroid. We also give some decomposition results in terms of matroids. (Received September 24, 2018)

1145-52-1957 **Ali Mohajer*** (mohajer@math.uic.edu), 1835 Soniat St, New Orleans, LA 70115. *A new upper density bound on binary packings of disks of radius 0.7 and 1 in the plane.*

In 2003, sharp upper density bounds were established by Aladar Heppes for two-radius packings which admit arrangements wherein each disk is tangent to a ring of disks, each of which is tangent to its two cyclic neighbors. In this talk we will develop methods for establishing upper density bounds for saturated two-radius packings of disks when no such regularity exists, and discuss recent progress in establishing a bound sharper than the best one known for a specific ratio of radii. (Received September 24, 2018)

1145-52-2025 **Francis Edward Su*** (su@math.hmc.edu), Department of Mathematics, Harvey Mudd College, 301 Platt Blvd, Claremont, CA 91106, and **Frédéric Meunier** (frederic.meunier@enpc.fr), Université Paris-Est, CERMICS (ENPC), 6-8 avenue Blaise Pascal, 77455 Marne-la-Vallée, France. *Multilabeled versions of Sperner's and Fan's lemmas and applications.*

We propose a general technique related to the polytopal Sperner lemma for proving old and new multilabeled versions of Sperner's lemma. A notable application of this technique yields a cake-cutting theorem where the number of players and the number of pieces can be independently chosen. We also prove multilabeled versions of Fan's lemma, a combinatorial analogue of the Borsuk-Ulam theorem, and exhibit applications to fair division and graph coloring. (Received September 24, 2018)

1145-52-2313 **Dustin G. Mixon*** (mixon.23@osu.edu). *SqueezeFit: Label-aware dimensionality reduction.*

Given labeled points in a high-dimensional vector space, we seek a low-dimensional subspace such that projecting onto this subspace maintains some prescribed distance between points of differing labels. Intended applications include k-nearest neighbors and compressive classification. This talk will introduce a semidefinite relaxation of this problem, along with various performance guarantees. (Joint work with Culver McWhirter (OSU) and Soledad Villar (NYU).) (Received September 25, 2018)

1145-52-2661 **Kyle Leland Chapman*** (kyle.chapman.topology@gmail.com), Athens, GA 30605. *A Division of the Space of Knots, 3D Equilateral Polygons, into Isometric Simplexes.*

There is a nice geometric space, together with a toric-symplectic structure, which acts as a coordinate system for equilateral polygons. This geometric space provides a nice way of sampling, as well as rigorous analysis of certain properties of knots. I show a subdivision of this convex polytope into isometric simplexes, as well as a way of interpreting some of the known results, and generating geometric knots in amortized O(n) time. (Received September 25, 2018)

53 ► Differential geometry

1145-53-77 **Justin Sawon*** (sawon@email.unc.edu), Department of Mathematics, University of North Carolina, Chapel Hill, NC 27599-3250. *Generalized twistor spaces of quaternionic manifolds.* Preliminary report.

Quaternionic manifolds are equipped with families of complex structures (in some cases, local and/or almost complex structures). The twistor construction is a convenient way of packaging these different complex structures into a single complex manifold, known as the twistor space. Quaternionic manifolds also admit large families of generalized complex structures, in the sense of Hitchin, and one would like to package these all in a single generalized complex manifold. Together with my student Rebecca Glover, we constructed such generalized twistor spaces for hyperkahler manifolds. In this talk, we describe this construction and its extension to another class of quaternionic manifolds: quaternion-Kahler manifolds. (Received July 22, 2018)

1145-53-116 **Ryad Ghanam*** (raghanam@vcu.edu), Virginia Commonwealth University in Qatar, Doha, Qatar, and **Gerard Thompson**, University of Toledo, Toledo, OH. *Symmetries of the Eikonal equation.*

In this presentation we consider the n-dimensional Eikonal equation. We show that the infinitesimal algebra of Lie symmetries of the Eikonal equation is isomorphic to o(n + 1 , 2) when there are n independent variables. We also give an explicit basis that is aligned with the standard basis coming from the standard matrix representation of o(n + 1 , 2) thereby making it possible to read off inequivalent one-dimensional symmetry vector fields. The symmetries are used to construct various solutions of the Eikonal equation. (Received August 02, 2018)

1145-53-117 **Hemangi M Shah*** (hemangimshah@hri.res.in), Chhatnag Road, Jhunsi, Allahabad, UP 211019, India, and **Akhil S Ranjan**. *Harmonic manifolds with minimal horospheres.*

For a non-compact harmonic manifold M, we show that the harmonic spaces having minimal horospheres do admit polynomial volume growth. Further, we show that volume density function of M has polynomial growth, then, M is flat. This partially answers a question of Szabo namely, which density functions determine the metric of a harmonic manifold. (Received August 03, 2018)

1145-53-618 **Thomas Andrew Bell*** (thomas.bell@svu.edu), 2505 Holly Avenue, Buena Vista, VA 24416. *Uniqueness of Conformal Ricci Flow using Energy Methods.*

We analyze an energy functional associated to Conformal Ricci Flow along closed manifolds with constant negative scalar curvature. Given initial conditions we use this functional to demonstrate the uniqueness of both the metric and the pressure function along Conformal Ricci Flow. (Received September 11, 2018)

1145-53-1185 **Ivan Contreras*** (icontreraspalacios@amherst.edu) and **Rui Fernandes**. *The Hurewicz theorem for Lie algebroids and Lie groupoids.*

Lie algebroids are natural objects in differential geometry and they serve as a 'vector-bundle' version of Lie algebras. In this talk we study the existence of an abelian integration of the abelianization of Lie algebroids and how this extends the classical Hurewicz theorem. (Received September 19, 2018)

1145-53-1384 **Laura P. Schaposnik*** (schapos@uic.edu), 851 S. Morgan St., Office 509, Chicago, IL 60607, and **Steve Bradlow**, **Lucas Branco** and **Sebastian Schulz**. *Geometric correspondances between singular fibres of the Hitchin fibration.* Preliminary report.

Higgs bundles are pairs of holomorphic vector bundles and holomorphic 1-forms taking values in the endomorphisms of the bundle, and their moduli spaces carry a natural hyperkahler structure, through which one can study Lagrangian subspaces (A-branes) or holomorphic subspaces (B-branes). Notably, these A and B-branes have gained significant attention both within mathematics and string theory. In this talk we shall consider novel correspondences between branes lying completely within the singular fibres of the Hitchin fibration, which can be understood through group isomorphisms. The talk is based on work in progress with Steve Bradlow and Lucas Branco, and with Sebastian Schulz. (Received September 21, 2018)

1145-53-1649 **Edward Burkard*** (edwardburkard@rmc.edu), Randolph-Macon College, Department of Mathematics, 204 Henry Street, Ashland, 23005. *On the Fundamental Group of Symplectic Embeddings of 4-dimensional Ellipsoids.*

We show that the space of symplectic embeddings of an ellipsoid $E(1,x)$ into an infinite cylinder $Z(c)$ has two non-homotopic loops, given by rotations of the ellipsoid $E(1,x)$ in the z_1 and z_2-planes, provided $c < \min\{2,x\}$ for $1 \leq x \leq 4$, thereby showing that the fundamental group of this embedding space is non-trivial. We also give a constructive proof to show that these two loops are homotopic if $c \geq c_{MS}(x)$ for all $x \geq 1$, where $c_{MS}(x)$ is the McDuff-Schlenk embedding capacity. We contrast this with a result which gives conditions on the size of an ellipsoid $E(a,b)$ and a ball $B^4(R)$ such that the fundamental group of the space of unparametrized embeddings of $E(a,b)$ into $\mathring{B}^4(r) \setminus E(a,b)$ is nontrivial. (Received September 23, 2018)

1145-53-1720 **Richard Alan Wentworth*** (raw@umd.edu), Department of Mathematics, University of Maryland, College Park, MD 20742. *Harmonic maps, pleated surfaces, and the asymptotic structure of the SL(2,C) character variety of a surface group.* Preliminary report.

The topic of this report is the asymptotic structure of the SL(2,C) character variety of a closed surface group. Recent work has given a precise description of the large scale behavior of solutions to the Hitchin equations in terms of certain limiting configurations. I will explain how these correspond in a precise way, via harmonic maps, to Bonahon's parametrization of pleated surfaces in hyperbolic 3-space by transverse and bending cocycles for a geodesic lamination. The result gives a geometric interpretation of the asymptotics of Hitchin's integrable system. This is joint work with Andreas Ott, Jan Swoboda, and Michael Wolf. (Received September 24, 2018)

1145-53-1779 **Tom Needham*** (needham.71@osu.edu). *Knot types of generalized Kirchhoff rods.*

Kirchhoff energy is a classical functional on the space of arclength-parameterized framed curves whose critical points approximate configurations of springy elastic rods. We introduce a generalized functional on the space of framed curves of arbitrary parameterization modeling rods with axial stretch or cross-sectional inflation. The periodic critical points of this generalized functional have interesting topological features. For example, the critical sets contain one-parameter families of framed torus knots, mirroring a result of Ivey and Singer for classical Kirchhoff energy. In contrast to the classical theory, the generalized functional has knotted critical points which are not torus knots. We will describe connections with fluid dynamics via the symplectic geometry of framed loop space. (Received September 24, 2018)

1145-53-1783 **Nishanth Gudapati*** (nishanth.gudapati@cmsa.fas.harvard.edu) and **Marcus Werner** (werner.marcuschristian.6e@kyoto-u.ac.jp). *Gravitational Lensing in Stationary Spacetimes: A Finsler Geometry Approach.*

A goal of the mathematical studies of gravitational lensing is to establish a relation between observables using geometric and topological information of the optical metric. In the work of Gibbons-Werner (2008), such a relation is established between the deflection angle of observation and the Gauss curvature of the optical metric of a static spacetime. In view of the fact that the corresponding optical geometry of static spacetimes is Riemannian, the Gauss-Bonnet theorem was used in a fundamental way. In contrast with static spacetimes, the optical metric for stationary spacetimes is of Randers-Finsler type. In this talk we shall discuss some results on Finsler geometry approach for stationary spacetimes. Joint with Marcus Werner (Kyoto University). (Received September 24, 2018)

1145-53-1992 **Jeffrey S Meyer*** (jeffrey.meyer@csusb.edu), Jack Brown Hall, Room 370, 5500 University Parkway, San Bernardino, CA 92407, and **Sara Lapan** and **Benjamin Linowitz**. *Systole Growth Up Congruence Covers.*

The systole of a closed hyperbolic manifold is the minimal length of a nontrivial closed geodesic. The systole of such a manifold says something deep about how symmetric, and conversely how pinched, the manifold is. Question: How does the systole grow up a tower of covers? For an arithmetic hyperbolic manifold and its covers, the systole can be analyzed using number theoretic techniques. In this talk, I will outline the history of the problem, the relevant connections between hyperbolic geometry and number theory, and then discuss recent joint work with Benjamin Linowitz and Sara Lapan in which we show that for all arithmetic hyperbolic manifolds, the systole growth up a p-congruence tower is at least logarithmic in volume. This result adds to the literature which suggests that congruence covers are particularly symmetric. In particular, heuristically, this result can be understood to be dual to the result that the Cheeger constant up a p-congruence tower is uniformly bounded from below. (Received September 24, 2018)

1145-53-2052 **Joseph Ansel Hoisington*** (jhoisington@smith.edu), Clark Science Center, Smith College, 44 College Lane, Northampton, MA 01063. *On the Total Curvature and Betti Numbers of Complex Projective Manifolds.*

We will show that the sum of the Betti numbers of a complex projective manifold can be bounded above in terms of its total curvature, and we will characterize the complex projective manifolds whose total curvature is minimal. These results extend the classical theorems of Chern and Lashof to complex projective space. (Received September 24, 2018)

1145-53-2324 **Matthew A Morena*** (matthew.morena@cnu.edu). *Predictability Heat Maps of Chaotic Attractors.*

We present a new method for identifying the regions on a chaotic attractor that are locally more stable and hence potentially more predictable than other regions. To do this, we construct a local reference frame at each point along a fiducial trajectory that takes into account the local separation rates of nearby trajectories. Thus, in each neighborhood of a chaotic attractor, we construct an independent coordinate system in which one axis is aligned with the local flow direction and each remaining axis aligns with the remaining dynamical directions. This moving reference frame evolves along a given trajectory, but is independent in the sense that its axes are determined by the attractor's local dynamical geometry and not by parametric properties of the trajectory itself. The novelty of our technique lies in its ability to consider the local dynamics of chaotic systems, while being robust to both noise and to any nonlinearities in the governing equations. All of this allows for a predictability heat maps of entire attractors to be generated, where "hot" regions correspond to relatively high separation rates, and hence to lower predictability, and conversely for the "cold" regions and lower separation rates. (Received September 25, 2018)

1145-53-2423 **Zheting Dong*** (dongzh@oregonstate.edu), Corvallis, OR 97330. *Symmetry rank of non-negatively curved manifolds.*

The group of isometries G of a compact Riemannian manifold M is a compact Lie group. The symmetry rank of M is defined as the rank of G. For a manifold with positive sectional curvature, we know that the symmetry rank is roughly half the dimension of M by results of Grove and Searle. For the case of a closed, simply-connected, non-negatively curved manifold, it is conjectured that the symmetry rank is roughly two-thirds the dimension of the manifold. In this talk we will discuss recent work on closed, simply-connected, non-negatively curved manifolds that admit an almost isotropy-maximal torus action.

This is joint work with Christine Escher and Catherine Searle. (Received September 25, 2018)

1145-53-2521 **Lauren N Crider*** (lcrider@asu.edu). *Stochastic filtering on the grassmannian.* Preliminary report.

The problem of estimating a K-dimensional subspace of an N-dimensional vector space from $M > K$ noisy measurement vectors arises in numerous multi-sensor remote sensing applications, including multistatic radar and electronic surveillance. This work regards developed subspace estimators (in any context) as elements of the Grassmannian $G(K,N)$. This work further assumes the subspace of interest evolves on $G(K,N)$ in time according to a discrete-time dynamical system, i.e., the subspace at time $t+1$ is obtained from the subspace at time t by action of an element of $\mathrm{SO}(N)$ that is comprised of a fixed, known element and a perturbation element that is distributed in a small neighborhood of the identity. At each time, an estimate of the subspace is formed from M noisy measurement vectors observed at that time. A stochastic filter that combines the estimate from data collected at time t and estimates from times $t-1,\ t-2,\ldots,0$ is proposed. The performance of this proposed filter is examined as a function of the measurement noise and the noise in the system dynamics. It is shown to provide substantially better estimation accuracy at time $t > 0$ than an estimator that uses only data collected at time t. (Received September 25, 2018)

1145-53-2563 **Gunay Dogan*** (gunay.dogan@nist.gov), National Institute of Standards & Technology, 100 Bureau Dr. Stop 8910, Gaithersburg, MD 20899-8910, and **Javier Bernal** and **Charles R Hagwood**. *An Optimization Algorithm for Elastic Shape Distances between 2d Object Boundaries.*

For many problems in science and engineering, one needs to quantitatively compare shapes of objects in images, e.g., anatomical structures in medical images, detected objects in images of natural scenes. One might have large databases of such shapes, and may want to cluster, classify or compare such elements. To be able to perform such analyses, one needs the notion of shape distance quantifying dissimilarity of such entities. In this work, we focus on the elastic shape distance of Srivastava et al. [PAMI, 2011] for closed planar curves. This provides a flexible and intuitive geodesic distance measure between curve shapes in an appropriate shape space, invariant to translation, scaling, rotation and reparametrization. Computing this distance, however, is computationally expensive. The original algorithm proposed by Srivastava et al. using dynamic programming runs in cubic time with respect to the number of nodes per curve. In this work, we propose a new fast hybrid iterative algorithm to compute the elastic shape distance between shapes of closed planar curves. The asymptotic time complexity of our iterative algorithm is O(N log(N)) per iteration. However, in our experiments, we have observed almost a linear trend in the total running times depending on the type of curve data. (Received September 25, 2018)

1145-53-2939 **Jonathan Epstein*** (jepstein@ou.edu). *Polynomial Entropy and the Heisenberg Group.* Preliminary report.

Polynomial entropy is a numerical invariant that was introduced to study completely integrable Hamiltonian systems. Subsequently it was shown that polynomial entropy distinguishes the geodesic flows of flat metrics among the geodesic flows of all Riemannian metrics on a torus. In this vein, we present some results on the polynomial entropy of left-invariant Riemannian metrics on the Heisenberg group. (Received September 25, 2018)

54 ► General topology

1145-54-215 **Soumyadip Acharyya*** (acharyys@erau.edu), **Sudip Kumar Acharyya**, **Sagarmoy Bag** and **Joshua Sack**. *Topologies on the Rings of Measurable functions.*

Let $(X, \mathcal{A})$ stand for a nonempty set X equipped with a σ-algebra $\mathcal{A}$ over X. The set of all real-valued $\mathcal{A}$-measurable functions on X forms a commutative lattice ordered ring with unity if the relevant operations are defined pointwise. My talk will focus on the so-called m-topology on this ring $\mathcal{M}(X, \mathcal{A})$ and its measure-theoretic generalization. Important topological properties including first countability and connectedness will be discussed. (Received August 20, 2018)

1145-54-369 **Hannah Schwartz*** (hrschwartz@brynmawr.edu). *Using 2-torsion to obstruct topological isotopy.*

Two knots in S^3 are ambiently isotopic if and only if there is an orientation preserving automorphism of S^3 carrying one knot to the other. In this talk, we will examine a family of smooth 4-manifolds in which the analogue of this fact does *not* hold, i.e. each manifold contains a pair of smoothly embedded, homotopic 2-spheres that are related by a diffeomorphism, but not smooothly isotopic. In particular, the presence of 2-torsion in the fundamental groups of these 4-manifolds can be used to obstruct even a topological isotopy between the 2-spheres; this shows that Gabai's recent "4D Lightbulb Theorem" does not hold without the 2-torsion hypothesis. (Received September 04, 2018)

1145-54-640 **Eylem Zeliha Yildiz*** (eylemzeliha@gmail.com), 619 Red Cedar Rd, Dept of Math C515 Wells Hall, Michigan State University, East Lansing, MI 48824. *Knot concordance in 3-manifolds.*

I will discuss PL and smooth knot concordances in 3-manifolds. In particular I will show that all knots in the free homotopy class of $S^1 \times pt$ in $S^1 \times S^2$ are concordant to each other. I will also discuss an application of these concordances to constructing exotic 4-manifolds. (Received September 12, 2018)

1145-54-759 **Joan E Hart***, University of Wisconsin Oshkosh, Mathematics Department, 800 Algoma Boulevard, Oshkosh, WI 54901-8631, and **Kenneth Kunen**. *Hereditarily Good Properties.*

We consider regular Hausdorff spaces that are Hereditarily Good (HG). The HG property is a natural strengthening of both Hereditarily Separable (HS) and Hereditarily Lindelöf (HL). A space X has the property HG iff X has no weakly separated ω_1-sequences iff for all assignments $\mathcal{U} = \langle (x_\alpha, U_\alpha) : \alpha < \omega_1 \rangle$, where each $x_\alpha \in U_\alpha$ and each U_α is open, $\exists \alpha \neq \beta \; [x_\beta \in U_\alpha \;\&\; x_\alpha \in U_\beta]$. Then, as for HS and HL, (see, for example, the S and L surveys by Rudin or Roitman) a space X is strongly HG (stHG) if each finite power X^n is HG. Replacing the pair α, β by $\aleph_1$ elements of X strengthens stHG to super HG (suHG); that is, a space X is suHG iff $\forall \mathcal{U} \; \exists I \in [\omega_1]^{\aleph_1} \; \forall \alpha, \beta \in I \; [x_\alpha \in U_\beta]$. So every space having countable net weight is trivially suHG. We introduce an HG property that is equivalent to countable net weight. (Received September 14, 2018)

1145-54-829 **Nancy C Scherich*** (nscherich@math.ucsb.edu). *Discrete Representations of the Braid Groups.*

Many well known representations of the braid groups are parameterized. Using a little algebraic number theory, I will show how to carefully choose evaluations of the parameter so that the image is a discrete group, and sometimes lands in a lattice! It is exciting to see how algebraic techniques give rise to more geometric results. (Received September 15, 2018)

1145-54-961 **Carmen Galaz-Garcia***, carmengg@math.ucsb.edu. *New examples of pseudomodular jigsaw groups.* Preliminary report.

The cusp set of a discrete subgroup Γ of $PSL(2,(R)$ is the set of points fixed by parabolic elements of Γ. It can be checked that the cusp set of $PSL(2,\mathbb{Z})$ is $\mathbb{Q}\cup\{\infty\}$. The question that arises then is: how strong is the cusp set as an invariant of discrete subgroups of $PSL(2,(R)$? More precisely, if G also has cusp set equal to $\mathbb{Q}\cup\{\infty\}$, is it commensurable with $PSL(2,\mathbb{Z})$? The answer on the negative was provided by D. Long and A. Reid on 2001 with finitely many examples, calling them pseudomodular groups. On 2016 Lou, Tan and Vo produced two infinite families of pseudomodular groups, and called them jigsaw groups. In this talk we will show a third family of pseudomodular groups obtained with the jigsaw construction. (Received September 17, 2018)

1145-54-1911 **Mustafa Hajij**, **Jesse S F Levitt*** (jslevitt@usc.edu) and **Radmila Sazdanovic**. *Machine Learning Revelations from the Color Jones Polynomial.* Preliminary report.

A multitude of knot invariants have been found and calculated in the last few decades. In this talk we discuss several lessons machine learning has gathered from analyzing this menagerie of information. Critically, we find that the color Jones polynomial encodes a significant level of information about the signature of a knot. This has important ramifications for a conjecture of Garoufalidis and the calculation of the Khovanov polynomial. (Received September 24, 2018)

1145-54-1931 **Marla Williams*** (marla.williams@huskers.unl.edu). *Trisections of Surface Bundles over Surfaces.* Preliminary report.

Trisections of smooth 4-manifolds are a generalization of Heegaard splittings of 3-manifolds, and a trisection can be similarly described by a set of curves on Σ_g, a genus g surface. This talk will introduce an algorithm for finding minimal genus trisections and trisection diagrams of (closed) surface bundles. These trisections are balanced, and the diagrams are symmetric (in the case of trivial bundles) or nearly symmetric (when the monodromy is nontrivial). (Received September 24, 2018)

1145-54-2053 **Leona Sparaco*** (lhsparaco@smcm.edu). *Character Varieties of* $(2k+1,3,2k+1)$ *Knots.* Preliminary report.

Let M be an orientable finite-volume hyperbolic manifold. The $SL_2(\mathbb{C})$ character variety of M is essentially the set of all representations $\rho:\pi_1(M)\to SL_2(\mathbb{C})$ up to trace equivalence. This algebraic set encodes geometric properties of M. In this talk we will look at the character variety of the $(2k+1,3,2k+1)$ knots, a family of 2-bridge knots with symmetry. (Received September 24, 2018)

1145-54-2256 **Tim Morris*** (tuf28547@temple.edu), 1228 Tasker Street, Philadelphia, PA 19148. *Some Non-Abelian Covers of Knot Complements.*

Let K be a tame knot embedded in $\mathbf{S}^3$. We address the following, find a finite non-cyclic cover $p:X\to\mathbf{S}^3\smallsetminus K$ such that $[\pi_1\left(\mathbf{S}^3\smallsetminus K\right):p_*\left(\pi_1\left(X\right)\right)]$ is minimal. When K has non-trivial Alexander polynomial modulo a prime p we construct finite non-abelian representations $\rho:\pi_1\left(\mathbf{S}^3\smallsetminus K\right)\to G$, and provide bounds for the order of G in terms of the crossing number of K. Which is an improvement on a result of Broaddus in this case. Using classical covering space theory along with the theory of Alexander stratifications we establish an upper and lower bound for the first betti number of the cover X_ρ associated to the $\ker(\rho)$ of $\mathbf{S}^3\smallsetminus K$, consequently showing that it can be arbitrarily large. Providing an effective proof of a result due to Cooper, Long, and Reid. (Received September 25, 2018)

1145-54-2378 **Katie Tucker***, katherine.tucker@huskers.unl.edu. *Computational methods applied to local moves on knots.*

A (tame) knot is the image of a smooth embedding $S^1\hookrightarrow S^3$, and two knots are considered equivalent if they are equivalent under isotopy. A local move on a knot, however, disregards isotopy to replace a tangle in the knot diagram with another tangle. In this talk we examine new computational methods for examining the effects of local moves on knots and links. (Received September 25, 2018)

1145-54-2677 **David B. Damiano**, **Ellen Gasparovic** and **Michael J. Marlett*** (mmarle19@g.holycross.edu), 1 College St., P.O. box 1787, Worcester, MA 01610, and **Robert Righi**. *Macular Degeneration Classification through Topology and Convolutional Neural Networks.*

Macular degeneration is a disease of the retina that affects the macula, the region in the center of the retina responsible for high-resolution, color vision that is possible in good light. The loss of central vision makes it difficult to recognize faces, drive, read, or perform other activities of daily life. The classification of macular degeneration in the retina involves the ability to differentiate between three different types of macular degeneration, drusen, choroidal neovascularization, and diabetic macular edema as well as healthy retina. In this project, we combine methods from computational topology and deep learning to analyze a data set consisting of 83,711 optical coherence tomography (OCT) images of healthy and diseased retinas. In the first stage of this project we have applied convolutional neural networks to this data set. Our goal is to improve upon non-topological based analyses of OCT images. (Received September 25, 2018)

1145-54-2864 **Anthony Bosman*** (bosman@andrews.edu). *Link Shake Concordance and Link Homotopy.*

Link homotopy is an equivalence relation on links, introduced by Milnor, where each component is allowed to move via homotopy through itself but not allowed to move through other components. It is well-known that link concordance implies link homotopy. We show how this extends to shake concordance, a generalization of link concordance. Shake concordance was first introduced by Akbulut in the setting of knots, but naturally generalizes to links. (Received September 25, 2018)

1145-54-2895 **Shelley B Kandola*** (kando004@umn.edu). *The Topological Complexity of Finite Models of Spheres.*

The topological complexity (TC) of a connected space X can be thought of as the minimal number of continuous motion planning rules required to instruct a robot to move from one position in X to another position. A common introductory example is a robot whose range of motion is S^1, e.g., a rotating security camera. In this case, $\mathrm{TC}(S^1) = 2$. The TC of spheres has been studied in depth by Farber (products of spheres) and González (subcomplexes of products of spheres). In 2018, Tanaka introduced Combinatorial Complexity (CC) as an analog of TC for finite spaces. In that paper, the author proves that the definitions of CC and TC coincide on finite spaces, and that the TC of a minimal finite model of S^1 has TC equal to 4. In this talk, I explore the TC of non minimal finite models of spheres. First, I prove a more general theorem that $\mathrm{TC}(X') \leq \mathrm{TC}(X)$, where X' is the barycentric subdivision of a finite space X. Lastly, I give an explicit construction of the Lusternik-Schnirelmann category of non-minimal finite models of S^1. (Received September 25, 2018)

1145-54-3022 **Esteban G Escobar*** (estebanescobar7@gmail.com), 3519 Gibson RD, El Monte, CA 91731. *Enhancing the detection of Atrial Fibrillation from existing models using Persistent Homology-based feature.*

Atrial Fibrillation is an irregular heartbeat that leads to blood clots, heart failure, and other heart-related complication. It is difficult to detect and diagnose because symptoms can come and go on their own. In respond the PhysioNet/Computing in Cardiology challenge focus to make a model that will help differentiation Atrial Fibrillation using variety of tradition and novel methods. It is possible to take the winning and losing models and modify them to better differentiation Atrial Fibrillation. Incorporate Persistent Homology-based feature to these models will help look at the data set in a different perspective. This method provides a strategy for constructions the topological information of point cloud data. The typical output of persistent homology are persistent barcodes and persistent diagrams. Persistent barcodes provide crucial information, each bar represents a persistent feature and for one point cloud the persistent barcodes of each dimensional hole are generated. It has been shown that implementing this method has significant enhance the detection of some of the model. By comparing the Persistent Homology-based for both datasets of regular heart rhythm and Atrial Fibrillation it is easy to diagnose the condition and give the appropriate medications. (Received September 26, 2018)

55 ► *Algebraic topology*

1145-55-141 **Steve Huntsman*** (steve.huntsman@baesystems.com) and **Michael Robinson** (michaelr@american.edu). *Topology of basic blocks.* Preliminary report.

Dowker's theorem gives a homotopy equivalence between the two natural simplicial complexes formed from a relation between two finite sets. The topology of these complexes encodes information about the underlying relation. In the special case of homology with $\mathbb{F}_2$ coefficients, the complexes do not even need to be explicitly constructed. These observations have by now a long tradition of applications spanning Q-analysis (from the 1970s!), topological navigation and mapping, and computing lower bounds in privacy analyses. In many cases of potential interest, one or both sets underlying a relation to be analyzed is a topological space in its own right, and this leads to a cosheaf structure and attendant notion of local homology, which to our knowledge has not yet been applied. Here, we sketch the application of these ideas to the analysis of basic blocks, i.e., computer programs without control flow. In particular, using the example of matrix multiplication, we give evidence that topological invariants can capture salient information about algorithms, versus merely about functions or programs. (Received August 08, 2018)

1145-55-504 **Wako Tasisa Bungula*** (wako-bungula@uiowa.edu), 14 MacLean Hall, Iowa City, IA 52246. *Filtration and Stability Of Mapper graphs for Point Cloud Data.*

The instability of TDA Mapper has been studied at least for topological space data and for PL functions. By extending Mapper to Multiscale Mapper and defining an ϵ-interleaving, stability theorems were stated by Tamal Dey and et al. However, for point cloud data, neither ϵ-interleaving nor stability have not been studied mainly because of the issues that arise with clustering algorithms. For example, hierarchical clustering algorithms use dendrograms (and cutting) to determine the clusters, and the issue is where to cut the dendrogram. The number of clusters may be very different if we cut at a height h_0 and $h_0 + \delta$. KMeans clustering has two issues. First, the number of clusters has to be specified by the user which could lead to misleading result about the actual clusters. Second, KMeans clustering is not stable. That is, if KMeans is run twice, the result is different. DBSCAN clustering takes two parameters to define a cluster, and these parameters are specified by the user. I will be talking about these clustering methods in detail and how ϵ-interleaving could be defined for point cloud data that will lead to stability of mapper graph. (Received September 07, 2018)

1145-55-581 **Jose A. Perea*** (joperea@msu.edu), joperea@msu.edu. *Learning with Nerve Complexes.*

The nerve complex, as a discrete approximation to the topology of a space, has been used widely in the theory and computation of persistent homology. I will show in this talk how the nerve construction can be used for other machine learning tasks, including dimensionality reduction, classification and regression. (Received September 10, 2018)

1145-55-591 **Marithania Silvero*** (marithania@us.es). *Polynomial braid combing.*

Braid combing is a procedure defined by Emil Artin to solve the word problem in braid groups. Despite it is conceptually simple, it becomes impractical when computing concrete cases. In fact, it is well-known that (classic) braid combing has exponential complexity.

In this talk we will use straight line programs to give a polynomial algorithm which performs braid combing. Moreover, this procedure provides the first algorithm which gives a solution for the word problem in braid groups on surfaces with boundary in polynomial time and space.

This is joint work with Juan González-Meneses. (Received September 11, 2018)

1145-55-709 **Erin Wolf Chambers*** (erin.chambers@slu.edu), Department of Computer Science, Ritter Hall, Saint Louis University, 220 N. Grand, Saint Louis, MO 63116. *Burning the Medial Axis.*

The medial axis plays a fundamental role in many shape matching and analysis, but is widely known to be unstable to even small boundary perturbations. Methods for pruning the medial axis are usually guided by some measure of significance, with considerable work done for both 2 and 3 dimensional shapes. However, the majority of significance measures over the medial axis are locally defined, and hence are unable to recognize more global topological features, or are difficult to compute and sensitive to perturbations on the boundary. In this talk, I will present recent work done in 2d and 3d to compute a new significance measure on the medial axis, which we call the burn time function. Using this function, we are able to generalize the classical notion of erosion thickness measure over the medial axes of 2D shapes. We demonstrate the utility of these shape significance measures in extracting clean, shape-revealing and topology-preserving skeletons in 2 and 3D which are robust to noise on the boundary. To conclude, I will also discuss applications of this work in ongoing research to quantify the shape of root systems, in order to identify genetic structures that govern root development. (Received September 13, 2018)

1145-55-722 **Daniel A Ramras** and **Mentor Stafa*** (mstafa@tulane.edu). *Homological stability of representation spaces.*

We study the spaces of pairwise commuting n-tuples in a Lie group G, that is $Hom(\mathbb{Z}^n, G)$, and their homological, when the group G is in a sequence of classical Lie groups. We show that for $n \geq 1$ these spaces, and other analogues, satisfy homological stability as G varies in a sequence of classical Lie groups. Moreover, we find a bound for the stable range. In our work we use the theory of representation stability and FI-modules. (Received September 13, 2018)

1145-55-796 **Joshua Cruz*** (joshua.cruz@duke.edu), Mathematics Department, Duke University, Box 90320, Durham, NC 27708-0320. *Cauchy Sequences in Categories with an Interleaving.*

In topological data science, categories with an interleaving functor have become ubiquitous, including examples like persistence modules, sheaves, and Reeb graphs. With the interleaving functor comes an interleaving distance, which (in theory) allows us to analyze our data using tools from probability and statistics. Many of these tools deal with convergence of sequences, so completeness of our metric space becomes important. This talk will explain a categorical condition which will guarantee completeness as well as describe the limit of a Cauchy sequence as the categorical limit of a specific diagram. (Received September 14, 2018)

1145-55-897 **Ellen Gasparovic*** (gasparoe@union.edu). *Homotopy types and persistence of metric gluings.*

This talk will focus on topological summary information that one can capture from metric wedge sums and gluings, with an emphasis on metric graphs. We will give a complete characterization of the persistence diagrams in dimension 1 for metric graphs under a particular intrinsic setting. We will show that the Vietoris-Rips (resp., Cech) complex of a wedge sum, equipped with a natural metric, is homotopy equivalent to the wedge sum of the Vietoris-Rips (resp., Cech) complexes. We also provide generalizations for when two metric spaces are glued together along a common isometric subset. As a result, we can describe the persistent homology, in all homological dimensions, of the Vietoris-Rips complexes of a wide class of metric graphs. This talk covers joint work with Michal Adamazsek, Henry Adams, Maria Gommel, Emilie Purvine, Radmila Sazdanovic, Bei Wang, Yusu Wang, and Lori Ziegelmeier. (Received September 17, 2018)

1145-55-955 **Jānis Lazovskis*** (jlazov2@uic.edu). *Sheaf theory on universal persistent homology spaces.*

The product of the Ran space and the nonnegative reals admits a stratification by simplicial complexes, through the Čech or Vietoris–Rips constructions. This leads to a cosheaf valued in diagrams of simplicial complexes for which every restriction to $\{P\} \times \mathbb{R}_{\geq 0}$ recovers the persistent homology of the data set P. (Received September 17, 2018)

1145-55-1105 **Wade Bloomquist*** (bloomquist@math.ucsb.edu) and **Zhenghan Wang**. *Applications of Quantum Representations of Mapping Class Groups.*

Certain tensor categories give rise to rich topological structure, namely a $2+1$ topological quantum field theory. One consequence of this structure is a tower of mapping class group representations for every genus surface. We dive into some applications of this construction, both in recovering classical topology and in topological quantum computing. An emphasis will be placed on the underlying tensor category and how properties there can have far reaching impact. (Received September 19, 2018)

1145-55-1337 **Alexander Wagner*** (wagnera@ufl.edu). *A Persistent Homology Measure for Morse Functions.* Preliminary report.

The persistence diagram is a stable, algebraic summary of the connectivity of spatial data. The points in the persistence diagram have a representation in the input space, but these representations are notoriously unstable and, as equivalence classes of sets of simplices, hard to visualize. To remedy the lack of canonical representatives for points in the persistence diagram, we take advantage of the fact that in the context of sublevel set filtrations of Morse functions, persistent homology pairs critical values. This pairing generically induces a pairing of critical points. However, the location of these critical point pairings can move wildly even if the Morse function is perturbed only slightly. We address this issue by taking as input a function-valued random variable and constructing a probability distribution on the domain that describes how critical points associated to regions of interest in the persistence diagram are dispersed. In this talk, I will discuss the definition and stability of this construction. (Received September 21, 2018)

1145-55-1347 **Leanne Elizabeth Merrill*** (merrill@wou.edu), Department of Mathematics, Western Oregon University, 345 Monmouth Avenue North, Monmouth, OR 97361. *Searching for v_n self-maps at the prime 2: an algebraic approach.*

Devinatz, Hopkins, and Smith tell us that certain types of finite spectra possess non-nilpotent self-maps known as v_n-maps. The most useful such spectra-map pairs have spectra with few cells and a v_n-map with a low power. Though the search for v_n-maps has been underway since the early 1980s, few concrete examples are known, and they often fail to satisfy one of the smallness conditions described above. Palmieri and Sadofsky describe an iterative algebraic algorithm to produce new examples of v_n-maps from related maps called u_i-maps. We describe the progress made in implementing this algorithm at the prime $p = 2$, including non-examples for low powers of v_2. (Received September 21, 2018)

1145-55-1377 **Lori Ziegelmeier*** (lziegel1@macalester.edu), **Henry Adams**, **Chad Topaz** and **Lu Xian**. *Using Topology to Measure Dynamics of Time-Varying Systems.* Preliminary report.

A time-varying collection of metric spaces as formed, for example, by a moving school of fish or flock of birds, can contain a vast amount of information. There is sometimes a need to simplify or summarize the dynamic behavior, and recently, topological tools have been applied to this purpose. One such method is a crocker plot, a 2-dimensional image that displays the (non-persistent but varying with scale) topological information at all times simultaneously. We apply this method to simulations arising from different choices of noise parameter (which controls the magnitude of stochasticity) of the highly-cited Viscek model. We then input the crocker plot of each simulation as a feature vector for the machine learning task of recovering the unknown underlying noise parameters. The topological features classify by noise parameter with a higher degree of accuracy than the more standard feature vector of the alignment order parameter. Further, we discuss an extension of the crocker plot, a crocker video, which is a persistent version of a crocker plot that is equivalent to the information in a vineyard and hence, inherits the nice stability properties of vineyards. For some purposes, the information in a vineyard is more accessible when instead displayed as a crocker video. (Received September 21, 2018)

1145-55-1486 **Hitesh Gakhar*** (hitesh.gakhar@gmail.com) and **Jose A. Perea**. *Kunneth Formulae in Persistent Homology.*

The classical Kunneth formula in homological algebra provides a relationship between the homology of a product space and those of its factors. In this talk, we will give similar results for persistent homology. That is, we will give relationships between barcodes of two different notions of product filtrations and that of their factor filtered spaces. We also present two applications: one gives faster algorithms for computing persistent homology in the setting of Vietoris-Rips complexes and the other gives barcodes for certain multiparameter persistence modules. (Received September 22, 2018)

1145-55-1489 **Hee Rhang Yoon*** (iris.yoon@math.gatech.edu), iris.yoon@math.gatech.edu, and **Robert Ghrist**. *Cellular cosheaves for distributed computation of persistent homology.*

We present a distributed computation mechanism of persistent homology using cellular cosheaves. Our construction is an extension of the generalized Mayer-Vietoris principle to filtered spaces obtained via a sequence of spectral sequences. We discuss a general framework in which the distribution scheme can be adapted according to a user-specific property of interest. The resulting persistent homology reflects properties of the topological features, allowing the user to perform refined data analysis. Finally, we apply our construction to perform a multi-scale analysis to detect features of varying sizes that are overlooked by standard persistent homology. This is joint work with Robert Ghrist. (Received September 24, 2018)

1145-55-1493 **Rachel A. Neville*** (ranveille@math.arizona.edu), Department of Mathematics, University of Arizona, P.O. Box 210089, Tucson, AZ 85721. *Topological Techniques for Characterization of Pattern Forming Systems.*

Complex spatial-temporal patterns can be difficult to characterize quantitatively, especially similar patterns formed under different conditions. Persistent homology provides a meaningful low-dimensional quantitative summary of topological structure of dynamic data. These summaries retain a remarkable amount of information that allows for the investigation of the influence of nonlinear parameters, classification of data by parameters, and study of defect evolution. (Received September 22, 2018)

1145-55-1522 **Chad Giusti*** (cgiusti@udel.edu), Department of Mathematical Sciences, 501 Ewing Hall, University of Delaware, Newark, DE 19716. *Topological measures of network dynamics.* Preliminary report.

Understanding dynamic processes supported on complex networks is a fundamental challenge for many modern scientific fields. Noise in both the systems and observations, along with the increasing size of the networks of interest, conspire to make exact solutions to these dynamics intractable. Often, however, such precise information is unnecessary to answer questions of interest, and modern topological methods provide a range of qualitative characterizations that are both human-understandable and computable. We will survey some of these methods, as well as provide preliminary reports on their applications in theoretical and clinical neuroscience. (Received September 22, 2018)

1145-55-1526 **Chad Giusti*** (cgiusti@udel.edu), Department of Mathematical Sciences, 501 Ewing Hall, University of Delaware, Newark, DE 19716. *Rational cochains on the space of persistence vineyards.* Preliminary report.

Applications of persistent homology to the study of dynamic systems or time series data sometimes produce sequences of persistence diagrams. These sequences are often encoded as so-called persistence vineyards, paths in the space of persistence diagrams. However, the complexity of persistence diagrams means understanding these objects is often just as difficult as characterizing the original system. Building on techniques from rational homotopy theory and classical cellular models for configuration spaces, we construct computable rational cochains on the space of persistence vineyards, and discuss their potential uses. (Received September 22, 2018)

1145-55-1721 **Robert Ghrist*** (ghrist@math.upenn.edu). *Topological Defense Analysis: the how and why of US Department of Defense research.*

Many mathematicians have trepidations about working with the US Department of Defense on research. While respecting those reservations, I am going to argue in this talk that engaging with technical aspects of national defense is a positive good for mathematics. This talk will be part retrospection, part instruction-manual, and part vision for better engagement of the mathematics community with society. Along the way, I'll talk about novel applications of algebraic topology to sensor networks, signal processing, threat detection, target tracking, and pursuit problems. (Received September 24, 2018)

1145-55-1746 **Bernd Sturmfels**, **Paul Breiding** and **Sara Kalisnik*** (skalisnikver@wesleyan.edu), 265 Church Street, Middletown, CT 06459, and **Madeleine Weinstein**. *Learning Algebraic Varieties from Samples.*

I will discuss how to determine a real algebraic variety from a fixed finite sample of points and what to do with that information. For example, from the equations defining a variety one can learn the degree and the dimension of the variety. One can also construct ellipsoid complexes which, based on the experiments, strengthen the topological signal for persistent homology. All the algorithms needed are made available in a Julia package. (Received September 24, 2018)

1145-55-1787 **Mathieu Carriere*** (mathieu.carriere3@gmail.com). *Statistical analysis and parameter selection for Mapper.*

In this presentation, I will study the question of the statistical convergence of the 1-dimensional Mapper algorithm to its continuous analogue, the Reeb graph. In particular, I will show how, building on recent theoretical advances about the structure of the Mapper, one can prove that the Mapper is an optimal estimator of the Reeb graph, which gives, as a byproduct, a method to automatically tune its parameters and compute confidence regions on its topological features, such as its loops and flares. This allows to circumvent the issue of testing a large grid of parameters and keeping the most stable ones in the brute-force setting, which is widely used in visualization, clustering and feature selection with the Mapper. (Received September 24, 2018)

1145-55-1789 **Alejandro Adem*** (adem@math.ubc.ca). *Topology of Commuting Matrices.*

In this talk we will discuss the structure of spaces of commuting elements in a compact Lie group. Their connected components and other basic topological properties will be discussed. We will also explain how they can be assembled to produce a space which classifies certain bundles and represents an interesting cohomology theory. A number of explicit examples will be provided for orthogonal, unitary and projective unitary groups. (Received September 24, 2018)

1145-55-1872 **Bei Wang*** (beiwang@sci.utah.edu). *An Introduction to Discrete Stratified Morse Theory.*

Inspired by the works of Forman on discrete Morse theory, which is a combinatorial adaptation to cell complexes of classical Morse theory on manifolds, we introduce a discrete analogue of the stratified Morse theory of Goresky and MacPherson, referred to as the discrete stratified Morse theory (DSMT). We describe the basics of this theory and prove fundamental theorems relating the topology of a general simplicial complex with the critical simplices of a discrete stratified Morse function on the complex. We also provide an algorithm that constructs a discrete stratified Morse function out of an arbitrary function defined on a finite simplicial complex; this is different from simply constructing a discrete Morse function on such a complex. We then discuss on-going research efforts that connect DSMT with point cloud data, discrete dynamics, and visualization. This is a joint work with Kevin Knudson. (Received September 24, 2018)

1145-55-1913 **Justin Mauger***, jmauger@spawar.navy.mil. *Characterization of Radar Signals via Topological Data Analysis and Spiking Neuron Networks.*

The use of Topological Data Analysis (TDA) in data science has become commonplace today. TDA views data as points in a high dimensional vector space and calculates *persistent homology* to differentiate between transient and persistent features at different scales. It is actively used in neuroscience to find patterns in timing dependencies between different neurons' spikes.

In addition to TDA, Artificial Neural Networks and Convolutional Neural Networks have garnered much attention recently due to their success in classification tasks. A Spiking Neuron Network is an alternative approach that more closely mimics the way the brain processes information, namely, through time-dependent spikes. We use a combination of Spiking Neuron Networks and Topological Data Analysis to characterize radar signals from different emitters. (Received September 24, 2018)

1145-55-2046 **Ojaswi Acharya** (oacharya@smith.edu), **Chen Li** (sli97@smith.edu), **David C Meyer** (dmeyer@smith.edu) and **Jasmine Noory*** (jnoory@smith.edu). *The variety of interleavings.* Preliminary report.

In topological data analysis, persistence modules are used to distinguish the legitimate topological features of a finite data set from noise. Interleavings between persistence modules feature prominently in the analysis. It is known that for any ϵ positive, the collections of ϵ-interleavings between two fixed persistence modules has an algebraic structure. In this project, we investigate how this structure changes when the value of ϵ increases. (Received September 24, 2018)

1145-55-2067 **Lu Xian*** (lxian@macalester.edu), 1600 Grand Avenue, Saint Paul, MN, and **Lori Ziegelmeier** and **Maitrayee Deka**. *Using Order Parameters and Persistent Homology to Analyze Biological Aggregations.* Preliminary report.

In this project, we explore the dynamics of biological aggregations which are groups of organisms, such as fish schools, bird flocks, and insect swarms, formed through social interaction and coordinated behaviors like attraction, repulsion, and/or alignment. We aim to classify by parameter numerical simulations generated from the highly-cited Vicsek model using both topology and the classic alignment order parameter. The topology approach computes the persistent homology at all time values of a simulation and summarizes this information as a crocker plot. The order parameter approach computes the normalized average of the velocity (that is, the alignment), producing a time series of the simulation. The outputs of both approaches for every simulation are input as feature vectors to machine learning clustering algorithms. We show that clustering with topology yields better results than clustering with order parameter, and therefore, topology can be used as a reasonable means for parameter identification. (Received September 25, 2018)

1145-55-2193 **Ezra Miller*** (ezra@math.duke.edu). *Algebra and geometry of persistence.* Preliminary report.

The classical setup of persistent homology views the homology of fattenings of finite samples from a probability distribution as families of vector spaces. Paying close attention to the algebraic structure of these families is important when trying to learn geometric features of the distribution. (Received September 25, 2018)

1145-55-2199 **William A. Bogley** (bill.bogley@oregonstate.edu), Mathematics, Oregon State University, Corvallis, OR 97331, and **David Pengelley*** (davidp@nmsu.edu), Mathematics, Oregon State University, Corvallis, OR 97331. *How can symmetries of a rectangle, tethered up to homotopy, provide a physical model for the quaternion group? Generalizations?* Preliminary report.

The 8-element quaternion group can be represented by rectangle symmetries up to tethered homotopy. But tethered how? Via a strip, or strings, which may realize different groups? And can this be generalized, e.g., to a tethered tetrahedron, icosahedron, or other objects? What groups arise? (Received September 25, 2018)

1145-55-2251 **Nina Otter*** (notter@ucla.edu). *Homology theories for (finite) metric spaces.*

In his work on the generalization of cardinality-like invariants, Leinster introduced the magnitude of a metric space, an isometric invariant that encodes the "effective number of points" of the space. Subsequently Hepworth, Willerton, Leinster and Shulman introduced a homology theory for metric spaces called magnitude homology, which categorifies the magnitude of finite metric spaces. In their paper Leinster and Shulman list a series of open questions, two of which are as follows: "Magnitude homology only 'notices' whether the triangle inequality is a strict equality or not. Is there a 'blurred' version that notices 'approximate equalities?' Almost everyone who encounters both magnitude homology and persistent homology feels that there should be some relationship between them. What is it?" In this talk I will introduce magnitude homology, and give an answer to these questions, which I show are intertwined: it is the blurred version of magnitude homology that is related to persistent homology. If time allows I will then discuss how the ordinary and blurred versions of magnitude homology differ in the limit: ordinary magnitude homology is trivial, while blurred magnitude homology coincides with Vietoris homology. (Received September 25, 2018)

1145-55-2345 **Nina Otter*** (notter@ucla.edu). *Invariants for multiparameter persistence and their computation.*

Persistent homology (PH) is arguably one of the best known methods in topological data analysis. PH allows to study topological features of data across different values of a parameter, which one can think of as scales of resolution, and provides a summary of how long individual features persist across the different scales of resolution. In many applications, data depend not only on one, but several parameters, and to apply PH to such data one therefore needs to study the evolution of qualitative features across several parameters. While the theory of 1-parameter PH is well understood, the theory of multiparameter PH is hard, and it presents one of the biggest challenges of topological data analysis. In this talk I will briefly introduce persistent homology, and then explain how tools from commutative algebra give computable invariants for multiparameter PH, which are able to capture homology classes with large persistence. If time remains I will discuss efficient algorithms for the computation of these invariants and demonstrate how they can be computed in practice on a computer. This talk is based on joint work with A. M. del Campo, H. Harrington, H. Schenck and U. Tillmann. (Received September 25, 2018)

1145-55-2366 **Ann E. Sizemore*** (annsize@seas.upenn.edu) and **Danielle S. Bassett**. *Meaningful Voids: Applying Algebraic Topology to Network Neuroscience.*

A web of interacting pieces and parts is a common construct in neuroscience, making techniques from network science invaluable for analyses and interpretation at nearly any biological scale. While network science has assuredly progressed our understanding of the brain, by nature network techniques are most tuned towards densely connected network motifs such as communities. Algebraic topology, a branch of mathematics neighboring graph theory, instead sees voids or topological cavities within the network and thus offers a unique but complementary perspective on network structure. We first give a gentle introduction to applied algebraic topology and demonstrate how topological voids in networks interact with common network statistics. We show that topological voids exist at multiple levels and areas of neuroscience, from chromatin to cognition, and suggest that these gaps may be essential for proper function. Finally we discuss interpretations and explore the possibility of functionally relevant topological voids in other biological systems. (Received September 25, 2018)

1145-55-2429 **Haibin Hang*** (hhang@math.fsu.edu), **Woojin Kim**, **Facundo Memoli** and **Washington Mio**. *Stability of a Multi-Parameter Persistent Homology Approach to Functional and Structural Data.*

We present a multi-parameter persistent homology approach to functional data on compact topological spaces and structural data treated as compact metric measure spaces. For functional data, we combine sub-level sets and Rips complexes to construct bi-filtered complexes from which we derive homological invariants. We prove a stability theorem for multidimensional persistent homology with respect to a metric in which closeness means that the topology of regions where signals are strong are similar regardless of the global topology of the domains. We construct topological invariants for metric measure spaces by mapping them to functional spaces via centrality functions. For a fixed metric domain, the general stability results imply stability with respect to the Wasserstein metric. (Received September 25, 2018)

1145-55-2592 **Brittany Terese Fasy*** (brittany.fasy@montana.edu), **Ahmed Abdelkader**, **Geoff Boeing** and **David L. Millman**. *Local Persistent Homology-Based Distances between Nonplanar Road Networks.* Preliminary report.

Comparing graphs embedded in a metric space is an important task in the field of transportation network analysis. Graphs of interest may represent various networks, including transportation networks (e.g., subway or road networks) or utility networks. In order to compare these networks, we must define a distance measure that takes both spatial proximity and structural similarity into account. We define a topology-based distance between transportation networks that removes the common planarity assumption among theoretical research, thus allowing bridges and tunnels to be represented accurately. The transportation network is modeled as a set of layers, each containing a planar subset of the full network, thus allowing us to employ prior related research on planar graphs in the non-planar setting. This work lays the foundation for using a layered representation of networks for graph comparison. (Received September 25, 2018)

1145-55-2596 **Ivan Dungan*** (ivan.dungan@fmarion.edu). *Capturing Persistent Homotopic Information.* Preliminary report.

With the popularity of persistent homology and its applications, there has been growing interest in a persistent homotopy theory. Of course, there are the immediate computational difficulties to make it an immediate success like the prior. We will focus on the differences and identify how to capture some homotopic information that may advance current applications of persistent homology. (Received September 25, 2018)

1145-55-2620 **Vladimir Itskov***, Department Of Mathematics, The Pennsylvania State University, University Park, PA 16802, and **Alexandra Yarosh**. *Directed complexes, sequence dimension and inverting a neural network.*

What is the embedding dimension, and more generally, the geometry of a set of sequences? This problem arises in the context of neural coding and neural networks. Here one would like to infer the geometry of a space that is measured by unknown quasiconvex functions. A natural object that captures all the inferable geometric information is the directed complexes (a.k.a. semi-simplicial sets). It turns out that the embedding dimension as well as some other geometric properties of data can be estimated from the homology of an associated directed complex. Moreover each such directed complex gives rise to a multi-parameter filtration that provides a dual topological description of the underlying space. I will also illustrate these methods in the neuroscience context of understanding the "olfactory space". This is a joint work with Philip Egger and Alexandra Yarosh. (Received September 25, 2018)

57 ► Manifolds and cell complexes

1145-57-240 **Joseph A Quinn*** (quinn@momath.org), Chief of Mathematics, National Museum of Mathematics, 11 East 26th Street, New York, NY 10010. *Macfarlane hyperbolic 3-manifolds.*

We identify and study a class of hyperbolic 3-manifolds whose (generalized) quaternion algebras admit a geometric interpretation analogous to Hamilton's classical model for Euclidean rotations. We call these Macfarlane manifolds, as they incorporate a modern generalization of Alexander Macfarlane's classical ideas about hyperbolic quaternions. We characterize these manifolds arithmetically, and show that infinitely many commensurability classes of them arise in diverse topological and arithmetic settings. We then use this perspective to introduce a new method for computing their Dirichlet domains. We also give similar results for a class of hyperbolic surfaces and explore their occurrence as subsurfaces of Macfarlane manifolds. (Received August 23, 2018)

1145-57-286 **Siddhi Krishna*** (siddhi.krishna@bc.edu), Department of Mathematics, Maloney Hall, Fifth Floor, Boston College, Chestnut Hill, MA 02467. *Taut Foliations, Positive 3-Braids, and the L-Space Conjecture.*

The L-Space Conjecture is taking the low-dimensional topology community by storm. It aims to relate seemingly distinct Floer homological, algebraic, and geometric properties of a closed 3-manifold Y. In particular, it predicts a 3-manifold Y isn't "simple" from the perspective of Heegaard-Floer homology if and only if Y admits a taut foliation. The reverse implication was proved by Ozsvath and Szabo. In this talk, we'll present a new theorem supporting the forward implication. Namely, we'll discuss how to build taut foliations for manifolds obtained by surgery on positive 3-braid closures. No background in Heegaard-Floer or foliation theories will be assumed. (Received August 28, 2018)

1145-57-311 **Ryo Ohashi*** (ryoohashi@kings.edu), 133 North River Street, Wilkes-Barre, PA 18711. *The finite group actions on the projective plane.* Preliminary report.

A finite G-action on a manifold M is a monomorphism $\varphi : G \to Homeo(M)$, where G is a finite group. In this talk, M is the projective plane $\mathbb{P}^2$, and our goal is to describe all possible finite G-actions on $\mathbb{P}^2$. Since the universal covering space of $\mathbb{P}^2$ is the 2-sphere $\mathbb{S}^2$, we will lift the acting group on $\mathbb{P}^2$ to $\widetilde{G}$ on $\mathbb{S}^2$.

It has been known the finite group actions on $\mathbb{S}^2$, hence we visualize the actions on $\mathbb{S}^2$ by an appropriate triangulation on it. $\widetilde{G}$ acting on $\mathbb{S}^2$ is embedded into S_n for some $n \in \mathbb{N}$, thus the triangulation on $\mathbb{S}^2$ contains n vertices and $\widetilde{G}$ permutes these vertices. This process enables us to analyze the finite G-actions on $\mathbb{P}^2$ by observing a fundamental region on $\mathbb{S}^2$ and to see the quotient spaces $\mathbb{P}^2/\varphi$.

Conversely, for a given non-orientable 2-dimensional closed orbifold, is it covered by $\mathbb{P}^2$ uniquely? The answer to this question is to look at the generators of $\widetilde{G}$. Notice all elements in $\widetilde{G}$ contain geometric and topological "DNA" in addition to algebraic information such as their order. A typical DNA is orientability or an existence of fixed point. (Received August 31, 2018)

1145-57-479 **Adam M Lowrance*** (adlowrance@vassar.edu) and **Radmila Sazdanovic**. *Gordian distance and spectral sequences in Khovanov homology.*

The Gordian distance between two knots is the fewest number of crossing changes necessary to transform one knot into the other. Khovanov homology is a categorification of the Jones polynomial that comes equipped with several spectral sequences. In this talk, we show that the page at which some of these spectral sequences collapse gives a lower bound on the Gordian distance between a given knot and the set of alternating knots (and also on other related Gordian distances). We also discuss connections to the existence of torsion in Khovanov homology. (Received September 07, 2018)

1145-57-563 **Juanita Pinzon-Caicedo*** (jpinzon@ncsu.edu) and **Matthew Hedden**. *Operations of Infinite Rank in Concordance.*

Oriented knots are said to be concordant if they cobound an embedded cylinder in the interval times the 3-sphere. This defines an equivalence relation under which the set of knots becomes an abelian group with the connected sum operation. The importance of this group lies in its strong connection with the study of 4.manifolds. Indeed, many questions pertaining to 4–manifolds with small topology (like the 4–sphere) can be addressed in terms of concordance. A powerful tool for studying the algebraic structure of this group comes from satellite operations or the process of tying a given knot P along another knot K to produce a third knot P(K). In the talk I will describe how to use SO(3) gauge theory to provide a general criterion sufficient for the image of a satellite operation to generate an infinite rank subgroup of the smooth concordance group. (Received September 10, 2018)

1145-57-594 **Yuanan Diao*** (ydiao@uncc.edu), Department of Mathematics and Statistics, University of North Carolina Charlotte, 9201 University City Blvd, Charlotte, NC 28223. *Realizing knots by physical ropes.*

When one tries to tie a knot using a physical rope, one immediately realizes that if the rope is not long enough, then you cannot tie the knot. The minimum length of a rope of unit thickness required to tie a certain knot is called the ropelength of the knot. In this talk, various problems and progresses concerning the ropelength of knots will be discussed. These include the global minimum ropelength of all non-trivial knots, the general lower bounds and upper bounds for the ropelength of various knot families in terms of their crossing numbers. In general, for any given knot with crossing number n, the ropelength is bounded below by $O(n^{3/4})$ and it is known that the 3/4 power in the bound is sharp. On the other hand, $O(n^{3/4})$ is not a general upper bound since there are infinitely many knots whose ropelength is at least of the order of $O(n)$. While there are many knots whose ropelength is bounded above by $O(n)$, it is not known whether this is the best upper bound. To date, the best known upper bound is of the order of $O(n \ln^5(n))$. The talk also discussed the counterpart of the ropelength problem in the discrete setting, namely the minimum length of a knot realized on the simple cubic lattice. (Received September 11, 2018)

1145-57-651 **Carolyn A Otto*** (ottoa@uwec.edu). *Genus one knots and their derivatives.*

In this talk we will discuss the relationship of genus one knots and their derivatives. Specifically, we will prove that if a knot is algebraically slice and genus one, we will always be able to find a derivative of the knot with an Arf invariant of zero. Using this result, we will be able to show that there are families of knots, that are created by an infection operator, that admit a derivative with vanishing Arf invariant. We will end by showing how this result generalizes to higher genus knots. (Received September 12, 2018)

1145-57-665 **Paige Graves**, **Sam Nelson** and **Sherilyn Tamagawa***, Department of Mathematics, South Hall, Room 6607, University of California, Santa Barbara, CA 93106. *Niebrzydowski Algebras and Trivalent Spatial Graphs.*

In this talk, we will introduce Niebrzydowski algebras, algebraic structures with a ternary operation and a partially defined multiplication, whose axioms are motivated by the Reidemeister moves for Y-oriented trivalent spatial graphs and handlebody-links. We will also show that the counting invariant distinguishes some trivalent spatial graphs and handlebody-links. (Received September 12, 2018)

1145-57-728 **Allison K Henrich*** (henricha@seattleu.edu), 901 12th Ave, PO Box 222000, Seattle, WA 98122. *The curious universe of virtual knots.*

What does it mean for a knot be virtual? If we regard it from a certain perspective, the theory of virtual knots is a rather natural generalization of the theory of knots. In this virtual universe, what we normally call knots are just special types of virtual knots, but there are also strange creatures that live in the universe. In this talk, we will learn several ways of describing what these virtually knotted creatures are. We will also learn about some tools for exploring the virtual universe as well as how virtual knot theory provides tools to learn about other sorts of knotted objects. (Received September 13, 2018)

1145-57-768 **Christian R Millichap*** (christian.millichap@gmail.com), **Jeffrey Meyer** and **Rolland Trapp**. *Arithmeticity of Fully Augmented Links.*

Fully augmented links (FALs) are a large class of links whose complements admit hyperbolic structures that can be explicitly described in terms of combinatorial information coming from their respective link diagrams. In this talk, we will briefly describe how to build these hyperbolic structures and then discuss recent progress made towards classifying which FALs are arithmetic. Both geometric and number theoretic tools will come into play for this classification problem. (Received September 14, 2018)

1145-57-799 **Charles Camacho Anthony Charles*** (camachoc@math.oregonstate.edu). *Counting the Number of Quasiplatonic Topological Actions of the Cyclic Group on Surfaces.*

A quasiplatonic topological action of a finite group G on a surface X of genus at least two is an embedding of G into $\mathrm{Homeo}^+(X)$ whose orbit space X/G has genus zero and whose action ramifies over three points. Define $QC(n)$ to be the number of quasiplatonic topological actions of the cyclic group C_n on surfaces. We use formulas of Benim and Wootton to give an explicit formula for $QC(n)$. In addition, we relate the number of quasiplatonic topological actions of C_n to the number of regular dessins d'enfants (highly symmetric embedded bipartite graphs) having C_n as their group of automorphisms. (Received September 15, 2018)

1145-57-901 **Mauricio Gutierrez** and **Zbigniew Nitecki*** (znitecki@tufts.edu). *Crossing Matrices for Braids.*

The crossing matrix of a braid on N strands is the $N \times N$ integer matrix with zero diagonal whose i, j entry is the algebraic number (positive minus negative) of crossings by strand i over strand j . When restricted to the subgroup of pure braids, this defines a homomorphism onto the additive subgroup of $N \times N$ symmetric integer matrices with zero diagonal–in fact, it represents the abelianization of this subgroup. As a function on the whole N-braid group, it is a derivation defined by the action of the symmetric group on square matrices. The set of all crossing matrices can be described using the natural decomposition of any braid as the product of a pure braid with a "permutation braid" in the sense of Thurston, but the subset of crossing matrices for positive braids is harder to describe. We formulate a finite algorithm which exhibits all positive braids with a given crossing matrix, if any exist, or declares that there are none. (Received September 17, 2018)

1145-57-972 **Margaret Nichols*** (mnichols@math.uchicago.edu). *Taut sutured handlebodies as twisted homology products.*

A basic problem in the study of 3-manifolds is to determine when geometric objects are of 'minimal complexity'. We are interested in this question in the setting of sutured manifolds, where minimal complexity is called 'tautness'.

One method for certifying that a sutured manifold is taut is to show that it is homologically simple - a so-called 'rational homology product'. Most sutured manifolds do not have this form, but do always take the more general form of a 'twisted homology product', which incorporates a representation of the fundamental group. The question then becomes, how complicated of a representation is needed to realize a given sutured manifold as such?

We explore some classes of relatively simple sutured manifolds, and see one class is always a rational homology product, but that the next natural class contains examples which require twisting. We also find examples that require twisting by a representation which cannot be 'too simple'. (Received September 17, 2018)

1145-57-975 **Bo-hyun None Kwon*** (bortire74@gmail.com), 109-304, Wolgok-ro 14 Road 26, Seongbuk-gu, Seoul, 02794, South Korea. *A generalization of the rectangle condition.*

In this talk, we define the connecting rectangle condition to check whether or not a Heegaard splitting is strongly irreducible which is a variation of the rectangle condition by Casson and Gordon. Then we define a general version of the rectangle condition. Moreover, with a similar condition defined on an n-bridge decomposition, we can check whether or not the Hampel distance of an n-bridge decomposition is greater than or equal to two. We would give an interesting example on n-bridge decomposition of knots which satisfy the connecting rectangle condition by using the train track argument. (Received September 17, 2018)

1145-57-982 **Oleg Viro*** (oleg.viro@gmail.com), Mathematics Department, Stony Brook University, Stony Brook, NY 11794. *Crystal colorings of framed graph diagrams and categorifications.* Preliminary report.

Some vertex state sum formulas which represent a quantum invariant look like sums over colorings of a planar diagram with elements of crystal bases of the representations which define the invariant. The summands can be used as generators of the complex that provides a categorification for the invariant. This approach gives the

Khovanov homology as a categorification of the Jones polynomial. In the talk it will be applied to construct categorifications of other invariants. (Received September 17, 2018)

1145-57-985 **Nur Saglam***, kadriye@ucr.edu, and **Anar Akhmedov**. *Constructions of Lefschetz fibrations using cyclic group actions.*

We construct families of Lefschetz fibrations over $\mathbb{S}^2$ using finite order cyclic group actions. In some cases, we also obtain more families of Lefschetz fibrations by applying rational blow-down operation. This is a joint work with Anar Akhmedov. (Received September 18, 2018)

1145-57-1009 **Nicolas Petit*** (petitnicola@gmail.com). *Finite-type invariants of virtual knots and tangles.*

We will be discussing some recent results in the theories finite-type invariants for virtual knots and virtual tangles. We will present some invariants and discuss their strength. (Received September 18, 2018)

1145-57-1045 **Katherine Walsh Hall*** (katie.hall@uconn.edu), Department of Mathematics, University of Connecticut, 341 Mansfield Rd, Storrs, CT 06269. *Patterns and Higher Order Stability in the Coefficients of the Colored Jones Polynomial.*

The colored Jones polynomial is a knot invariant that assigns to each knot a sequence of Laurent polynomials. For many families of knots, the coefficients of these polynomials are known to stabilize. We will discuss this stabilization as well as other patterns that arise in the coefficients. These patterns are related to some geometric properties of the knot including the hyperbolic volume. (Received September 18, 2018)

1145-57-1067 **Christian K Zickert*** (zickert@math.umd.edu). *Shape and Ptolemy coordinates for higher dimensional manifolds.* Preliminary report.

We discuss how the theory of shape and Ptolemy coordinates on representation varieties extends to higher dimensional manifolds. (Received September 18, 2018)

1145-57-1088 **David Futer*** (dfuter@temple.edu), Philadelphia, PA 19122. *The geometry of fibered knots and links.*

A knot complement in S^3 is called *fibered* if it has a map to S^1 without critical points, or equivalently if there is a Seifert surface F whose complement is homeomorphic to $F \times I$. For hyperbolic knots, a lot of the geometry of the knot complement can be predicted from the structure of the fibration. I will survey some of what is known on this topic, as well as some open problems. (Received September 18, 2018)

1145-57-1110 **Charles Frohman*** (charles-frohman@uiowa.edu), Department of Mathematics, The University of Iowa, Iowa city, IA 52242, and **Joanna Kania-Bartoszynska** and **Thang Le**. *The dimension of the Kauffman bracket skein algebra at roots of unity.*

Let ζ be an nth root of unity and let F be a connected oriented surface of finite type having negative Euler characteristic. The Kauffman bracket skein algebra of F at ζ, $K_\zeta(F)$, is a finite rank module over its center $Z_\zeta(F)$ that has no nontrivial zero divisors. Localizing at the nonzero central elements yields a division algebra $\widetilde{K}_\zeta(F)$ over the field $\widetilde{Z}_\zeta(F)$. First we compute the dimension of the algebra as a vector space over $\widetilde{Z}_\zeta(F)$. Next we compute the normalized trace

$$tr : \widetilde{K}_\zeta(F) \to \widetilde{Z}_\zeta(F),$$

coming from the action of $\widetilde{K}_\zeta(F)$ on itself by left multiplication. Finally we show how to construct bases for the algebra coming from a pair of pants decompositions of the surface. (Received September 19, 2018)

1145-57-1131 **Louis H Kauffman*** (kauffman@uic.edu), Math, UIC, 851 South Morgan Street, Chicago, IL 60607-7045. *Virtual Khovanov Homology.* Preliminary report.

The purpose of this talk is to discuss the structure of virtual Khovanov homology in the framework used by Vassily Mantorov and modified by Dye,Kaestner and Kauffman. We will discuss the present state of results of this theory including Lee virtual homology, generalizations of Rasmussen's theorem and the possiblity of constructing a Lipshitz-Sarkar type homotopy theory for the virtual Khovanov homology. (Received September 19, 2018)

1145-57-1148 **Sara Maloni*** (sm4cw@virginia.edu), 911 Flat Waters Lane, Charlottesville, VA 22911, and **Frederic Palesi** and **Tian Yang**. *On type-preserving representations of thrice punctured projective plane group.*

Abstract: In this talk we consider type-preserving representations of the fundamental group of the three-holed projective plane N into PGL(2, R). First, we prove Kashaev's conjecture on the number of connected components with non-maximal euler class. Second, we show that for all representations with euler class 0 there is a one simple closed curve which is sent to a non-hyperbolic element, while in euler class 1 or -1 we show that there are six components where all the simple closed curves are sent to hyperbolic elements and 2 components where there are some simple closed curves sent to non-hyperbolic elements. This answers a generalisation of a question asked by Bowditch. In addition, we show also, in most cases, that the action of the pure mapping class group Mod(N) on these non-maximal components is ergodic. (This is joint work with F. Palesi and T. Yang.) (Received September 19, 2018)

1145-57-1214 **Elizabeth Denne***, Washington & Lee University, Robinson Hall, Lexington, VA 24450. *Folded ribbon knots in the plane.* Preliminary report.

We study Kauffman's model of a folded ribbon knot: a knot made from a thin strip of paper folded flat in the plane. The folded ribbonlength is the length to width ratio of such a ribbon, and it turns out the way a ribbon is folded influences the ribbonlength. We give upper bounds on ribbonlength for several different families of knots. We also relate the ribbonlength of a knot to the crossing number of the knot, again giving bounds for several different families of knots. This is joint work with undergraduate students. (Received September 20, 2018)

1145-57-1245 **David Fisher**, **Jean-Francois Lafont**, **Nicholas Miller** and **Matthew Stover***, Temple University, Philadelphia, PA 19122. *Geodesic submanifolds of hyperbolic hybrids.*

Let M be a finite-volume hyperbolic n-manifold, $n > 2$ with fundamental group Γ. Mostow rigidity and the Margulis commensurator theorem imply that arithmeticity of Γ is equivalent to Γ having infinite index in its abstract commensurator. This has geometric consequences: if M contains a properly immersed totally geodesic hypersurface, then it contains infinitely many and they are everywhere dense. Reid and McMullen independently asked whether this geometric property implies arithmeticity, that is, if M contains infinitely many totally geodesic hypersurfaces then is Γ necessarily arithmetic?

I will explain progress toward a positive solution to this question, which is joint work with D. Fisher, J.-F. Lafont, and N. Miller. We proved that many nonarithmetic hyperbolic manifolds constructed from cut-and-paste methods, e.g., all the famous examples of Gromov and Piatetski-Shapiro, have the property that the set of maximal totally geodesic hypersurfaces is finite. These produce the first examples of hyperbolic n-manifolds for which the collection of geodesic hypersurfaces is known to be finite but nonempty. I will also discuss the generalization to higher codimension. (Received September 20, 2018)

1145-57-1254 **Sujoy Mukherjee*** (`sujoymukherjee@gwu.edu`). *Even Khovanov homology and odd torsion.*

Khovanov homology is a categorification of the Jones polynomial. Parts of the PS braid conjecture state that the order of the torsion subgroups in the Khovanov homology of a closed braid are less or equal to its braid index. On one hand, with the discovery of links with large even torsion in their Khovanov homology, this statement has been partially resolved. On the other hand, it is known that there exist infinite families of knots and links with odd torsion upto $\mathbb{Z}_7$. In this talk, we will focus on knots and links with larger odd torsion than $\mathbb{Z}_7$, like $\mathbb{Z}_9$, $\mathbb{Z}_{27}$, and $\mathbb{Z}_{25}$. Finally, we will discuss other recent developments in the study of torsion in Khovanov homology. (Received September 20, 2018)

1145-57-1472 **Wenzhao Chen*** (`chenwenz@msu.edu`). *A lower bound for the double slice genus.*

Given a knot in the 3-sphere, its double slice genus is the minimal genus of unknotted surfaces in the 4-sphere that contain the knot as a cross-section. Obviously twice the slice genus is a lower bound for the double slice genus. One really basic question is whether the double slice genus can be arbitrarily large compared to twice the slice genus. In this talk I will introduce a lower bound that can be used to answer this question. (Received September 22, 2018)

1145-57-1547 **Eric Chesebro**, **Jason DeBlois*** (`jdeblois@pitt.edu`) and **Priyadip Mondal**. *Which hyperbolic knot complements have hidden symmetries?*

The titular question was asked by Neumann and Reid in a paper published in 1992. Despite some progress since then, it's not clear that we're much closer to an answer today. In this talk I'll define and motivate terms, tie the question to the number theory of hyperbolic three-manifolds (very loosely construed) following Neumann and Reid, and describe some aspects of my own recent work on it with Eric Chesebro and Priyadip Mondal. (Received September 23, 2018)

1145-57-1665 **Razvan Gelca*** (`razvan.gelca@ttu.edu`), 1108 Memorial Circle Dr., Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79410. *The action of the Kauffman bracket skein algebra of the torus on the skein module of a knot complement.*

In Chern-Simons theory there is a quantum mechanical model for the quantization of the moduli space of connections on the torus. In the case of the gauge group $SU(2)$, the action of the Kauffman bracket skein algebra of the torus on the reduced Kauffman bracket skein module of the solid torus (or any manifold bounded by a torus) provides a good approximation of that model (though does not coincide exactly with it). But how does this action look like if we do not reduce the skein module? This is what the present talk wants to explain. (Received September 23, 2018)

1145-57-1716 **Ivan Dynnikov*** (steklov@mi-ras.ru), 8 Gubkina street, Steklov Mathematical Institute of RAS, Moscow, 119991, Russia. *On the equivalence of Legendrian knots.*

It is claimed in the manuscript arXiv:0909.4326 that two Legendrian knots that cobound an annulus in a tight contact 3-manifold such that the knots have zero relative Thurston–Bennequin invariant and relative rotation number, are equivalent. However, the proof in this manuscript is far from being complete. It is conjectured in [Dynnikov, I. A.; Prasolov, M. V. Rectangular diagrams of surfaces: representability. Sb. Math. 208 (2017), no. 5-6, 791–841] that the claim is false, and a potential counterexample is proposed. Namely, an annulus is constructed such that the two components of the boundary are Legendrian knots having zero relative invariants, with no obvious Legendrian isotopy from one component to another. Jointly with V.Shastin we now show that these Legendrian knots are indeed inequivalent. The proof is based on the techinque of the manuscirpt arXiv:1712.06366. The main technical difficulty is to show in a verifiable way that the symmetry group of the knots is trivial. This is done by analyzing the Alexander polynomial of the knots. (Received September 24, 2018)

1145-57-1724 **Jakob Hansen** (jhansen@math.upenn.edu) and **Robert Ghrist*** (ghrist@math.upenn.edu). *Towards a Spectral Theory of Cellular Sheaves.*

Spectral graph theory — the examination of spectral properties of the graph Laplacian — is an important tool in data analysis and other applications. By interpreting the graph Laplacian as the Hodge Laplacian of a constant sheaf, one is naturally led to the consideration of nontrivial sheaves over higher-dimensional cell complexes. This talk will trace out the first sketches of such a theory of spectral sheaves with potential applications. (Received September 24, 2018)

1145-57-1754 **Matthew Hedden** and **Miriam Kuzbary*** (miriam.kuzbary@rice.edu), 6100 Main St, Houston, TX 77005. *Link Concordance and Groups.*

Since its introduction in 1966 by Fox and Milnor the knot concordance group has been an invaluable algebraic tool for examining the relationships between 3- and 4- dimensional spaces. Though knots generalize naturally to links, this group does not generalize in a natural way to a link concordance group. In this talk, I will present joint work with Matthew Hedden where we define a link concordance group based on the"knotification" construction of Ozsv{a}th and Szab{o}. This group is compatible with Heegaard Floer theory and, in fact, much of the work on Heegaard Floer theory for links has implied a study of these objects. Moreover, we have constructed a generalization of Milnor's group-theoretic higher order linking numbers in a novel context with implications for our link concordance group. (Received September 24, 2018)

1145-57-1757 **Miles Clikeman**, **Rachel Morris** and **Heather M. Russell*** (hrussell@richmond.edu). *Ineffective sets and region crossing change.* Preliminary report.

A region crossing change (RCC) is an operation performed on a link diagram in which one reverses all crossings incident to a specific region of the diagram. This operation partitions the set of all diagrams with a fixed underlying projection into RCC equivalence classes. Recent work counts the number of classes for knot and link diagrams in the plane and checkerboard colorable diagrams on surfaces. An ineffective set of regions of a diagram has the property that performing RCCs on all regions in that set changes no crossings of the diagram. Ineffective sets are a key tool in the literature investigating RCC. In this talk, we explore ineffective sets for plane diagrams giving an easy method for finding all ineffective sets for any diagram. (Received September 24, 2018)

1145-57-1772 **Kenneth Cary Millett*** (kmillett@gmail.com), Department of Mathematics, UCSB, Santa Barbara, CA 9316. *Topological Entanglement in Macromolecules.*

The structure and consequences of topological entanglement in a macromolecular chain will be described using a local knotting and linking fingerprints that has been created for this specific purpose. They will be applied to several difference circumstances arising in the study of protein structures illustrating their character in these scientifically interesting instances. (Received September 24, 2018)

1145-57-1817 **Uwe Kaiser*** (ukaiser@boisestate.edu), Department of Mathematics, Boise State University, 1910 University Drive, Boise, ID 83725, and **Rama Mishra**. *Multi-sum representations of the colored Jones polynomial.* Preliminary report.

We relate and study three different multi-sum representations of the colored Jones polynomial of a knot, discuss extensions to the link case and apply to certain families of weaving knots. Special emphasis will be put on understanding non-triviality and cancellation of terms in the multi-sums. (Received September 24, 2018)

1145-57-1847 **Colin C. Adams**, **Or Eisenberg** and **Jonah Greenberg*** (jag9@williams.edu), 66 Hoxsey St, Williamstown, MA 01267, and **Kabir Kapoor**, **Kate O'Connor**, **Natalia Pacheco-Tallaj**, **Zhen Liang** and **Yi Wang**. *Hyperbolicity and Turaev Hyperbolicity of Knots and Virtual Knots.*

Since Thurston's work in the 1970's, we have known that many knots in S^3 are hyperbolic with the corresponding hyperbolic volume as an invariant. We extend this invariant to virtual knots and links and discuss implications. Furthermore, we consider links in Turaev surfaces arising from projections of classical and virtual links. We show any link has a projection that can be realized as a hyperbolic link in the thickened Turaev surface. We therefore can assign a new hyperbolic invariant which we call the Turaev volume to the entire class of virtual and classical knots and links. (Received September 24, 2018)

1145-57-1860 **Ramlah Ahmad**, **Mai Dao*** (mdao@smith.edu) and **Tommi Gans**. *Invariants of Colored Knots.* Preliminary report.

Given a diagram of a knot, a three-coloring is an assignment of one of three colors to each arc of the diagram, in such a way that at each crossing, either all three colors appear, or only one color appears. The number of different three-colorings of a knot is a knot invariant. We study other invariants derived from three-colorings of knots, including the classical dihedral linking number, from both diagrammatic and computational perspectives. (Received September 26, 2018)

1145-57-1910 **Cynthia L. Curtis** and **Kate O'Connor*** (oconnk17@tcnj.edu). *Weights of Essential State Surfaces: A Combinatorial Approach.* Preliminary report.

In this talk, we investigate the essential surfaces in the complements of two-bridge knots. The slopes of such surfaces contribute to computations of Culler-Shalen semi-norms, $SL(2,\mathbb{C})$ Casson invariants, and polytopes for A-polynomials, and some slopes are weighted more heavily than others in these computations. Ohtsuki has computed the weights of these surfaces for two-bridge knots. We present a more geometric method for computing these weights which we hope will lend itself to generalization to the computation of weights of essential state surfaces obtained by smoothings of diagrams for more general knots. (Received September 24, 2018)

1145-57-1918 **Ryan Blair**, **Patricia Cahn*** (pcahn@smith.edu) and **Alexandra Kjuchukova**. *Singular Branched Covers of the Four-Sphere.*

Which four-manifolds arise as three-fold branched covers of the four-sphere? We study this question for connected, embedded branching sets, with one singularity modelled on the cone on a knot K. We describe such a cover using a colored singular tri-plane diagram, which is a collection of three trivial tangles with compatible 3-colorings, satisfying certain additional properties. We describe new families of examples, and use these examples to study Kjuchukova's signature invariant, a ribbon obstruction derived from singular dihedral branched covers. (Received September 24, 2018)

1145-57-1940 **Kirk McDermott*** (kirk.mcdermott@sru.edu). *On the topology of groups of type $\mathcal{Z}$.*

For each group G of type $\mathcal{Z}$ there exists a spherical picture $\mathbb{P}$ over its cyclic presentation $\mathcal{P}$, and under certain conditions $\mathbb{P}$ gives rise to a Heegaard diagram for a 3-manifold M inducing $\mathcal{P}$. The groups of type $\mathcal{Z}$ arise as finite index subgroups of certain centrally extended triangle groups, the so-called shift extension of G. Having solved for example the finiteness and fixed point problems for groups of type $\mathcal{Z}$, it is possible to obtain a variety of topological conclusions. For instance, it follows immediately that the manifolds under consideration are all Seifert fibered. Examples are highlighted when a group of type $\mathcal{Z}$ demonstrates interesting shift dynamics (e.g. commensurability, fixed points). The topological interest lies in the fact that each manifold M can be described as a cyclic branched covering of a lens space, where the shift behaves as a periodic covering transformation. The 3-manifolds break down into two subfamilies, one of which includes and extends earlier results of Cavicchioli, Repovs, and Spaggiari. (Received September 24, 2018)

1145-57-1973 **Bakul Sathaye*** (sathaybv@wfu.edu). *Obstructions to Riemannian smoothings of locally CAT(0) manifolds.*

In this talk I will discuss obstructions to having a smooth Riemannian metric with non-positive sectional curvature on a locally CAT(0) manifold. I will focus on the obstruction in dimension = 4 given by Davis-Januszkiewicz-Lafont and show how their method can be extended to construct more examples of locally CAT(0) 4-manifolds that do not have a Riemannian smoothing. The universal covers of these manifolds satisfy the isolated flats condition and contain a collection of 2-dimensional flats with the property that their boundaries at infinity form non-trivial links in the boundary 3-sphere. (Received September 24, 2018)

1145-57-2014 **Maxime Bergeron***, mbergeron@math.uchicago.edu. *The topology, geometry and arithmetic of representation varieties.* Preliminary report.

Let Γ be a finitely generated group and let G be a complex reductive algebraic group defined over the integers. I will discuss the topology of the space or representations $Hom(\Gamma, G)$ and ask questions about its relationship to the arithmetic of the underlying variety. (Received September 24, 2018)

1145-57-2045 **Erica Flapan** (elf04747@pomona.edu), **Emille Davie Lawrence*** (edlawrence@usfca.edu) and **Robin Wilson** (robinwilson@cpp.edu). *Topological Symmetry Groups of the Heawood Graph.*

The study of graphs embedded in S^3 has been motivated by chemists' need to predict molecular behavior. The symmetries of a molecule can explain many of its chemical properties, however we draw a distinction between rigid and flexible molecules. Flexible molecules may have symmetries that are not merely a combination of rotations and reflections. Such symmetries prompted the concept of the *topological symmetry group* of a graph in S^3. We will discuss recent work on the classification of all groups which arise as the topological symmetry group for some embedding of the Heawood graph in S^3. (Received September 24, 2018)

1145-57-2055 **David Freund*** (dfreund@math.harvard.edu). *Singular Based Matrices for Virtual 2-Strings.* Preliminary report.

A singular virtual 2-string α is a wedge of two circles on a closed oriented surface. Up to equivalence by virtual homotopy, α can be realized on a canonical surface Σ_α. We use the homological intersection pairing on Σ_α to associate an algebraic object to α called a singular based matrix. We show that singular based matrices can be used to distinguish virtual homotopy classes of 2-strings and compute the virtual Andersen–Mattes–Reshetikhin bracket. (Received September 24, 2018)

1145-57-2075 **Jennifer Hom** (hom@math.gatech.edu), **Adam Simon Levine*** (alevine@math.duke.edu) and **Tye Lidman** (tlid@math.ncsu.edu). *Knot concordance in homology cobordisms.*

While not every knot in the 3-sphere bounds a smoothly embedded disk in the 4-ball, every such knot bounds a non-locally-flat piecewise-linear (PL) disk. For knots in the boundaries of other contractible 4-manifolds, however, even this weaker statement need not hold; the second author gave the first examples of knots in homology spheres that cannot bound PL disks in any homology 4-ball. In other words, the group of knots in homology 3-spheres that bound homology 4-balls, modulo non-locally-flat PL concordance in homology cobordisms, is nontrivial. In the present talk, we shall show that this group is infinitely generated and contains elements of infinite order. (Received September 24, 2018)

1145-57-2106 **Mark C Hughes*** (hughes@mathematics.byu.edu) and **Seungwon Kim**. *Immersed Möbius bands in knot complements and representatives of $\mathbb{Z}_2$-homology classes.*

We study the 3-dimensional immersed crosscap number of a knot, which is a nonorientable analogue of the immersed Seifert genus. We study knots with immersed crosscap number 1, and show that a knot has immersed crosscap number 1 if and only if it is a nonntrivial $(2p, q)$-torus or $(2p, q)$-cable knot. We show that unlike in the orientable case the immersed crosscap number can differ from the embedded crosscap number by arbitrarily large amounts, and that it is neither bounded below nor above by the 4-dimensional crosscap number. We then use these constructions to find, for any $n \geq 2$, an oriented 3-manifold Y_n and class $\alpha_n \in H_2(Y_n; \mathbb{Z}_2)$ such that α_n can be represented by an immersed $\mathbb{RP}^2$, but any embedded representative of α_n has a component S with $\chi(S) \leq 1 - n$. (Received September 24, 2018)

1145-57-2117 **Cory Glover*** (cory.s.glover@gmail.com), **Mark Hughes**, **Leslie Colton** and **Samantha Sandberg**. *Representing knot types by elements of a symmetric group.*

Petal projections are defined as a special class of knot projection with a single multi-crossing (called an uber-crossing), which causes the formation of loops entering and exiting the crossing. Petal projections can be described by elements in a symmetric group, called petal words, which describe the permutation of the strands as they pass through the uber-crossing. In this talk, I will discuss the symmetric group action on the set of petal words, and define a complete set of moves which is sufficient to relate any two petal words which represent the same knot type. (Received September 24, 2018)

1145-57-2119 **Caitlin Leverson*** (leverson@math.gatech.edu) and **Dan Rutherford**. *DGA Representations, Ruling Polynomials, and the Colored HOMFLY-PT Polynomial.*

Given a pattern braid $\beta \in J^1(S^1)$, to any Legendrian knot Λ in $\mathbb{R}^3$ with the standard contact structure, we can associate the Legendrian satellite knot $S(\Lambda, \beta)$. We will discuss the relationship between counts of augmentations of the Chekanov-Eliashberg differential graded algebra of $S(\Lambda, \beta)$ and counts of certain representations of the algebra of Λ. We will then define an m-graded n-colored ruling polynomial from the m-graded ruling polynomial, analogously to how the n-colored HOMFLY-PT polynomial is defined from the HOMFLY-PT polynomial, and extend results of the second author, to show that the 2-graded n-colored ruling polynomial appears as a specialization of the n-colored HOMFLY-PT polynomial. (Received September 24, 2018)

1145-57-2163 **Constance Leidy*** (cleidy@wesleyan.edu), Department of Mathematics & CS, 265 Church Street, Middletown, CT 06457. *Searching for structure in the knot concordance group.*

Two knots are concordant if they cobound a smoothly embedded annulus in $S^3 \times I$. Slice knots are those that are concordant to the unknot, or equivalently those that cobound a smoothly embedded disk in the 4-ball. The collection of concordance classes forms an abelian group, with identity element given by the collection of slice knots. In this talk, we will give an overview of knot concordance and will focus on attempts to find structure in the knot concordance group. (Received September 24, 2018)

1145-57-2203 **Radmila Sazdanovic*** (rsazdan@ncsu.edu), Department of Mathematics NC State Univeristy, PO box 8205, Raleigh, NC 27695, and **Vladimir Baranovsky**. *On factorization and chromatic graph homology.* Preliminary report.

Factorization homology, introduced by Ayala, Francis, and Tanaka, generalizes Hochschild homology. Helme-Guizon and Rong's chromatic homology, a Khovanov-type homology for graphs, approximates Hochschild homology when applied to cycle graphs. We provide alternative construction for the chromatic homology, similar to factorization homology. The main difference between the two constructions stems from using derived versus underived products. Therefore the chromatic homology of any graph can be thought of as an approximation of factorization homology. (Received September 25, 2018)

1145-57-2249 **Sandy Ganzell**, **Mercedes Gonzalez*** (gonzal20@southwestern.edu), **Chloe' Marcum**, **Nina Ryalls** and **Mariel Santos**. *Restrictions on Homflypt and Kauffman Polynomials Arising from Local Moves.* Preliminary report.

We study the effects of certain local moves on Homflypt and Kauffman polynomials. We show that all Homflypt (or Kauffman) polynomials are equal in a certain nontrivial quotient of the Laurent polynomial ring. As a consequence, we discover some new properties of these invariants. (Received September 25, 2018)

1145-57-2329 **Adam S Sikora***, 244 Math Bldg, North Campus, SUNY Buffalo, Buffalo, NY 14260. *Toric Degenerations of SL(2)-character varieties of surfaces.* Preliminary report.

We explore the properties of SL(2)-character varieties of surfaces using the theory of pseudo-Anosov diffeomorphisms and of measured foliations. In particular, we introduce the notion of transversal homology of surface foliations and show that each measured foliation on a surface S defines a toric degeneration of the SL(2)-character variety of S to the group ring of its transversal homology. (That gives a novel proof of irreducibility and of reduceness of SL(2)-character varieties of surfaces.) (Received September 25, 2018)

1145-57-2427 **Adam S Sikora*** (asikora@buffalo.edu), 244 Math Bldg, North Campus, University at Buffalo, SUNY, Buffalo, NY 14260. *Skein Algebras and Teichmuller Theory.* Preliminary report.

We explore the properties of skein algebras of surfaces using the theory of pseudo-Anosov diffeomorphisms and of measured foliations. In particular, we prove that every sufficiently generic measured foliation of a surface F realizes the skein algebra of F as a deformation of a polynomial algebra. That provides a novel proof of skein algebras being Ore domains. (Received September 25, 2018)

1145-57-2464 **Mariel Vazquez*** (mrlvazquez@ucdavis.edu), Department of Mathematics, UC Davis, One Shields Ave., Davis, CA 95616. *Topological modeling of DNA recombination.*

DNA replication in bacteria yields two interlinked circular chromosomes. Returning the chromosomes to an unlinked monomeric state is essential to cell survival. Simplification of DNA topology is mediated by enzymes, such as recombinases and topoisomerases. We here focus on site-specific recombinases that recognize two short segments of DNA (the recombination sites), introduce two double stranded breaks and recombine the ends. The local action of site-specific recombinases is a reconnection event which is modeled mathematically as a band surgery. The banding is coherent or non-coherent, depending on the relative orientation of the recombination sites. We use tools from low dimensional topology to investigate the mechanism of action of these enzymes, and we compliment the analytical work with computer simulations. The numerical work provides a quantitative measure to distinguish among pathways of topology simplification by recombination, and also informs the search for bandings between specific pairs of link types. This is joint work with Allison Moore, Michelle Flanner, Koya Shimokawa and Robert Stolz (Received September 25, 2018)

1145-57-2468 **Charles D Frohman** and **Joanna Kania-Bartoszynska***, jkaniaba@nsf.gov, and **Thang Le**. *Stabilized Dehn-Thurston coordinates for curves on a closed surface and their applications.*

Simple diagrams on a closed, oriented surface can be parametrized via Dehn-Thurston coordinates coming from pants decomposition. We show how to define stabilized DT coordinates and apply these to studying the Kauffman Bracket Skein Algebra. (Received September 25, 2018)

1145-57-2506 **Leslie Colton***, 828 E 1080 N, Orem, UT 84097, and **Corey Glover**, **Samantha Sandberg** and **Mark Hughes**. *A Complete Set of Moves on Petal Diagrams.*

In 2012 Adams et. al. described a new way of representing knots using a special class of diagrams with a single multicrossing (or übercrossing), called petal diagrams. Each petal diagram can be represented by a string of natural numbers where each number corresponds to the height of the strand in the übercrossing of the petal diagram. We call this string of numbers a "petal word". In this talk I will discuss a complete set of moves on petal words whereby one can transform the petal word of a knot into any other petal word representing the same knot type. (Received September 25, 2018)

1145-57-2871 **Andrew A Cooper***, Box 8205, North Carolina State University, Raleigh, NC 27695, and **Vin de Silva** and **Radmila Sazdanovic**. *Simplicial Complexes and Configuration Spaces.*

We introduce a generalization of the configuration space of n points in a manifold X, which takes as its data a simplicial complex S. The simplicial configuration space $M(S,X)$ gives rise to two invariants of S: the compactly-supported cohomology $H^*_c(M(S,X))$ and its Euler characteristic $\chi_c(S,X)$.

Both the homology and the Euler characteristic satisfy deletion-contraction type relations with respect to minimal nonfaces; thus we regard them as 'chromatic' invariants of S. Many well-known facts about configuration spaces – work of Fadell-Neuwirth, Bendersky-Gitler, Fulton-Macpherson, and Baranovsky-Sazdanović – generalize nicely to simplicial configuration spaces. We will discuss these geometric results and how they can be used to locate information about the topology and combinatorics of the complex S within the (co)homology of $M(S,X)$. (Received September 25, 2018)

1145-57-2897 **Alan Durfee*** (adurfee@mtholyoke.edu). *Rankings, combinatorial Hodge theory and statistics.* Preliminary report.

Suppose there are sports teams playing one another. We know the scores of each match, and we would like to use these scores to rank the teams. There are a number of methods for doing this, and I will describe two of them. The first rather sophisticated method is from a paper by Jiang et al (2011). It sets up the teams and matches as a one-dimensional simplicial complex K; a team corresponds to a vertex and a match to an edge. (Not all teams play one another so not all vertices are connected by edges.) A score then becomes an element of $C^1(K)$ and rank to an element of $C^0(K)$. Combinatorial Hodge theory (Eckmann, 1945) applied to this situation gives a ranking. Another more elementary was described by Massey in his undergraduate senior thesis (1997). It reworks the problem of finding a ranking to a problem in regression analysis. Under some simple assumptions these two methods are the same; the operators of combinatorial Hodge theory correspond to the equations of regression. I will explain how this happens. (Received September 25, 2018)

58 ► Global analysis, analysis on manifolds

1145-58-830 **Xavier Ramos Olive*** (olive@math.ucr.edu), **Shoo Seto**, **Guofang Wei** and **Qi S. Zhang**. *Zhong-Yang eigenvalue lower bound for the Laplacian on closed manifolds with integral Ricci curvature bounds.* Preliminary report.

On a closed Riemannian manifold with nonnegative Ricci curvature, using a gradient estimate of the eigenfunctions of the Laplace-Beltrami operator, Zhong-Yang proved a sharp lower bound for its first non-zero eigenvalue λ_1. The pointwise lower bound on the Ricci curvature is an assumption that comes from the derivation of the gradient estimate, which makes use of Bochner's formula.

Recently, similar gradient estimates have been obtained on manifolds where the pointwise lower bound has been replaced by an L^p bound on the negative part of the Ricci curvature. In this talk, we will see how these techniques can be applied to obtain a Zhong-Yang lower bound on manifolds with small negative Ricci curvature in the L^p sense, where the lower bound only depends on geometric parameters and recovers the classical Zhong-Yang lower bound in the limit $\mathrm{Ric} \geq 0$. (Received September 15, 2018)

1145-58-839 **Pierre Albin*** (palbin@illinois.edu), 1409 West Green St, Urbana, IL 61801. *On the Hodge theory of stratified spaces.*

I will discuss recent work with collaborators on analysis on singular spaces. These spaces show up naturally even when studying smooth objects, e.g., as algebraic varieties or orbit spaces of group actions. I will discuss how these analytic tools allow us to study the signature of stratified spaces. Time permitting I will discuss applications to the Novikov conjecture and to the Atiyah-Singer index theorem. (Received September 16, 2018)

60 ► Probability theory and stochastic processes

1145-60-47 **Parisa Fatheddin*** (paf49@pitt.edu), 301 Thackeray Hall, Pittsburgh, PA 15213, and **P. Sundar** and **Jie Xiong**. *Exit Times and The Law of the Iterated Logarithm for a Class of SPDEs.*

We introduce two commonly studied population models referred to as super-Brownian motion and Fleming-Viot Process, which were characterized by unique solutions to SPDEs by Jie Xiong. Using the large and moderate deviation results on these SPDEs, we derive exit times and two types of Law of the iterated logarithm: classical and Strassen's Compact law. The results are based on joint work with P. Sundar and J. Xiong. (Received July 03, 2018)

1145-60-50 **Leila Setayeshgar*** (leila_setayeshgar@alumni.brown.edu), 1 Cunningham Square, Providence, RI 02918, and **Mohammud Foondun**. *Large Deviations for a Class of Stochastic Semilinear Partial Differential Equations.*

Standard approaches to large deviations analysis for stochastic partial differential equations (SPDEs) are often based on approximations. These approximations are mostly technical and often onerous to carry out. In 2008, Budhiraja, Dupuis and Maroulas, employed the weak convergence approach and showed that these approximations can be avoided for many infinite dimensional models. Large deviations analysis for such systems instead relied on demonstrating existence, uniqueness and tightness properties of certain perturbations of the original process. In this talk, we use the weak convergence approach, and establish the large deviation principle for the law of the solutions to a class of semilinear SPDEs. Our family of semilinear SPDEs contains, as special cases, both the stochastic Burgers' equation, and the stochastic reaction-diffusion equation. (Received July 06, 2018)

1145-60-69 **Aaron Michael Yeager***, 913 S. Orchard, Stillwater, OK 74074. *On the Variance of the Number of Roots of Complex Random Orthogonal Polynomials Spanned by OPUC.*

Let $\{\varphi_k\}_{k=0}^{\infty}$ be a sequence of orthonormal polynomials on the unit circle (OPUC) with respect to a probability measure μ. We study the variance of the number of zeros of random linear combinations of the form

$$P_n(z) = \sum_{k=0}^{n} \eta_k \varphi_k(z),$$

where $\{\eta_k\}_{k=0}^{n}$ are complex-valued random variables. Under the assumption that μ satisfies $d\mu(\theta) = w(\theta)d\theta$, with $w(\theta) \geq c > 0$ for $\theta \in [0, 2\pi)$, and the distribution for each η_k satisfies certain uniform bounds for the fractional and logarithmic moments, we show that the variance of the number of zeros of P_n in annuli that contain the unit circle is at most of the order $n\sqrt{n \log n}$ as $n \to \infty$. When μ is symmetric with respect to conjugation and in the Nevai class, and $\{\eta_k\}_{k=0}^{n}$ are i.i.d. complex-valued standard Gaussian, we prove a formula for the limiting value of variance of the number of zeros of P_n in annuli that do not contain the unit circle. (Received July 18, 2018)

1145-60-82 **Indranil SenGupta*** (indranil.sengupta@ndsu.edu), NDSU Dept # 2750, Minard Hall 408, Fargo, ND 58108-6050, and **William Wilson** and **William Nganje**. *Hedging oil, corn, and soybean using the Barndorff-Nielsen and Shephard model.*

In this presentation, the Barndorff-Nielsen and Shephard (BN-S) model is implemented to find an optimal hedging strategy for various commodities (oil, corn, soybean) in North Dakota. One of the main assumptions made in a portfolio model of hedging is that the quantity of inventory or demand is fixed. However, this is inappropriate in many hedging situations. Quantity risk compounds the difficulty of determining the optimal size of position under both price and production risk. In this presentation, we provide a novel way of handling the quantity of risk in connection to the BN-S model. The model is analyzed in connection to the quadratic hedging problem and related analytical results are developed. (Received July 24, 2018)

1145-60-137 **Po-Keng Cheng***, 50 avenue Tony Garnier, ISFA, Laboratoire SAF EA2429, F-69366, 69366 Lyon, France, and **Frédéric Planchet**. *Stochastic deflator for an economic scenario generator with five factors.*

In this paper, we implement a stochastic deflator with four economic and financial risk factors: interest rates, stock prices, default intensities, and convenience yields. We examine the deflator with different financial assets, such as stocks, zero-coupon bonds, vanilla options, and corporate coupon bonds. Our numerical results show the reliability of the deflator approach in pricing financial derivatives. (Received August 08, 2018)

1145-60-216 **John C. Wierman*** (jwierma1@gmail.com), Dept. of Applied Mathematics & Statistics, 100 Whitehead Hall, Johns Hopkins University, Baltimore, MD 21218. *Recent progress on bounding bond percolation thresholds.* Preliminary report.

Percolation is an infinite random graph model which is one of the simplest models to exhibit a phase transition. In the bond percolation model, a random subgraph is obtained from an infinite connected graph G by retaining each edge independently with probability p, $0 < p < 1$. The percolation threshold $p_c(G)$ is the edge retention probability value above which the random subgraph contains an infinite connected component. The exact percolation threshold is known for only a few periodic lattice graphs, and rigorous bounds for unsolved graphs are generally rather poor.

We will discuss two comparison methods, which relate the threshold of an unsolved lattice graph to the threshold of an exactly-solved lattice. The substitution method uses stochastic ordering, symmetry reduction, non-crossing partitions, and network flow algorithms to compute improved bounds, and has been used to disprove long-standing conjectured exact values for two common planar lattices. A growth process approach obtains upper bounds for the bond percolation thresholds of common three-dimensional lattices, by exploring a sub-cluster of the open cluster as a dynamic process, then projecting onto a selected plane to obtain a two-dimensional growth process, for comparison with an exactly-solved lattice. (Received August 20, 2018)

1145-60-256 **Joe P Chen*** (jpchen@colgate.edu), Department of Mathematics, Colgate University, Hamilton, NY 13346. *Hydrodynamics on resistance spaces: from the asymmetric exclusion process to a nonlinear heat equation.*

I will present an overview of the analysis of the boundary-driven weakly asymmetric exclusion process—a model of multiple random walks subject to the exclusion rule—on the Sierpinski gasket, and discuss its hydrodynamic scaling limit. Our key results are as follows: the empirical density converges to the unique weak solution of a semilinear heat equation with a divergence-form nonlinear term; a large deviation principle for the empirical density in the symmetric exclusion process; and analysis of the said large deviation rate function.

Our proofs use the "entropy method" of Varadhan, and in doing so we discover a number of new technical results, in particular, a "moving particle lemma" which is optimal on any finite weighted graph, from which one can deduce local ergodicity on any strongly recurrent weighted graph, with or without translational invariance. As such we expect our proof methods to be applicable to the exclusion process on a state space equipped with Kigami's resistance form; or the zero-range process on the said state space.

Based partly on joint work with Michael Hinz and Alexander Teplyaev. (Received September 08, 2018)

1145-60-289 **Maria-Veronica Ciocanel***, ciocanel.1@osu.mbi.edu, and **John Fricks**, **Peter Kramer** and **Scott McKinley**. *A renewal reward approach for studying intracellular transport models.*

Many biological agents transition between different biophysical states during movement. For example, proteins inside cells bind and unbind to and from cellular roads called microtubules, switching between bidirectional transport, diffusion, and stationary states. Since models of intracellular transport can be analytically intractable, asymptotic methods are useful in investigating the effective cargo transport properties as well as their dependence on model parameters. We consider these models in the framework of renewal processes and derive the effective velocity and diffusivity of cargo at large time for a general class of problems. We also illustrate applications of the proposed method to macroscopic models of mRNA localization in developing oocytes and microscopic models of processive cargo movement by teams of molecular motor proteins. (Received August 28, 2018)

1145-60-334 **Fanhui Xu***, KAP 104, Department of Mathematics, University of Southern California, 3620 S. Vermont Ave., Los Angeles, CA 90089-2532, and **Remigijus Mikulevicius**, KAP 104, Department of Mathematics, University of Southern California, 3620 S. Vermont Ave., Los Angeles, CA 90089-2532. *The Rate of Convergence of Strong Euler Approximation for Lévy-driven SDEs.*

A SDE driven by an α-stable (Lévy) process with its coefficient being Lipschitz, the drift being β-Hölder continuous and α in [1,2) is considered. In particular, the existence and uniqueness of the strong solution to this SDE with non-Lipschitz drift is proved by applying Euler approximation and deriving the rate of convergence in L^p sense when $\beta < 1$, $\beta + \alpha/2 > 1$. When $\beta = 1$, i.e. in the Lipschitz case, the rate of convergence is provided as well. It turns out that it is better than the standard estimation on SDEs driven by a Wiener process. "Ito-Tanaka trick" is adequately used in the case of Hölder drift, properties of the solution to a backward Kolmogorov equation play an important role here. (Received September 02, 2018)

1145-60-404 **Oleksii Mostovyi*** (`oleksii.mostovyi@uconn.edu`), University of Connecticut, Department of Mathematics, 341 Mansfield Road, U1009, Storrs, CT 06268. *Asymptotic analysis of the expected utility maximization problem with respect to perturbations of the numeraire.*

In an incomplete model, where under an appropriate numeraire, the stock price process is driven by a sigma-bounded semimartingale, we investigate the sensitivity of the expected utility maximization problem to small perturbations of the numeraire. We establish a second-order expansion of the value function and a first-order approximation of the terminal wealth. Relying on a description of the base return process in terms of its semimartingale characteristics, we also construct wealth processes and corrections to optimal strategies that match the indirect utility function up to the second order. Finally, we relate the asymptotic expansions to the existence of the risk-tolerance wealth process. (Received September 05, 2018)

1145-60-465 **Mira Gordin*** (`miriam_gordin@brown.edu`). *Non-Hermitian Anderson Operators and their Spectral Properties.*

The random Non-Hermitian Anderson operator has both real eigenvalues and complex eigenvalues located on smooth analytic curves in the complex plane. We consider the global and microscopic distribution of the spacings between nearest eigenvalues and investigate the transition from of the eigenvalue distribution from the Poisson to the picket fence distribution. This work was completed as a part of the 2018 Williams College SMALL REU Program. (Received September 06, 2018)

1145-60-526 **Gunduz Caginalp*** (`caginalp@pitt.edu`), Mathematics Department, Univ of Pittsburgh, Pittsburgh, PA 15260. *Volatility maxima as a forecaster of trading price extrema.*

This is joint work with Carey Caginalp. The relationship between price volatility and a market extremum is examined using a fundamental economics model of supply and demand. By examining randomness through a microeconomic setting, we obtain the implications of randomness in the supply and demand, rather than assuming that price has randomness on an empirical basis. Within a very general setting the volatility has a maximum that precedes the extremum of the price. A key issue is that randomness arises from the supply and demand, and the variance in the stochastic differential equation governing the logarithm of price must reflect this. Analogous results are obtained by further assuming that the supply and demand are dependent on the deviation from fundamental value of the asset. The supply/demand approach also shows that fat tails (in particular with x^{-2} falloff) are endogenous to the trading mechanism. (Received September 08, 2018)

1145-60-614 **Upul H Rupassara*** (`upul@siu.edu`), Southern Illinois University, Department of Mathematics, 1245 Lincoln Drive, Carbondale, IL 62901. *Joint exit time and place distribution for Brownian motion on Riemannian manifolds.* Preliminary report.

We derive the formulas for the joint distribution of first exit time T, and place X_T of Brownian motion from normal balls of sufficiently small radius, in terms of the curvature of the Riemannian Manifolds. We use the asymptotic expansion of the Laplace transform of T to obtain the formulas for the different moments of the exit time. Additional curvature conditions are derived for the case where T and X_T are statistically independent. (Received September 17, 2018)

1145-60-622 **Benjamin D Schweinhart*** (schweinhart.2@osu.edu), Ohio State University, Mathematics Tower, 231 W 18th Ave, Columbus, OH 43210. *The Persistent Homology of Random Geometric Complexes on Fractals.*

We study the asymptotic behavior of the persistent homology of i.i.d. samples from a d-Ahlfors regular measure on a metric space — one that satisfies uniform bounds of the form

$$\frac{1}{c}\, r^d \leq \mu\big(B_r(x)\big) \leq c\, r^d$$

for all sufficiently small r and all x in the support of μ, where d can be any positive real number. Our main result is that if $x_1, \dots x_n$ are sampled from a d-Ahlfors regular measure on a metric space and $E_\alpha(x_1, \dots, x_n)$ denotes the α-weight of the minimal spanning tree on $x_1, \dots, x_n$:

$$E_\alpha(x_1, \dots, x_n) = \sum_{e \in T(x_1, \dots, x_n)} |e|^\alpha$$

then

$$E_\alpha(x_1, \dots, x_n) \approx n^{\frac{d-\alpha}{d}}$$

with high probability as $n \to \infty$, where the symbol $\approx$ denotes that the denotes that the ratio between the two quantities is bounded between two positive constants.

We prove similar results about the asymptotic behavior of weighted sums defined in terms of higher-dimensional persistent homology, under more restrictive hypotheses. As an application, we show that the fractal dimension of a measure can be computed from the persistent homology of i.i.d. samples from that space, in a manner similar to that proposed in the experimental work of Adams et al. (Received September 11, 2018)

1145-60-642 **Patricia Alonso-Ruiz*** (patricia.alonso-ruiz@uconn.edu), 341 Mansfield Road, U-1009, Storrs, CT 06269. *Heat kernels and functional inequalities on generalized diamond fractals.*

Generalized diamond fractals constitute a parametric family of spaces that arise as scaling limits of so-called diamond hierarchical lattices. The latter appear in the physics literature in the study of random polymers, Ising and Potts models among others. In the case of constant parameters, diamond fractals are self-similar sets. This property was exploited in earlier investigations by Hambly and Kumagai to study the corresponding diffusion process and its heat kernel. These questions are of interest in this setting in particular because the usual assumption of volume doubling is not satisfied. For general parameters, also the self-similarity is lost. Still, a diamond fractal can be regarded as an inverse limit of metric measure graphs and a canonical diffusion process obtained through a general procedure proposed by Barlow and Evans. This approach will allow us to provide a rather explicit expression of the associated heat kernel and deduce several of its properties. As an application, we will discuss some functional inequalities of interest. (Received September 12, 2018)

1145-60-650 **Alexandru Hening***, alexandru.hening@tufts.edu, and **Dang Hai Nguyen**. *When does the competitive exclusion principle hold in stochastic environments?*

The Competitive Exclusion Principle is a fundamental principle in ecology. It states that a number of species competing for a smaller number of resources cannot coexist. However, it has been observed empirically that in many instances this principle gets violated. Hutchinson famously coined the term 'the paradox of the plankton': an instance where a large number of phytoplankton species coexist while competing for a very limited number of resources. It has been shown theoretically that in some instances environmental fluctuations can help competing species coexist. In this talk I will showcase how different types of environmental stochasticity help preserve or violate the Competitive Exclusion Principle. The dynamics of the populations will be modeled by stochastic differential equations, piecewise deterministic Markov processes, or stochastic difference equations.

I will give conditions under which the competitive exclusion principle holds as well as provide examples of when it fails. The results show that stochastic factors have a strong effect on competitive exclusion and, therefore, should not be neglected. (Received September 12, 2018)

1145-60-677 **Ioannis Karatzas*** (ik1@columbia.edu), Department of Mathematics, Columbia University, 2990 Broadway, New York, NY 10027. *Arbitrage Theory Via Numeraires.*

We develop a mathematical theory for finance based on the "viability" principle that it should not be possible to fund, starting with arbitrarily small initial capital, a nonnegative liability which is strictly positive with positive probability. In the context of continuous semimartingale asset prices, we show that proscribing such egregious arbitrages (but allowing for the possibility that one portfolio might outperform another) turns out to be equivalent to each of the following conditions:

(i) a portfolio with the local martingale numeraire property exists, (ii) a growth-optimal portfolio exists, (iii) a portfolio with the log-optimality property exists, (iv) a strictly positive local martingale deflator exists, (v) the market has locally finite maximal growth.

These equivalent conditions can be formulated in terms of the characteristics of the underlying asset prices. Theories for hedging and optimization, and the important notion of "market completeness", are developed in such a setting. The semimartingale property of asset prices is equivalent to viability, when investment is discrete and long-only. (Joint work-book of the same title-with Constantinos Kardaras.) (Received September 12, 2018)

1145-60-682 **Duy Nguyen***, 3399 North Road, Poughkeepsie, NY 12601. *Optimal trading rules in a partial observable market.*

This work provides an optimal trading rule that allows buying and selling of an asset sequentially over time in a partial observable market. The asset price follows a Markovian regime switching geometric Brownian motion model. The objective is to de- termine a sequence of trading times to maximize an overall return. The corresponding value functions are characterized by a set of quasi variational inequalities. A solution is obtained under suitable conditions. The sequence of trading times can be given in terms of a set of threshold levels. Finally, numerical examples are given to demonstrate the results (Received September 12, 2018)

1145-60-700 **Andrew Papanicolaou*** (ap1345@nyu.edu), 12 Metrotech Center, Department of Finance and Risk Engineering, Brooklyn, NY 11201. *Nonlinear Filtering and Non-Markov Control in Financial Portfolio Optimization.*

Latent states are filtered from financial data using the Zakai equation. However the ensuing portfolio optimization problem is a non-Markov decision process because the posterior distribution of states is path dependent. There are a number of ways to solve this type of optimization, including backward stochastic differential equations (BSDEs) or through polynomial basis approximation. This talk explores these methods. (Received September 13, 2018)

1145-60-753 **Nobuhiro Asai*** (nasai@auecc.aichi-edu.ac.jp), Department of Mathematics, Aichi University of Education, 1 Hirosawa, Igaya, Kariya, Aichi 448-8542, Japan. *Probability distributions of a field operator associated with a q-deformed algebra.* Preliminary report.

The main purpose of this talk is to show that the q-field operator of Meixner type on q-Fock space in the sense of H. Yoshida (JPA 2011) can be realized on the (α, q)-Fock space in the sense of Bożejko-Ejsmont-Hasebe (JFA, 2015) in terms of (α, q)-operators if a special choice $\alpha = -q$ is considered. (Received September 14, 2018)

1145-60-785 **Weijie Pang*** (wpang@wpi.edu) and **Stephan Sturm**. *XVA Valuation Under Market Illiquidity.*

Before the 2008 financial crisis, most option pricing methods ignored the effects of counterparties' default and funding illiquidity. Recently models were proposed to compute the total valuation adjustment (XVA) of a European claim, including funding costs, counterparty credit risk and collateralization. However, those models abstract from an important fact: the repo market froze during the 2008 financial crisis, because of the rarity of general collateral and loss of confidence in other collaterals. The frozen repo market led to a shutdown of short trades in stock. Thus, it's very important to include the different behavior of repo and stock market in normal and financial crisis status. In our research we describe the switching between two financial status by an alternating renewal process, which switches between zero and one with inter-arrival times following exponential distributions. We develop a framework for pricing the XVA of a European claim in this state-dependent framework. We show the existence of a unique classical solution to the pricing BSDE based on a martingale decomposition theorem on a space generated by not-independent increment stochastic processes. (Received September 14, 2018)

1145-60-791 **David Saunders*** (dsaunders@uwaterloo.ca), Statistics and Actuarial Science, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2N3M3, Canada, and **Fei Meng** (feimengchen@yahoo.com), Statistics and Actuarial Science, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2N3M3, Canada. *Mathematical Problems Arising from Hedge Fund Fee Structures.*

Traditional fee structures for hedge funds involve a flat fee expressed as a percentage of assets under management, together with a performance fee that has the structure of a call option. This structure has disadvantages for investors both in terms of expenses, as well as the incentives it provides for hedge fund managers. We will discuss a new fee structure that has been adopted by some funds in the industry, referred to as the shared-loss fee structure. In this framework, in return for receiving upside participation, the fund manager provides some

downside protection against losses to the investors. We study a number of problems including the optimal stopping problem of an investor deciding when to withdraw funds from a hedge fund operating with a shared loss fee structure. We will consider properties of the value function, characterized as the solution of a variational inequality, and the small-time behaviour of the stopping boundaries. (Received September 14, 2018)

1145-60-811 **Arka Ghosh** and **Steven Noren*** (snoren@lssu.edu), 650 W. Easterday Avenue, CAS 206-I, Sault Sainte Marie, MI 49783, and **Alexander Roitershtein**. *Favorite sites of a persistent random walk on $\mathbb{Z}$.*

We consider favorite (i.e., most visited) sites of the symmetric persistent random walk on $\mathbb{Z}$, a discrete-time process typified by the correlation of its directional history. We show that the cardinality of the set of favorite sites is eventually at most three. This is a generalization of a result by Tóth for a simple random walk, used to partially prove a longstanding conjecture by Erdős and Révész. (Received September 15, 2018)

1145-60-819 **Peter Jan van Leeuwen*** (p.j.vanleeuwen@reading.ac.uk). *Transportation Particle Filter for high-dimensional geophysical applications.*

Data assimilation, the science of combining large observation sets with complex high-dimensional numerical models, is often highly nonlinear. Particle filters are promising for these problems but traditionally suffer from filter degeneracy where only one particle is weighted high by the observations, and the rest obtain very low weights. The way forward seems to be particle filters that have equal weights by construction. One of those filters is transportation, in which the particles are transported from samples of the prior to samples of the posterior. By embedding the flow map (not the prior or the posterior!) in a Reproducing Kernel Hilbert Space we develop a smooth iterative mapping that minimises the KL-divergence between the intermediate pdfs and the posterior. We will show results of this methodology on realistic high-dimensional geophysical problems and specifically discuss issues related to the high-dimensional applications. (Received September 15, 2018)

1145-60-822 **Paul Bourgade***, bourgade@cims.nyu.edu, and **Fan Yang**, **Horng-Tzer Yau** and **Jun Yin**. *Random band matrices in the delocalized phase.*

I will survey recent mathematical results about the spectrum of random band matrices and the problem of their Anderson transition. In particular, I will present a method to obtain delocalization and universality in sparse regimes, highlighting the role of quantum unique ergodicity. (Received September 15, 2018)

1145-60-873 **Xin T Tong*** (mattxin@nus.edu.sg), Room 806, Block S17, 10 Lower Kent Ridge Road, Singapore, 119076. *Local ensemble Kalman filter in high dimension.*

Ensemble Kalman filter (EnKF) is an important data assimilation method for high dimensional geophysical systems. Efficient implementation of EnKF in practice often involves the localization technique, which updates each component using only information within a local radius. We rigorously analyze the local EnKF (LEnKF) for linear systems, and show that the filter error can be dominated by the ensemble covariance, as long as 1) the sample size exceeds the logarithmic of state dimension and a constant that depends only on the local radius; 2) the forecast covariance matrix admits a stable localized structure. The analysis also reveals an intrinsic inconsistency caused by the localization technique, and a stable localized structure is necessary to control this inconsistency. While this structure is usually taken for granted for the operation of LEnKF, it can also be rigorously proved for linear systems with sparse local observations and weak local interactions. These theoretical results are also validated by numerical implementation of LEnKF on a simple stochastic turbulence in two dynamical regimes. (Received September 16, 2018)

1145-60-884 **K Solna*** (ksolna@math.uci.edu), UC Irvine, Irvine, CA 92617, and **J Garnier**, Paris. *Beam Wave Scattering and Imaging in Clutter.*

We will consider waves transmitted through and reflected from a complex medium in the case in which the medium has fine scale three-dimensional random fluctuations. We show how we can characterize statistically the beam wave in this case. Moreover, we show how we can use this characterization in the context of imaging and detection in very complex environments. (Received September 17, 2018)

1145-60-933 **Marcus Michelen*** (marcusmi@sas.upenn.edu). *Central Limit Theorems from the Roots of Probability Generating Functions.*

Given a sequence of random variables X_n taking values in $\{0, 1, \ldots, n\}$, what information can be deduced about the distribution of X_n based on the roots of their generating functions? We show that if the roots uniformly avoid a neighborhood of 1 in the complex plane, then there is a central limit theorem provided the variance of X_n isn't subpolynomial in n. An application to combinatorial problems such as counting subgraphs with small maximum degree will be discussed. Time permitting, further limit theorems and examples will be briefly described. This is based on joint work with Julian Sahasrabudhe. (Received September 17, 2018)

1145-60-957 **Adrian D. Banner*** (abanner@intechjanus.com), One Palmer Square, Suite 441, Princeton, NJ 08540. *Competing Diffusive Particle Systems and Models of Large Equity Markets: A Survey.*

Stock-price processes are often modeled as exponential semimartingales. One can model large equity markets with a collection of a large number of such processes, but special care must be taken to ensure that the model exhibits stability properties consistent with real-world observations. For example, the capital distribution of equity markets, along with average occupation times for given capitalization-ranks, are observed to be stable. This survey talk will focus on hybrid atlas-type models, which are constant-parameter models of exponential semimartingales, in which the growth rates and variances depend only on capitalization rank and stock identity. These models approximate the observed stability properties described above, while being simple enough to permit analytic study. The methodologies used in these analyses touch upon the question of triple points; in particular, some choices of parameters may permit triple points to occur, but there is no resultant effect on any stability properties. Joint works with T. Ichiba, I. Karatzas, R. Fernholz, V. Papathanakos, S. Pal and M. Shkolnikov. (Received September 17, 2018)

1145-60-1170 **Aadrita Nandi*** (aadrita.nandi@ttu.edu) and **Linda J.S. Allen** (linda.j.allen@ttu.edu). *Probability, Final Size, and Duration of an Outbreak in Stochastic Multigroup Models.*

A serious concern to public health is emerging infectious diseases, including those of zoonotic origin such as SARS, MERS and Ebola and re-emerging diseases such as measles and pertussis. Amplification and spread of infection in several emerging diseases have been attributed to highly infectious individuals known as superspreaders. Vaccine waning or lack of vaccine protection are some of the reasons for disease outbreaks in re-emerging diseases. We apply Markov chain models and branching process approximations in the setting of multigroup models to investigate the probability, final size and duration of an outbreak when there are differences between the groups in either host infectivity potential or host susceptibility to infection. One conclusion of the models is that probability of a major disease outbreak is much greater when initiated by individuals with the highest infectivity potential (e.g., superspreaders). Also, the models show that if groups are characterized by their infectivity potential as opposed to their susceptibility to infection, the overall probability of an outbreak is smaller but the final size is greater. (Received September 19, 2018)

1145-60-1189 **Adrian Dietlein** (aelgart@vt.edu) and **Alexander Elgart***, type address 2. *Level spacing and Poisson statistics for continuum random Schrödinger operators.*

For the standard Anderson model on the lattice, Minami's estimate implies that, with high probability, the eigenvalues of the Anderson model are well-spaced. Unfortunately, the method fails beyond rank one random perturbation. We will describe a new, more flexible approach towards such a level-spacing estimate. In particular, it works for the continuum Anderson model, at the bottom of its spectrum. If the single-site probability distribution is sufficiently regular, it leads to a Minami-type estimate and Poisson statistics of eigenvalues for this model. (Received September 19, 2018)

1145-60-1259 **Nils Detering*** (detering@pstat.ucsb.edu), University of California, South Hall 5505, Statistics and Applied Probability, Santa Barbara, CA 93106, and **Thilo Meyer-Brandis**, **Konstantinos Panagiotou** and **Daniel Ritter**. *An Asymptotic Model for Fire Sales.*

In this article, we propose an asymptotic model for fire sales in financial systems. Our starting point is a setup for finite financial systems which consist of institutions holding shares of certain assets and capital. Caused by an initial shock and described by some exogenous sale function institutions start selling some of their shares. This provokes a decline in the asset price described by some price impact function and more institutions might be forced to sell assets. We describe the final state of the system by a fixed point equation. Under mild regularity assumptions, we can then consider the limit as the size of the system tends to infinity and we derive explicit analytic results for the final price impact (which is of interest also to investors outside the considered financial system) and the number of finally defaulted institutions. Moreover, we characterize resilient and non-resilient systems and determine capital requirements to make systems resilient. Our results allow to analyze the trade-off between objectives for single firm risk management (diversification) and those for systemic risk management (non-overlapping portfolios). (Received September 20, 2018)

1145-60-1279 **Ram Sharan Adhikari*** (radhikari@rsu.edu), 1701 W Will Rogers Blvd, Claremore, OK 74014. *A weak rectangular method for a class of stochastic differential equations and mean square stability analysis.*

This work proposes a novel weak rectangular method for numerical solution for a class of stochastic differential equations. We show that such a method has weak convergence of order one. The proposed weak rectangular method has the potential to overcome some of the numerical instabilities that are often experienced when using explicit Euler method. This work also aims to determine the mean-square stability region of the weak rectangular method for linear stochastic differential equations with multiplicative noises. In this work, a mean-square stability region of the weak rectangular is identified, and step-sizes for the numerical method where errors propagation are under control in well-defined sense are given. The main results are illustrated with numerical examples. (Received September 20, 2018)

1145-60-1365 **Tathagata Banerjee** and **Zachary Feinstein*** (zfeinstein@wustl.edu). *Pricing debt in financial networks with comonotonic endowments.*

In this talk we present formulas for the pricing of debt and equity of firms in a financial network under comonotonic endowments. We demonstrate that the comonotonic setting provides a lower bound to the price of debt under Eisenberg-Noe financial networks with consistent marginal endowments. Such financial networks encode the interconnection of firms through debt claims. The proposed pricing formulas consider the realized, endogenous, recovery rate on debt claims. Special consideration will be given to the setting in which firms only invest in a risk-free bond and a common risky asset following a geometric Brownian motion. (Received September 21, 2018)

1145-60-1453 **Adina Oprisan*** (oprisana@canisius.edu), Department of Mathematics and Statistics, Canisius College, Buffalo, NY 14208. *Large deviations for additive functionals of semi-Markov processes.*

In this talk, a class of additive functionals of ergodic semi-Markov processes is considered. Limiting theorems such as functional central limit theorem, almost sure convergence for the associated empirical processes and large deviation principle will be discussed. (Received September 22, 2018)

1145-60-1579 **Ambar N Sengupta*** (ambar.sengupta@uconn.edu), Department of Mathematics, University of Connecticut, 341 Mansfield Road, Storrs, CT 06269, and **Jeyaraj Vadiveloo** and **Jiatian Xu**. *The Actuarial HLE Model: Mathematical Aspects and Applications.* Preliminary report.

We describe an actuarial Healthy Life Expectancy (HLE) model and its applications developed at UConn's Goldenson Center. (Received September 23, 2018)

1145-60-1590 **Gregory Handy*** (handy@math.utah.edu), **Sean D Lawley** and **Alla Borisyuk**. *Influence of Receptor Recharge on the Statistics of Captured Particles.*

We consider a setup where particles are released into a domain and diffuse freely. Part of the boundary is absorbing, where the particles can escape the domain, another part is reflecting. The rest of boundary consists of capture regions that switch between being reflecting and absorbing. After capturing a particle, the capture region becomes reflecting for an exponentially distributed amount of time. This non-zero recharge time correlates the particles' paths, complicating the mathematical analysis of this system. We are interested in the distribution of the number of particles that are captured before they escape. Our results are derived from considering our system in several ways: as a full spatial diffusion process with recharging traps on the boundary; as a continuous-time Markov process approximating the original system; and lastly as a system of ODEs in a mean-field approximation. We discuss the conditions required for the approximations to yield similar results as the spatial process. We then apply them to investigate time courses for the expected number and higher ordered statistics of captured particles. We find that the number of expected cumulative captures increases linearly before saturating, and find an analytical expression for the duration of the linear growth. (Received September 23, 2018)

1145-60-1597 **Aurel I Stan*** (stan.7@osu.edu), OSU, Columbus, OH 43210. *A characterization of probability measures in terms of their semi-quantum operators.* Preliminary report.

Given a probability measure on the Borel subsets of R^d, having finite moments of all orders, we can construct the joint quantum operators: creation, preservation, and annihilation operators of that measure. Splitting each preservation operator into two halves, and adding one half to the corresponding creation operator, and the other half to the corresponding annihilation operator, we obtain the semi-quantum operators: semi-creation and semi-annihilation operators. We give first a canonical definition of the semi-quantum operators, and then

we characterize the polynomially symmetric and polynomially factorisable probability measures in terms of the semi-quantum operators. (Received September 23, 2018)

1145-60-1756 **Mauro Maggioni*** (mauro@math.jhu.edu), Department of Mathematics, 3400 N Charles St, Baltimore, MD 21218. *Statistical Learning and Geometric techniques for Dynamical Systems.*

We discuss problems on statistical learning for dynamical systems. We assume to have access to a (large number of expensive) simulators that can return short paths of the stochastic system, and introduce a statistical learning framework for estimating local approximations to the system, that can be (automatically) pieced together to form a fast global reduced model for the system, called ATLAS. ATLAS is guaranteed to be accurate (in the sense of producing stochastic paths whose distribution is close to that of paths generated by the original system) not only at small time scales, but also at large time scales, under suitable assumptions on the dynamics. We discuss applications to homogenization of rough diffusions in low and high dimensions, as well as relatively simple systems with separations of time scales, and deterministic chaotic systems in high-dimensions, that are well-approximated by stochastic diffusion-like equations. We also discuss the problem of learning interaction laws in agent systems, given only observed trajectories. This is joint work with M. Crosskey, F. Lu, S. Tang, and M. Zhong. (Received September 24, 2018)

1145-60-1795 **Olivier Menoukeu Pamen*** (olivier@aims.edu.gh), African Institute for Mathematical Sciences, Cape Coast, DL 676, Ghana. *A stochastic maximum principle for controlled stochastic factor model.*

In this talk, we propose a stochastic maximum approach to solve an optimal control problem for a stochastic factor model. We show that this problem is reduced to an optimal control for a class of stochastic partial differential equation. We first derive a necessary stochastic maximum principle. Second, we derive an equivalent stochastic maximum principle. Finally, we apply the obtained results to study both pricing and hedging problem for stochastic factor model in commodity market via utility theory. (Received September 24, 2018)

1145-60-1798 **Marko Weber***, mhw2146@columbia.edu, and **Agostino Capponi**. *Optimal portfolio allocations in a heterogeneous banking system.*

We study the portfolio choice implications of leverage constrained banks, which need to deleverage in response to price shocks so to satisfy regulatory leverage requirements. Banks select their asset holdings in order to minimize their expected execution costs, in a financial market consisting of multiple assets. Consistent with the classic theory of portfolio choice, diversification is optimal if each bank neglects the impact caused by the other agents' liquidation actions. If banks are heterogeneous in their leverage ratios, in equilibrium they reduce portfolio overlapping and seek diversity, at the expenses of sacrificing diversification benefits on the individual level. The bank's equilibrium allocation is not socially efficient. A benevolent social planner aiming for minimum deadweight losses from liquidation should provide banks with incentives to increase their diversity. (Received September 24, 2018)

1145-60-1925 **William A Massey*** (wmassey@princeton.edu), ORFE Department, Sherrerd Hall, Princeton University, Princeton, NJ 08544. *Dynamic Queueing Transience.*

Inspired by communication systems and healthcare services, we summarize the innovative stochastic analytic methods developed to understand the transient behavior of dynamic rate queues. The static, steady-state, equilibrium analysis for queues with constant rate parameters no longer applies here. For stochastic queueing models that are typically time-inhomogeneous or have time-varying parameters, their evolution is best summarized by deterministic dynamical systems.

Many of these new insights are obtained by applying a specific asymptotic method called uniform acceleration. This scaling analysis can be applied to the transition probabilities of the underlying dynamic rate Markovian models. When these same asymptotics are applied directly to the random sample path behavior of a large class of queueing models, they also yield both functional strong law of large numbers and functional central limit theorems that gives us our dynamical systems. We can also find these associated differential equations directly for many queueing models by appealing to the theory of Poisson random measures or Hermite polynomial closure approximations applied to Gaussian random variables. (Received September 24, 2018)

1145-60-1981 **Mela Hardin*** (melahardin@asu.edu) and **Nicolas Lanchier**. *Opinion Dynamics with Confidence Threshold.* Preliminary report.

Interacting particle systems is a field of probability theory devoted to the rigorous analysis of certain types of models that arise in other fields such as physics, biology, and economics. One popular example of such systems is the voter model for the dynamics of opinions. The general opinion model discussed in this talk is a variant of the voter model that views the set of opinions as a general connected graph, $G = (V, E)$, with vertices as opinions. Individuals with these opinions lie on a spatial connected graph, $\mathcal{G} = (\mathcal{V}, \mathcal{E})$, with vertices as individuals. Pairs of neighbors interact at rate one unless the geodesic distance between their opinions exceeds some confidence threshold $\tau \in \mathbb{N}$. Each interaction results in the opinion of one of the two individuals moving one step towards the opinion of the other individual. The main question about the general opinion model on infinite graphs is whether the system fluctuates and clusters, leading to a global consensus, or fixates in a fragmented configuration. When the underlying spatial structure is a finite connected graph, the process fixates after an almost surely finite time T, and we study lower bounds for the probability that, at this time, the system reaches a consensus. (Received September 24, 2018)

1145-60-2109 **Iuliana Teodorescu** and **Razvan Teodorescu*** (razvan@usf.edu), CMC 314, 4202 E Fowler Ave, University of South Florida, Tampa, FL 33620. *Stochastic dynamical systems under geometric constraints.*

We discuss the problem of defining stochastic dynamical systems under geometric constraints. These are important for applications such as modeling growth processes (biological, physical) or describing stochastic perturbations to constrained, correlated systems. The difficulty in defining such processes is due to the existence of global, nonlocal constraints which must be incorporated with local, random driving forces. We present a class of such models for which there exists a general formalism, based on integral transforms in two dimensions. (Received September 24, 2018)

1145-60-2125 **Eddie B. Tu*** (tue@dickinson.edu), 20 N. Pitt St., #2, Carlisle, PA 17013. *Association and other forms of positive dependence for Feller evolution systems.*

Feller evolution systems are a class of stochastic processes which contain interesting examples, such as additive processes and certain stochastic volatility models. These processes have Lévy-type behavior and can be temporally and spatially inhomogeneous. We propose methods of characterizing strong forms of positive dependence, such as association, positive supermodular association, and positive orthant dependence, for Feller evolution systems. We give characterizations for general Feller evolution systems and for jump-Feller evolution systems, and we will look at specific examples in additive processes and certain stochastic volatility models. (Received September 24, 2018)

1145-60-2278 **David Lipshutz*** (lipshutz@technion.ac.il), Faculty of Electrical Engineering, Technion — Israel Institute of Technology, 32000 Haifa, Israel, and **Rami Atar**. *Load balancing for queues using delayed information.*

We consider a load balancing problem for a network of parallel queues in which incoming jobs (or customers) are routed to one of the queues upon arrival. In our model, the routing decision depends only on past routing decisions and the delayed state of the queues. When a job arrives to the queue, the current state of the queues is estimated based on this information and the incoming job is routed to the queue with the shortest estimated length. We formulate a setting where the delay remains constant under heavy traffic scaling, so the effects of the delay do not disappear. We prove state space collapse of the estimated queue lengths under heavy traffic scaling. This allows us to formulate a diffusion model and prove convergence to it under several natural estimation schemes. (Received September 25, 2018)

1145-60-2398 **David Eric Weisbart*** (weisbart@math.ucr.edu). *A Product Formula for Functional Integrals over Rational Adelic Paths.*

For any prime p, the fundamental solutions to heat equations given by a large class of p-adic pseudo-Laplace operators give rise to measures on the Skorokhod space of paths valued in $\mathbb{Q}_p$. The subset of Adelic paths has full measure in this product space if and only if the infinite sum of the diffusion constants in each p-adic component is convergent. Furthermore, the induced measure on the Adelic Skorohod space is a measure given by an Adelic heat equation. The path integral representation for the dynamical semigroup associated with the Adelic Schrödinger-type operator given by this Adelic heat equation and a bounded simple Adelic potential is a product of path integrals over the p-adic components. (Received September 25, 2018)

1145-60-2399 **Sher B. Chhetri***, 777 Glades Rd., Boca Raton, FL 33431, and **Hongwei Long**, 777 Glades Rd., Boca Raton, FL. *Parameter Estimation for Jump Diffusion Model Driven by α-stable Lévy Motion.* Preliminary report.

In finance, various stochastic models are used to model the price movements of financial instruments. After Robert Morton's (1976) seminal work, several jump diffusion models for option pricing and risk management have been proposed. In this work, we add α-stable Lévy motion to the process related to dynamics of log-returns in the Black-Scholes model. We use sample characteristic functions to estimate parameters involved in the process that is discretely observed. We also discuss the consistency and asymptotic normality of the proposed estimators. Simulation results and applications to real data sets will be presented. (Received September 25, 2018)

1145-60-2424 **P. Sundar*** (psundar@lsu.edu), Department of Mathematics, Lockett Hall, Louisiana State University, Baton Rouge, LA 70803. *The Enskog process for hard and soft potentials.* Preliminary report.

The density of a moderately dense gas evolving in a vacuum is given by the solution of an Enskog equation. The stochastic process that corresponds to the Enskog equation is identified as the solution of a McKean-Vlasov equation driven by a Poisson random measure. Based on a suitable particle approximation with binary collisions, the existence of an Enskog process is established for a wide class of collision kernels. A suitable coupling inequality is shown which leads to a proof of uniqueness and stability of solutions to the Enskog equation and the Enskog process. This is a joint work with B. Ruediger and M. Friesen. (Received September 25, 2018)

1145-60-2451 **Nathan Hayford*** (n.hayford6@gmail.com), CMC 342, 4202 E Fowler Ave, University of South Florida, Tampa, FL 33620, and **Razvan Teodorescu**. *Defect formation probability in stochastic models of Ising type.*

In a statistical mechanics model of locally-interacting spin variables, the most likely configuration can be easily obtained as the solution of an associated optimization problem. When used to describe certain physical systems, the problem of predicting the probability of configurations different from the most likely one is particularly relevant. We describe analytical methods for characterizing the formation of such "unlikely" configurations, along with applications to the theory of computation. (Received September 25, 2018)

1145-60-2455 **Rohini Kumar** and **Hussein Nasralah***, hmnasralah@wpi.edu. *Portfolio optimization for small time horizons.*

We study the problem of portfolio optimization in an incomplete market and under general assumptions on the investor's utility function. By constructing classical sub- and supersolutions to the associated HJB equation, we obtain a first order approximation of the value function for small time horizons. A closed-form formula for a close-to-optimal portfolio is then obtained for small time horizons. A scheme to extend our small time results to larger finite horizons will then be discussed. (Received September 25, 2018)

1145-60-2510 **Andrey Sarantsev***, 1664 N Virginia St, Davidson Math & Science Center 314, University of Nevada, Reno, NV 89557. *Systems of Competing Brownian Particles.*

Brownian particles interacting through their ranks have been subject of much recent research, starting from 2005 onward. Here, we survey recent developments and propose new problems. (Received September 25, 2018)

1145-60-2551 **Greg Lawler*** (lawler@math.uchicago.edu). *Two-sided loop-erased random walk.*

A loop-erased walk on the integer lattice is a path without intersections obtained by erasing loops from a standard random walk. We construct a two-sided version of this in all dimensions which can be considered the measure on the path "viewed in the middle". In two dimensions the transition probabilities can be described in terms of random walk with some "negative weights". This includes joint work with Christian Benes and Fredrik Viklund. (Received September 25, 2018)

1145-60-2565 **Aziz Issaka*** (aissaka@uncc.edu), Department of Mathematics and Statistics, University of North Carolina at Charlotte, 9201 University City Blvd., Charlotte, NC 28223, and **Indranil SenGupta**. *Analysis of variance based financial instruments: swaps and price indices.*

In this presentation, various financial applications of a stochastic model are studied. Firstly, a number of aspects of the variance swap in connection to the Barndorff-Nielsen and Shephard model (BN-S) are studied. A partial integro-differential equation that describes the dynamics of the arbitrage-free price of the variance swap is formulated. Secondly, under appropriate assumptions for the first four cumulants of the driving subordinator, a "Vecer-type theorem" is proved. The bounds of the arbitrage-free variance swap price are also found. Finally, a price-weighted index modulated by market variance is introduced. The large-basket limit dynamics of the price index and the "error term" are derived. Empirical data-driven numerical examples are provided in support of the proposed price index. (Received September 25, 2018)

1145-60-2574 **Tingting Ou*** (tou2@jhu.edu), 3700 N Charles St, Apt 3B, Baltimore, MD 21218, and **Michelle Shu** (mshu1@jhu.edu), 1 E University Parkway, #604, Baltimore, MD 21218.
Probabilistic Counting-Out Game on a Line. Preliminary report.

Our research focuses on a novel problem posted on a question-and-answer website. There are n people in a line at positions $1, 2, \dots, n$. For each round, we randomly select a person at position k, where k is odd, to leave the line, and shift the people at position i such that $i > k$ to position $i-1$. We continue to select people until there is only one person left, who then becomes the winner. We are interested in two questions: which initial position has the greatest chance to win and which has the longest expected time to stay in the line. We have derived recursions to solve for exact values of the winning probabilities and expected time, the exact formula for the winning probabilities, and the asymptotic behaviors of the expected survival time. We have also considered a variation of the problem, where people are grouped into triples, quadruples, etc., and the first person in each group is at the risk of being selected. We will also present various sequences we have discovered while solving the variations, as well as other possible extensions and related findings concerning this problem. (Received September 25, 2018)

1145-60-2719 **Madalin Guta**, **Jonas Kahn**, **Richard Kueng*** (rkueng@caltech.edu) and **Joel A Tropp**. *Fast quantum state estimation with optimal error bounds.*

In quantum mechanics, the state of a physical system is described by a positive semidefinite matrix with unit trace. The task of determining this state from empirical observations is one of the most fundamental problems in quantum physics. Projected least squares (PLS) is an intuitive and numerically cheap technique for achieving this goal. It consists of computing the least squares estimator and projecting it onto the convex set of quantum states. Despite its simplicity, this technique may be equipped with rigorous convergence guarantees that are comparable to the best existing statements in the literature. What is more, PLS implicitly exploits low rank structure in a fashion similar to matrix completion. The results are derived by re-interpreting the least squares estimator as a sum of random matrices and applying a matrix-valued concentration inequality. (Received September 25, 2018)

1145-60-2749 **Rick Durrett**, **Matthew Junge*** (jungem@math.duke.edu) and **Si Tang**. *Coexistence in chase-escape.*

Imagine barnacles and mussels spreading across the surface of a rock. Barnacles move to adjacent unfilled spots. Mussels too, but they can only attach to barnacles. Barnacles with a mussel on top no longer spread. What conditions on the rock geometry (i.e. graph) and spreading rates (i.e. exponential clocks) ensure that barnacles can survive? Chase-escape can be formalized in terms of competing Richardson growth models; one on top of the other. New, tantalizing open problems will be presented. (Received September 25, 2018)

1145-60-2784 **Isabelle Kemajou-Brown*** (elisabeth.brown@morgan.edu), 1700 E Cold Spring Lane, Baltimore MD, MD 21251, and **Rachel Kuske** and **Fatemeh Norouzi**. *Linear and Non Linear GARCH(p,q) - Delay Fokker Planck Equation.*

In this talk, we will derive the delay Fokker Planck equation for which solution gives the probability density function (PDF) of the weak limit of Univariate GARCH(p,q). We will then explore the existence of both power law distribution and power spectral density of the power law form for Univariate GARCH(p,q). We also show some similar process with a possible modification for non linear GARCH(p,q). (Received September 25, 2018)

1145-60-2796 **Fatemeh Norouzi*** (fatemeh.norouzi@morgan.edu), 1700 E Cold Spring Lane, Baltimore, MD 21251, and **Isabelle Kemajou-Brown** and **Rachel Kuske**. *Linear Univariate GARCH(p,q) and Pink Noise.*

In this paper, we aim to use the Univariate Generalized Auto Regressive Conditional Heteroskedasticity (GARCH) model which have been using a lot in forecasting the conditional volatility of time series. We investigate the ability of the linear Univariate GARCH(p,q) to reproduce power law statistics and detect whether it has the pink noise out of power spectral density function. For this investigation, we are exploring derivations of stochastic delay differential equations from linear Univariate GARCH(p,q) process. (Received September 25, 2018)

1145-60-2903 **Jebessa B Mijena*** (jebessa.mijena@gcsu.edu), 190 Will PL, Milledgeville, GA 31061, and **Erkan Nane**. *Intermittence and space-time fractional stochastic partial differential equations.*

We consider time fractional stochastic heat type equation

$$\partial_t^\beta u_t(x) = -\nu(-\Delta)^{\alpha/2} u_t(x) + I_t^{1-\beta}[\sigma(u)\, \dot{W}\,(t,x)]$$

in $(d+1)$ dimensions, where $\nu > 0$, $\beta \in (0,1)$, $\alpha \in (0,2]$, $d < \min\{2, \beta^{-1}\}\alpha$, ∂_t^β is the Caputo fractional derivative, $-(-\Delta)^{\alpha/2}$ is the generator of an isotropic stable process, $\dot{W}(t,x)$ is space-time white noise, and $\sigma : \mathbb{R} \to \mathbb{R}$ is Lipschitz continuous. The time fractional stochastic heat type equations might be used to model phenomenon with random effects with thermal memory. We prove: (i) absolute moments of the solutions of this equation grows exponentially; and (ii) the distances to the origin of the farthest high peaks of those moments grow exactly linearly with time. These results extend the results of Foondun and Khoshnevisan and Conus and Khoshnevisan on the parabolic stochastic heat equations. (Received September 25, 2018)

1145-60-2995 **Julia L Pelesko*** (jlp192@case.edu), 221 Planet RD, Newark, DE 19711, and **Michael Hinczewski** and **Jacob Scott**. *Curing cancer faster: Optimizing drug scheduling protocols with a Fokker-Plank model.*

Mustonen and Lässig propose a Fokker-Planck equation whose solutions predict how allele frequencies change in populations exhibiting adaptive evolution. In particular, the emergence of resistance to chemotherapy drugs is an adaptive process. Thus, a Fokker-Planck model can be used to predict how populations of cancer cells will evolve under the influence of anti-cancer drugs. Evolutionary steering models already exist to predict drug schedules that minimize the probability of patient relapse; however, current models assume that each drug is taken for infinite time. This assumption is made to ensure genotype frequencies equilibrate before application of a second-line drug. We propose a modified Fokker-Plank model that yields counter-diabatic solutions, or solutions that achieve evolutionary equilibria on finite time scales. Using our model, we can design clinically feasible drug scheduling protocols that minimize the emergence of drug resistant populations of cancer cells. To test our predictions in vitro, we have constructed a morbidostat: an automated continuous culture device. Feedback from the morbidostat will allow us to fine tune the parameters of our Fokker Plank model, resulting in continual optimization of drug schedules. (Received September 26, 2018)

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1145-62-136 **Aaron Carl Smith*** (smithaz12@scps.k12.fl.us), Seminole County Public Schools, Assessment and Accountability, 400 East Lake Mary Blvd, Sanford, FL 32773. *Ways to Avoid Low Rank and Nearly Low Rank Predictors without Throwing Away Data.* Preliminary report.

Statistical modeling depends on predictor variables. Frequently out-of-the-box data is unable to reach its informative potential. Low rank and nearly low rank predictor matrices can wreck a model with over fitting. Not only does such a model give poor information, but it could have given strong results with proper data preparation. This talk will present techniques to improve your predictor matrices by making the vectors dissimilar to low rank matrices. (Received August 13, 2018)

1145-62-242 **Rasika Udara Rajapakshage*** (udara@knights.ucf.edu), 12005, solon dr ,apt 206, Orlando, FL 32826, and **Marianna Pensky** (marianna.pensky@ucf.edu), 4393 Andromeda Loop N, Orlando, FL 32816. *Clustering in Statistical Inverse Problems.*

In this paper, we consider the solution of a set of general ill-posed linear inverse problems $Af_m = q_m$, $m = 1, \cdots, M$, where A is a bounded linear operator that does not have a bounded inverse and the right-hand sides q_m are measured with error. In particular, we assume that some of the curves f_m and, hence, q_m are very similar to each other, so that they can averaged and recovered together. As a result, one supposedly obtains estimators of f_j with smaller errors. The grouping is usually unknown (as well as the number of groups) and is carried out at the pre-processing step applying one of the standard clustering techniques with the number of clusters determined by trial and error. Subsequently, the curves in the same cluster are averaged and the errors of those aggregated curves are used as true errors in the analysis. Problems of this kind appear in many areas of application such as medical imaging (tomography, dynamic contrast enhanced Computerized Tomography and Magnetic Resonance Imaging) and many others where similar curves are measured and can be recovered together. While in many of the applications, the main objective is clustering, we are not interested in the errors in group assignments and use clustering merely as a denoising technique. (Received August 23, 2018)

1145-62-298 **Brice Merlin Nguelifack*** (nguelifa@usna.edu), 1116 August Drive, Annapolis, MD 21403, and **Eddy Kwessi**. *Robust Signed-Rank Variable Selection in Monotone Single-Index Models with Wavelets via the Adaptive LASSO.*

A robust signed-rank estimation and variable selection for monotone single-index models is considered in this paper. A single-index model assumes that the expectation of the outcome is an unknown function of a linear combination of covariates. Assuming monotonicity of the unknown function is often reasonable, and allows for more straightforward inference. Wavelet are used to estimate the unknown function. The proposed estimator and selection procedure have an oracle property. Optimality of the robust signed-rank approach for data with long-tail, contaminated errors and, data containing high-leverage points is validated via finite sample simulations. A practical application is provided. (Received August 29, 2018)

1145-62-570 **Keyla Pagan-Rivera***, 4850 Mark Center Dr, Alexandria, VA 22311. *The use of Bayesian Logistic Models in Defense Analysis: a Case Study.* Preliminary report.

The use of Bayesian statistics as a tool to scope testing and analyze data related to defense has increased in recent years. Understanding which factors can affect a detector's performance can influence military tactics, techniques and procedures, and improve a commander's situational awareness when making decisions in an operational environment. Classical statistic techniques were previously used to predict an instrument's probability of detection. For this purpose, a simple logistic regression was fitted. In this talk, the results of a Bayesian multiple logistic model will be used to show how the operational environment can affect the detector's performance. (Received September 10, 2018)

1145-62-706 **Giulio Trigila*** (giulio.trigila@baruch.cuny.edu). *The data-driven Schrödinger bridge.*

Erwin Schrödinger posed, and to a large extent solved in 1931/32 the problem of finding the most likely random evolution between two continuous probability distributions. This talk considers this problem in the case when only samples of the two distributions are available. A novel iterative procedure is proposed, inspired by Fortet-Sinkhorn type algorithms. Since only samples of the marginals are available, the new approach features constrained maximum likelihood estimation in place of the nonlinear boundary couplings, and importance sampling to propagate the functions φ and $\hat{\varphi}$ solving the Schrödinger system. This method is well-suited to high-dimensional settings, where introducing grids leads to numerically unfeasible or unreliable methods. (Received September 13, 2018)

1145-62-780 **Alex Cloninger*** (acloninger@ucsd.edu), 9500 Gilman Dr, San Diego, CA 92093. *Fast Detection of Inter-Group Differences in Images.*

We will focus on fast algorithms to do two sample testing between groups, as well as algorithms for interpreting the tests and marking significant regions of difference, along with associated p-values of certainty that sed region isn't just due to random chance. We will focus on kernel methods and maximum mean discrepancy for the testing, and data that lies near or on low-dimensional manifolds, but the data sources can easily be preprocessed by neural networks, random forests, etc. We'll demonstrate applications on diffusion MRI, hyperspectral imaging, and other types of imaging modalities. (Received September 14, 2018)

1145-62-885 **Chong Sun*** (chong_sun@baylor.edu), 1, TX. *Forecasting Monthly Stock Return through K-Means Clustering and Support Vector Machine.* Preliminary report.

In this project, we try to predict returns of stocks in the future month with unsupervised clustering and support vector machine. Financial data especially stock prices are famous for its nonlinearity which makes it hard to predict their future movement. A common approach is to use local adaptive methods to deal with the nonlinearity. However local adaptive methods pose high computational difficulty especially for high dimensional data. We propose a K-Means clustering algorithm to partition the stock return data to 4 clusters to deal with the locality. We then fit a support vector machine for each of 4 clusters. This way we are able to deal with nonlinear nature of the data while keep the learning task easy to compute. The method can be viewed as a type of Bayesian methods in which partitioning can be treated as taking prior information into consideration during the learning process. (Received September 17, 2018)

1145-62-917 **Julie Zhang*** (jyzhang@uw.edu), 2512 201st Place SW, Lynnwood, WA 98036, and **Adam Quinn Jaffe**, **Theodore Faust** and **Marvin Pena**. *Comparing Object Correlation Metrics for Effective Space Traffic Management.*

In the near future, the number of satellites in Low Earth Orbit (LEO) is expected to grow tenfold. Therefore it is important to determine optimal space traffic management systems under various conditions. One essential part of space traffic management is the problem of object correlation: Given an a priori distribution of each object in space at a given time and noisy measurements of unknown objects at a later time, how can one best associate each measurement to an object? This process of correlation depends on the choice of metric to quantify the likelihood that a certain measurement pairs with a certain object. Many metrics are already defined and explored in the literature, such as Mahalanobis, Bhattacharyya, Kullback-Leibler, and Optimal Control Distance. We contributed to this discussion a flexible simulation framework for comparing the performance of these metrics in a variety of scenarios while varying many simulation inputs. We focused our analysis on the cases where satellites move towards a pinch point or move away from a pinch point, as well as a case that simulates a more realistic LEO-type environment. The data shows a preference for Mahalanobis overall, although other metrics are superior in a few cases of interest. (Received September 17, 2018)

1145-62-918 **Ramchandra Rimal***, 4393 Andromeda Loop N, Orlando, FL 32826, and **Marianna Pensky**. *Estimation in Popularity Adjusted Stochastic Block Model.*

In the present talk, we consider the Popularity Adjusted Stochastic Block Model (PABM) which has been recently introduced by Sengupta and Chen (2018). In the PABM, the probability of a connection between nodes is a product of popularity parameters that depend on the communities to which the nodes belong as well as on the pair of nodes themselves. The authors showed that PABM generalizes both the Stochastic Block Model (SBM) and the Degree-Corrected Block Model (DCBM) and suggested the quasi-maximum likelihood type procedure for estimation and clustering. However, the authors considered only the case of a small finite number of communities which is completely known. In addition, they did not provide any explicit expression for the error. In the present talk, we suggest an estimation procedure of the matrix of the connection probabilities between nodes when the number of classes is unknown and can grow with the number of nodes. (Received September 17, 2018)

1145-62-926 **Majid Noroozi*** (mnoroozi@knights.ucf.edu), Department of Mathematics at UCF, 4393 Andromeda Loop N, Orlando, FL 32816, and **Marianna Pensky** (marianna.pensky@ucf.edu), Department of Mathematics at UCF, 4393 Andromeda Loop N, Orlando, FL 32816. *Clustering in Popularity Adjusted Stochastic Block Model.*

In the present talk, we consider the Popularity Adjusted Stochastic Block Model (PABM) which has been recently introduced by Sengupta and Chen (2018). . In the PABM, the probability of a connection between nodes is a product of popularity parameters that depend on the communities to which the nodes belong as well as on the pair of nodes themselves. The authors showed that PABM generalizes both the Stochastic Block Model (SBM) and the Degree-Corrected Block Model (DCBM) and suggested the quasi-maximum likelihood type procedure for estimation and clustering. However, the authors considered only the case of a small finite number of communities, and the spectral clustering, that they used for implementation of the modularity optimization, does not recover communities reliably when the probability of connection of nodes in the network is very diverse. The purpose of the present talk is to address the deficiency of spectral clustering in the latter case. In particular, we propose to use a different type of clustering for the PABM data. Experiments on a synthetic data set demonstrate the effectiveness of our approach. (Received September 17, 2018)

1145-62-944 **Andrew V Sills***, asills@georgiasouthern.edu, and **Charles W Champ**. *Integer partitions and the exponential distribution analog of the Grubbs–Weaver method.*

In a 1947 paper, Grubbs and Weaver suggest a minimum-variance unbiased estimator for the population standard deviation of a normal random variable, where a random sample is drawn and a weighted sum of the ranges of certain subsamples is utilized. It turned out that the optimal choice, i.e. the partition that yields an estimate of minimum variance, involves using as many subsamples of size eight as possible. Grubbs and Weaver verified their results numerically for samples of size up to 100, and conjectured that their rule of eights is valid for all sample sizes greater than 100. In this talk, we examine the analogous problem where the underlying distribution is exponential instead of normal, and find that a "rule of fours" yields optimality. Because the order statistics of exponential random variables may be expressed in closed form, we can prove the result rigorously. Our proof involves reformulating the original statement of the problem into an integer linear program, and then solving it using combinatorial optimization techniques. (Received September 17, 2018)

1145-62-1044 **Didong Li*** (didongli@math.duke.edu), 120 Science Drive, 117 Physics Building, Campus Box 90320, Durham, NC 27708, and **Minerva Mukhopadhyay** and **David B Dunson**. *Efficient Manifold Approximation with Spherelets.*

Data lying in a high dimensional ambient space are commonly thought to have a much lower intrinsic dimension. In particular, the data may be concentrated near a lower-dimensional subspace or manifold. There is an immense literature focused on approximating the unknown subspace, and in exploiting such approximations in clustering, data compression, and building of predictive models. Most of the literature relies on approximating subspaces using a locally linear, and potentially multiscale, dictionary. In this talk, we propose a simple and general alternative, which instead uses pieces of spheres, or spherelets, to locally approximate the unknown subspace. Theory is developed showing that spherelets can produce lower covering numbers and MSEs for many manifolds. We develop spherical principal components analysis (SPCA). Results relative to state-of-the-art competitors show gains in ability to accurately approximate the subspace with fewer components. In addition, unlike most competitors, our approach can be used for data denoising and can efficiently embed new data without retraining. The methods are illustrated with standard toy manifold learning examples, and applications to multiple real data sets. (Received September 18, 2018)

1145-62-1137 **Santanu Chakraborty*** (santanu.chakraborty@utrgv.edu), School of Mathematical and Statistical Sc., University of Texas Rio Grande Valley, 1201 West University Drive, Edinburg, TX 78539, and **George P Yanev** (george.yanev@utrgv.edu), School of Mathematical and Statistical Sc., University of Texas Rio Grande Valley, 1201 West University Drive, Edinburg, TX 78539. *Characterizations of Exponential Distribution Based on Two-Sided Random Shifts.*

A new characterization of the exponential distribution is obtained. It is based on an equation involving randomly shifted (translated) order statistics. No specific distribution is assumed for the shift random variables. The proof uses a recently developed technique including the Maclaurin series expansion of the probability density of the parent variable. (Received September 19, 2018)

1145-62-1471 **Royal J Wang*** (rjwang@email.wm.edu), 4182 McCloskey ct, Chantilly, VA 20151, and **Daniel Vasiliu** (devasiliu@gmail.com), 4225 Teakwood Dr, Williamsburg, VA 23188. *Nonlinear Additive Modelling with Applications to the Assessment of House Prices.* Preliminary report.

Establishing a good framework for nonlinear inferences and modeling has been an ever-standing goal with great applications in functional data analysis and business analytics. The concept of generalized additive models in statistics was proposed by Hastie and Tibshirani and the main idea was stemming from the Kolmogorov-Arnold representation theorem; the argument was that any multivariate function could, in theory, be represented as sums and compositions of univariate functions. Introduced as an advanced regression technique, although with some simplifying assumptions, the idea of generalized additive modelling proved to be effective in various applications such as the valuation of houses or fixed assets, stock exchange, population dynamics, growth models and gene expression analyses.

We are considering both theoretical and practical aspects of the nonlinear additive models. Our aim is to study a new approach for obtaining a dictionary of functions that can be used to approximate the model and the challenge of dimension reduction along with a practical application to financial mathematics such as the analysis of the house data from Ames, Iowa. The practical goal is to improve the estimation of house prices given the fact that the data has a high dimensional feature space. (Received September 22, 2018)

1145-62-1559 **Nitish Bahadur** and **Randy Paffenroth***, Worcester Polytechnic Institute, 100 Institute Rd, Worcester, MA 01609. *Low-dimensional analysis of financial markets.*

The dimensionality of financial markets is the least number of factors, either linear or non-linear, required to approximately explain the market behavior. It is an empirical observation that during different market conditions the minimum number of factors required to decompose market behavior changes, consequently changing the dimensionality of the market. Classic approaches in this domain include linear techniques such as Principal Component Analysis, where new orthogonal features are created by linearly combining observed factors and projecting them along the direction of maximum variability. However, such simple approaches do not necessarily tell the full story and in this talk, we will discuss various techniques for estimating the dimensionality of financial markets. In particular, we consider techniques ranging from the non-linear (e.g. ISOMAP) to the robust (e.g. Robust Principal Component Analysis), including a foray into quite modern techniques that combine these two ideas including a type of neural network called a Robust Deep Autoencoder. (Received September 23, 2018)

1145-62-1567 **Dr. Joseph Omondi Ouno*** (ouno@mmarau.ac.ke), PO Box 861-20500, Narok, Kenya, and **Dr. Boniface Otieno Kwach** (bkwach@kibu.ac.ke), PO Box 1699-50200, Bungoma, Kenya. *Modeling of Market Equilibrium Price for Nairobi Security Exchange with Respect to Demand and Supply of Shares.*

Nairobi security exchange (NSE) is a success story in trading capital shares and this has made it attract many players both locally and internationally. It is interesting to note that these players do not have a reasonable mathematical model which can be used to predict equilibrium prices for their stock. Such a prediction can be achieved if there is a model for market equilibrium price for different capital shares. In this paper a market equilibrium price model is developed to help market players predict equilibrium price for capital shares. This model has been developed by the use of one of the methods commonly applied in estimating parameters of simultaneous equations models. This is the two stage least squares (2 SLS) method.

Keywords: Demand and supply functions, Dividend payment, Exogenous and Endogenous variables, simultaneous equations models, structural and reduced form equations (Received September 23, 2018)

1145-62-1702 **Fei Lu*** (feilu@math.jhu.edu). *Joint state and parameter estimation for non-linear stochastic energy balance models.*

We study the joint estimation of state and parameters of non-linear stochastic energy balance models (SEBMs) that arise in paleoclimate reconstructions of temperature. Since the data are sparse and noisy, there is large uncertainty in the estimation and we represent the uncertainty by the posterior distribution, i.e. following a Bayesian approach. We investigate particle MCMC methods for the inference. These methods combine sequential Monte Carlo methods with MCMC techniques and exploit the forward structure of the SEBM to efficiently approximate the posterior distribution. Results from a 1d example, which models global-mean temperature as a non-linear SDE, as well as from a spatially distributed version in terms of a parabolic SPDE, are presented. We focus on identifiability of model parameters within physically reasonable ranges and the ability to reconstruct the climate state from sparse and noisy observations. Joint work with Nils Weitzel and Adam Monahan. (Received September 25, 2018)

1145-62-1864 **Kevin J Lin*** (kevin.lin@afit.edu), 1253 Windsor Dr, Beavercreek, OH 45434. *SHM Factor Validation on Airframes.*

Validation of SHM systems for aircraft is complicated by the extent and number of factors for which the SHM system must demonstrate robust performance. Therefore, a time and cost-efficient method for examining all the sensitive factors must be conducted. In this paper, we demonstrate the utility of using the simulation modeling environment to determine the SHM sensitive factors for future experimentation. We demonstrate this concept by examining the effect of SHM system configuration and flaw characteristics on the response of a signal from a known piezoelectric wafer active sensor in an aluminum plate using simulation models of a particular hot spot. We derive the signal responses mathematically and through statistical design of experiments, determine the significant factors that affect the damage indices computed from the signal using only half the number of runs normally required. We determine that the transmitter angle is the largest source of variation for the damage indices considered, followed by signal frequency and transmitter distance to the hot spot. These results demonstrate that the use of efficient statistical design and simulation may enable a cost and time-efficient sequential approach to quantifying sensitive SHM factors and system validation. (Received September 24, 2018)

1145-62-1993 **Louis R. Camara*** (louis.camara@mga.edu), 1100 Second St. SE, Cochran, GA 31014. *On the Gamma-Logistic-Pareto Distribution.*

The Gamma-Logistic-Pareto distribution is defined and studied. Several of its properties are derived. The structural analysis of the distribution including moments, quantiles, mode, kurtosis, skewness, order statistics, and Shannon's entropy are derived. Model parameters are estimated. As an application, the Gamma-Logistic-Pareto distribution is used to model a real data set. (Received September 24, 2018)

1145-62-2094 **Diana Cai***, 35 Olden Street, Princeton, NJ 08544, and **Nate Ackerman** and **Cameron Freer**. *Digraphon estimation via step-function approximations.*

Exchangeable graphs arise via a sampling procedure from symmetric, measurable functions known as graphons, which characterize many popular network models for undirected graphs, such as the stochastic block model. A natural nonparametric function estimation problem is how well we can recover a graphon given a single graph sampled from it. One general framework for estimating a graphon uses step-functions obtained by partitioning the nodes of the graph according to some clustering algorithm. Regularity lemmas describe the size of the partition required to obtain a given quality of estimation.

In this talk, we present a few simple algorithms for graphon estimation with step-function approximations, based on clustering vertices according to their edge densities. Next, we also discuss how these can be extended to directed graphs via measurable objects known as digraphons. Using digraphons, we first show how to construct models for exchangeable directed graphs, including special cases such as tournaments, linear orderings, directed acyclic graphs, and partial orderings. We then show how to construct priors on digraphons via the infinite relational digraphon model (di-IRM), a new Bayesian nonparametric block model for exchangeable directed graphs. (Received September 24, 2018)

1145-62-2145 **Durga H Kutal***, kutaldh@fau.edu. *Non-Mixture Cure Model for right censored data with modified Gompertz Distribution.*

This project considers a non-mixture cure model for right censored data. The maximum likelihood method used to estimate model parameters in the non-mixture cure model with modified Gompertz distribution. The simulation study is based on non-mixture cure model with modified Gompertz susceptible distribution to evaluate the performance of the method. The proposed model is applied to a real data set on allogeneic marrow HLA-matched donors and ECOG phase III clinical trial e1684. (Received September 24, 2018)

1145-62-2264 **Jessica Rothman**, **Monica C Jackson*** (monica@american.edu), **Kimberly Sellers**, **Talithia Williams**, **Lance Waller** and **Subhash Lele**. *Correlation induced by missing spatial covariates: a connection between variance components models and kriging.*

Residual spatial correlation in linear models of environmental data is often attributed to spatial patterns in related covariates omitted from the fitted model. We connect the nonunique decom-position of error in geostatistical models into trend and covariance components to the similarly non-unique decomposition of mixed models into fixed and random effects. We specify spatial correlation induced by missing spatial covariates as a function of the strength of association and(spatial) covariation of the missing covariates. The connection with variance components models provides insight into estimation procedures. We showed how missing covariates in spatial linear models actually induces spatial autocorrelation in the covariates. This finding was confirmed through the use of simulated data and the Binary Steve dataset. (Received September 25, 2018)

1145-62-2306 **David M. Ruth*** (druth@usna.edu) and **Michael J. Wallace**. *A Nonparametric Multivariate Two-Sample Test Using Cumulative Counts of Ranked Edges.* Preliminary report.

The multivariate two-sample problem is one of ongoing interest in statistics. In the setting of graph-theoretic statistical approaches, the first consequential multivariate two-sample test was introduced decades ago by Freidman and Rafsky using minimum spanning trees. More recently, new approaches have been explored using other optimal subgraphs to detect group differences. Data observations are modeled as graph vertices and undirected edges are weighted by interpoint dissimilarity. The rationale of these tests is that, if two samples are from different distributions, observations would be preferentially closer to others from the same sample than those from the other sample, and that this preference might be detected with some appropriate edge-counting method. This presentation will describe methodology and results associated with a newly-developed test based on cumulative counts of ranked edges. The new test has several desirable properties: it is nonparametric, it is sensitive to differences in both location and scale, it retains test power in the presence of imbalanced sample sizes, and its computational cost is low relative to other graph-theoretic tests. Test performance will be demonstrated for both simulated and real-world data examples. (Received September 25, 2018)

1145-62-2414 **A. K. Criner*** (amanda.criner.1@us.af.mil), 2230 10th Street, Wright Patterson AFB, OH 45433. *How Your Data Will Lie to You.* Preliminary report.

(Alternate titles: Lies, darn lies, and results presented without assumptions acknowledged, and The crimes and consequences of zero mean, identically, independently distributed error) Zero mean, identically, independently distributed (i.i.d.) error is implicitly assumed in many data analysis algorithms. These assumptions are explained in example simulated data sets. Strategies to recognize violations in these assumptions are demonstrated on the example data sets. The consequences of violation of each of these assumptions include bias, over confidence and under confidence. Resources for accommodating the violation of the zero mean i.i.d. error assumption are presented. (Received September 25, 2018)

1145-62-2536 **Izzet Sozucok*** (izzet.sozucok_35@mavs.uta.edu), 2001 Grapevine Lane, Arlington, TX 76014. *Prediction of remaining lifetime distribution from functional trajectories under censoring data.*

The goal in functional studies on failure time or on death time of the objects is to find a relationship between age-at-death (failure time) and current values of a functional predictors. In this study, a novel technique is applied to predict the failure time of devices in the systems such as bearings and to predict age-at-death distributions under censoring data for situations where observed all covariant trajectories until current time t. The predictors observed up to current time can shown by time-varying principal component scores which is continuously updated as time progresses. We establish the estimation of modified survival function for longitudinal trajectories by inspiring Kaplan-Meire method in order to predict mean residual life distribution.Projecting the behavior of covariant trajectories on single index we reduce the dimensions of them to get predictions for each individual object . The proposed method is validated as the leave-one-out method and the approach is illustrated as well. (Received September 25, 2018)

1145-62-2608 **James Kerce*** (clayton.kerce@gtri.gatech.edu), 400 10th St. NW, CRB 259, Atlanta, GA 30332. *Machine Learning for Data Assimilation in Dynamic Physical Processes.* Preliminary report.

The process of combining a time series of (possibly disparate) errored measurements with a state estimate of a dynamical system is commonly referred to as data assimilation, the goal being to produce a new state estimate that is statistically optimal with respect to both the statistics of the prior state the measurement. This methodology is routinely employed in approximation for forecasting the states of the troposphere, ocean, and ionosphere. A typical compromise is to preform measurement assimilation on a coarse grained model and then map the updated state to a higher resolution grid for forecasting. This process introduces dynamical artifacts, the removal of which is often carried out either through dissipation or spectral filtering. Motivated by recent progress in applying convolutional artificial neural network (CNN) architectures to the time update in both the inviscid Euler Equation [1] and seismic wave equation [2], we examine the use of CNNs in solving for physical consistency between thermodynamic states in dynamic fluid models using machine learning (ML) techniques. These approaches have resulted in a significant reduction in runtime while maintaining short time error performance that allows for their use in feedback control and measurement assimilation schemes. (Received September 25, 2018)

1145-62-2811 **Andre K Waschka*** (akwaschka@berkeley.edu), Department of Statistics, UC Berkeley, Berkeley, CA 94704. *A Longitudinal Targeted Likelihood Estimator for an Optimal Time-to-Switch Treatment Rule.* Preliminary report.

We discuss how to formulate an estimate of a dynamic treatment rule for the optimal time to switch between two medical treatments. Here an optimal rule is defined to maximize the mean outcome under the dynamic treatment, while our candidate rules only respond to a user-supplied subset of the baseline and time-varying covariates. Our estimation problem uses a nonparametric statistical model, which differs from the majority of the current literature that relies on parametric assumptions. To estimate this optimal rule, we use a Longitudinal Targeted Likelihood Estimator (LTMLE) that accounts for both treatment variables. The method is illustrated using MIMIC data to help provide a decision rule for hypotensive patients where we find the optimal amount of fluids (treatment 1) for a patient to receive before switching over to vasopressors (treatment 2) to maximize their survival rate at 48 hours. (Received September 25, 2018)

1145-62-2974 **Tiffany Christian*** (tchristian@smith.edu), Smith College, Department of Mathematics and Statistics, Northampton, MA 01063. *A project in statistics.* Preliminary report.

We use statistical methods to analyze a project arising naturally from applications. (Received September 25, 2018)

1145-62-2999 **Luca Weihs**, **Bill Robinson*** (robinsonw@denison.edu), **Emilie Dufresne**, **Jennifer Kenkel**, **Kaie Kubjas**, **Reginald Reginald II**, **Nhan Nguyen**, **Elina Robeva** and **Mathias Drton**. *Determinantal Generalizations of Instrumental Variables.*

Linear structural equation models are a class of multivariate statistical models which study possible causal dependencies among variables. To these is associated a path diagram, which contain a directed acyclic part and a bidirected part. When a model has been specified, it is of interest to determine whether the model parameters can be recovered from the covariance matrix which they define. In this talk we will discuss recent work on the question of identifiability using algebraic methods. (Received September 26, 2018)

65 ► Numerical analysis

1145-65-122 **Muhammad Jaman Mohebujjaman*** (jaman@vt.edu), 422 McBryde Hall, Virginia Tech, 225 Stanger St, Blacksburg, VA 24060, and **Traian Iliescu** and **Leo G. Rebholz**. *Physically-Constrained Data-Driven Corrected Reduced Order Modeling of Fluid Flows.*

In this talk, we present two approaches for enforcing better conservation properties for reduced order models (ROMs) of fluid flows. In the first approach, to construct the centering trajectory, we use the Stokes extension instead of the standard snapshot average. We show that the Stokes extension yields significantly more accurate results. In the second approach, we enforce physical constraints in the data-driven modeling of the ROM closure term. The constrained data-driven ROM is significantly more accurate than its unconstrained counterpart. (Received August 03, 2018)

1145-65-128 **Joshua Buli***, jbuli001@ucr.edu, and **Yulong Xing**. *A Discontinuous Galerkin Method for the Aw-Rascle Traffic Flow Model on Networks.*

In this talk we consider the second-order Aw-Rascle (AR) model for traffic flow on a network, and propose a discontinuous Galerkin (DG) method for solving the AR system of hyperbolic PDEs with appropriate coupling conditions at the junctions. For the proposed method we apply the Lax-Friedrichs flux, and for comparison, we use the first-order Lighthill-Whitham-Richards (LWR) model with the Godunov flux. Coupling conditions are also required at the junctions of the network for the problem to be well-posed. As the choice of coupling conditions is not unique, we test different coupling conditions for the Aw-Rascle model at the junctions. Numerical examples are provided to demonstrate the high-order accuracy, as well as comparisons between the first-order LWR model and the second-order AR model. The ability of the AR model to capture the capacity drop phenomenon is also explored. (Received August 06, 2018)

1145-65-151 **Ugur Abdulla**, **Vladislav Bukshtynov** and **Ali Hagverdiyev*** (ahaqverdiyev2011@my.fit.edu), 300 Cornell Ave, Melbourne, FL 32901. *Gradient Method in Hilbert-Besov Spaces for the Optimal Control of Parabolic Free Boundary Problems.*

In this presentation I will talk about computational analysis of the inverse Stefan type free boundary problem, where information on the boundary heat flux is missing and must be found along with the temperature and the free boundary. We pursue optimal control framework introduced in *U.G. Abdulla, Inverse Problems and Imaging, 7, 2(2013), 307-340; 10, 4(2016), 869–898*, where boundary heat flux and free boundary are components of the control vector, and optimality criteria consist of the minimization of the quadratic declinations from the available measurements of the temperature distribution at the final moment, phase transition temperature on the free boundary, and the final position of the free boundary. We develop gradient descent algorithm based on Frechet differentiability in Hilbert-Besov spaces complemented with preconditioning of the Frechet gradient through implementation of the Riesz representation theorem. Five model examples with various levels of complexity are considered. Extensive comparative analysis through implementation of preconditioning and Tikhonov regularization, calibration of preconditioning and regularization parameters, effect of noisy data, comparison of simultaneous identification of control parameters vs. nested optimization is pursued. (Received August 09, 2018)

1145-65-156 **Leo Rebholz**, **Alex Viguerie** and **Mengying Xiao*** (mxiao01@wm.edu). *Analysis of Algebraic Chorin Temam splitting for incompressible Navier-Stokes equations.*

Algebraic splitting methods are a common approach to solving the saddle point linear systems that arise at each time step of an incompressible flow simulation. There are two main classes of these methods, those of Yosida-type and those of Algebraic Chorin Temam (ACT)-type, with the Yosida-type methods being predominantly used in practice. We show herein, through new analysis and extensive numerical testing, that ACT-type methods that include the viscous term stiffness matrix in the modified A-block, that ACT methods are unconditionally stable and can be superior to Yosida-type methods in a range of problems, and therefore should be given consideration as a solver. Particular situations where the ACT-type solvers are advantageous are problems where numerical stability is a concern, as well as problems where strong enforcement of the divergence constraint is important. (Received August 12, 2018)

1145-65-157 **Michael Neilan*** (neilan@pitt.edu), 301 Thackeray Hall, 139 University Place, Pittsburgh, PA 15260, and **Johnny Guzman** and **Guosheng Fu**. *Exact smoothed piecewise polynomial sequences on Alfeld splits.*

We develop exact polynomial sequences on Alfeld splits in any spatial dimension and any polynomial degree. An Alfeld split of a simplex is obtained by connecting the vertices of an n-simplex with its barycenter. We show that, on these triangulations, the kernel of the exterior derivative has enhanced smoothness. Byproducts of this theory include characterizations of discrete divergence-free subspaces for the Stokes problem, commutative projections, and simple formulas for the dimensions of smooth polynomial spaces. (Received August 13, 2018)

1145-65-178 **Caylah N Retz*** (cretz@uncc.edu). *Accurate and Efficient Calculation of Singular Electrostatic Potentials in Charge-Dielectric Spherical Systems.*

We introduce an efficient and accurate boundary element method for computing the electrostatic potential in closely-packed dielectric spheres systems. The electrostatic potential, which is described by the Poisson-Boltzmann equation, becomes highly singular under close interactions, resulting in computational difficulties. The singular behavior caused by the close proximity of the system is removed from the potential via a subtraction de-singularization technique within a hyper-singular, high order second kind integral equation formulation.

The resulting system of equations has a number of right-hand-side integrals that contain the bulk of the singular behavior. These auxiliary integrals require treatment in order to best capture the singular behavior while minimizing cost. Regularization techniques for the Hadamard finite part integral that appears in this method are then presented, where mathematical identities and adaptive meshes offer a means to compute the singular integral with the required level of accuracy at a much reduced computational cost. We demonstrate that numerical results of the singular potential for one and two closely-packed spheres have validated the effectiveness and accuracy of the proposed method. (Received August 16, 2018)

1145-65-182 **Guosheng Fu***, guosheng_fu@brown.edu. *An explicit divergence-free DG method for incompressible flow.* Preliminary report.

We present an explicit divergence-free DG method for incompressible flow with a velocity-only formulation. Efficient implementation of the scheme will be discussed. We also extension the method to the incompressible MHD equations that yield an exactly divergence free velocity and magnetic field. (Received August 16, 2018)

1145-65-234 **Tyler Kloefkorn*** (tkloefkorn@math.arizona.edu), **Andrew Gillette** (agillette@math.arizona.edu) and **Victoria Sanders** (victoriasanders@email.arizona.edu). *Computational Serendipity and Tensor Product Finite Element Differential Forms.*

Many conforming finite elements on squares and cubes are elegantly classified into families by the language of finite element exterior calculus and presented in the Periodic Table of the Finite Elements. Use of these elements varies, based principally on the ease or difficulty in finding a "computational basis" of shape functions for element families. The tensor product family, $\mathcal{Q}_r^-\Lambda^k$, is most commonly used because computational basis functions are easy to state and implement. The trimmed and non-trimmed serendipity families, $\mathcal{S}_r^-\Lambda^k$ and $\mathcal{S}_r\Lambda^k$ respectively, are used less frequently because they are newer and, until now, lacked a straightforward technique for computational basis construction. This represents a missed opportunity for computational efficiency as the serendipity elements in general have fewer degrees of freedom than elements of equivalent accuracy from the tensor product family. Accordingly, we present complete lists of computational bases for both serendipity families, for any order $r \geq 1$ and for any differential form order $0 \leq k \leq n$, for problems in dimension $n = 2$ or 3. The bases are defined via shared subspace structures, allowing easy comparison of elements across families. (Received August 23, 2018)

1145-65-319 **Xinyun Zhu*** (zhu_x@utpb.edu), Odessa, TX, and **Hong-tao Fan**, **Mehdi Bastani** and **Bing Zheng**. *A class of upper and lower triangular splitting iteration methods for image restoration.*

Based on the augmented linear system, a class of upper and lower triangular (ULT) split- ting iteration methods are established for solving the linear systems arising from image restoration problem. The convergence analysis of the ULT methods is presented for image restoration problem. Moreover, the optimal iteration parameters which minimize the spectral radius of the iteration matrix of these ULT methods and corresponding convergence factors for some special cases are given. In addition, numerical examples from image restoration are employed to validate the theoretical analysis and examine the effectiveness and competitiveness of the proposed methods. Experimental results show that these ULT methods considerably outperform the newly developed methods such as SHSS and RGHSS methods in terms of the numerical performance and image recovering quality. Finally, the SOR acceleration scheme for the ULT iteration method is discussed. (Received August 31, 2018)

1145-65-360 **Jiacheng Cai*** (jxcai@salisbury.edu) and **Hongtao Yang** (hongtao.yang@unlv.edu). *A Finite Volume - Alternating Direction Implicit Method for the Valuation of American Options under the Heston Model.*

A finite volume - alternating direction implicit method is proposed for numerical valuation of the American options under the Heston model. It is based on decoupling correlated stock price process and volatility process so that corresponding partial differential operator does not contain the mixed partial derivative term. Hence the proposed method is numerically simple and fast. Numerical results are presented to examine the accuracy of the proposed method and to compare it with the others. (Received September 06, 2018)

1145-65-419 **Qingguo Hong*** (huq11@psu.edu), **Shuonan Wu** (sxw58@psu.edu) and **Jinchao Xu** (xu@math.psu.edu). *Extended Galerkin Method.*

In this talk, we present an extended Galerkin (XG) method for the second order elliptic problems. The proposed method has four primal variables — $\boldsymbol{p}_h, \hat{p}_h, u_h, \hat{u}_h$ that contain all the possible variables in most of the existing FEMs. Therefore, it has the flexibility to cover most of the existing FEMs. In particular, we can obtain the hybrid discontinuous Galerkin (HDG) method and weak Galerkin (WG) method from the proposed formulation and further show that they are both equivalent to a special discontinuous Galerkin method. In addition, we then study two types of uniform inf-sup conditions for the proposed method, by which the well-posedness of the various FEMs follows naturally. (Received September 05, 2018)

1145-65-439 **Shuwang Li***, 10 West 32nd Street, RE building Room 208, Chicago, IL 60616. *An adaptive rescaling scheme for moving interface problems.*

In this talk, we present a time and space rescaling scheme for the computation of moving interface problems. The idea is to map time-space such that in the new frame the interfaces dynamics can be accelerated for a slowly expanding interface, or slowed down for a fast shrinking interface, while the area/volume enclosed by the interface remains unchanged. The rescaling scheme significantly reduces the computation time (especially for slow growth), and enables one to accurately simulate the very long-time dynamics of moving interfaces. (Received September 06, 2018)

1145-65-489 **Jiahua Jiang*** (jiahua@vt.edu), **Julianne Chung** (jmchung@vt.edu) and **Eric de Sturler** (sturler@vt.edu). *Truncation and Recycling Methods for Lanczos Bidiagonalization and Hybrid Regularization.*

Krylov methods for inverse problems have the nice property that regularization can be decided dynamically. However, this typically requires that the entire Krylov space is kept in memory, which is problematic for large problems that do not converge quickly. We propose strategies for truncating the search space while maintaining the possibility of dynamic regularization (for various regularization methods). In addition, these strategies have advantages if a sequence of related regularized solves is required. (Received September 07, 2018)

1145-65-505 **Xiu Ye*** (xxye@ualr.edu), 2801 S. University, Little Rock, AR 72204. *Discontinuous Galerkin method and Weak Galerkin Method.*

Interior penalty discontinuous Galerkin (IPDG) methods and weak Galerkin (WG) methods are studied to solve the problems such as Div-Curl problems and second order elliptic problems in non-divergence form. The numerical results of the both IPDG methods and WG methods are presented. Some new developments of the WG methods also are discussed. (Received September 07, 2018)

1145-65-558 **Chong Sun*** (chong_sun@baylor.edu), 1806 south 8th st, Waco, TX 76706, and **Qin Sheng** (qin_sheng@baylor.edu). *A dynamically balanced numerical method for solving stochastic Heston volatility option pricing model equations.*

Demands of highly efficient and effective numerical methods for solving option trading modeling equations have become increasingly high in recent years. Desirable computational procedures, however, are in general difficult to fulfill due to the cross-derivatives terms involved. This motivates our study. European options are targeted in this report. A dynamically balanced up-downwind finite difference method is proposed and analyzed for solving two-dimensional stochastic Heston volatility option pricing model equations. The ℓ_∞-norm is used in our stability, convergence, monotonicity and positivity analysis. Simulation experiments are given to illustrate our conclusions. (Received September 09, 2018)

1145-65-578 **Jenna C. Guenther*** (guenthjc@dukes.jmu.edu) and **Morgan A. Wolf** (wolf2ma@dukes.jmu.edu). *An Adaptive, Highly Accurate and Efficient, Parker-Sochacki Algorithm for Numerical Solution to Large Scale Dynamical Systems.* Preliminary report.

For nonlinear systems of differential equations, an explicit adaptive procedure using a foundation of the Parker-Sochacki Method (PSM) produces better accuracy in less time with significantly fewer steps when contrasted with many standard adaptive algorithms that use a Runge-Kutta (RK) foundation. First, two simple PSM functions are developed, illustrating a class of functions that represent the backbone of a future PSM tool for the scientific community. At each step across the domain, combinations of these functions efficiently and recursively generate the coefficients of the Taylor polynomial of the solution to the ODE system. An adaptive stepping algorithm is derived which provides a simple way to either increase or decrease the order of the method during computation. PSM Adaptive is first developed theoretically and then demonstrated on several examples, including a 2 degree of freedom system related to missile defense. Results are compared against standard RK adaptive algorithms including 4th/5th order Dormand Prince, the algorithm which serves as the foundation of MATLAB's renowned ODE45 solver. It is noted in the 2 degree of freedom example that PSM Adaptive takes roughly two orders of magnitude fewer steps and runs an order of magnitude faster for similar accuracy. (Received September 10, 2018)

1145-65-652 **James A Rossmanith*** (rossmani@iastate.edu), 411 Morrill Road, Ames, IA 50011, and **Lopamudra Palodhi** (lpalodhi@iastate.edu), 411 Morrill Road, Ames, IA 50011.
Locally-implicit Lax-Wendroff schemes for quasi-exponential moment-closure approximations of kinetic models.

In many applications, the dynamics of gas and plasma can be accurately modeled using kinetic Boltzmann equations, which are integro-differential systems posed in a high-dimensional phase space, which is typically comprised of spatial and velocity coordinates. If the system is sufficiently collisional, the kinetic equations may be replaced by a fluid approximation that is posed only in physical space. The precise form of the fluid approximation depends on the choice of the moment-closure. In general, finding a suitable robust moment-closure is still an open scientific problem.

In this work we consider a specific moment-closure based on a nonextensible entropy formulation. In particular, the true distribution is replaced by a Maxwellian distribution multiplied by a quasi-exponential function. We develop a high-order, locally-implicit, discontinuous Galerkin scheme to numerically solve resulting fluid equations. The numerical update is broken into two parts: (1) an update for the background Maxwellian distribution, and (2) an update for the non-Maxwellian corrections. We also develop limiters that guarantee that the inversion problem between moments of the distribution function and the parameters in the quasi-exponential function is well-posed. (Received September 12, 2018)

1145-65-751 **Chunmei Wang*** (chunmei.wang@ttu.edu), 2500 Broadway, Lubbock, TX 79424. *A New Primal-Dual Weak Galerkin Finite Element Method for Ill-posed Elliptic Cauchy Problems.*

The speaker will present a new numerical method which is devised and analyzed for a type of ill-posed elliptic Cauchy problems by using the primal-dual weak Galerkin finite element method. This new primal-dual weak Galerkin algorithm is robust and efficient in the sense that the system arising from the scheme is symmetric, well-posed, and is satisfied by the exact solution (if it exists). The speaker will show some numerical results to demonstrate the efficiency of the primal-dual weak Galerkin method as well as the accuracy of the numerical approximations. (Received September 13, 2018)

1145-65-763 **Marilyn Vazquez Landrove*** (marilyn_vazquez@brown.edu), **Tim Sauer** (tsauer@gmu.edu), **Tyrus Berry** (tberry@gmu.edu) and **Gunay Dogan** (gunay.dogan@nist.gov). *A Consistent Density-Based Clustering Algorithm and its Application to Microstructure Image Segmentation.*

Data clustering is a fundamental task for discovering patterns in data, and is central to machine learning. Often, a data set is assumed to live in a manifold and be sampled according to a probability measure. Then the clusters can be defined as peaks in the sampled probability density, and a clustering algorithm would need to identify the peaks in the density to compute the clusters. Some of the challenges in this approach include the non-uniform sampling of the density and the bridges between peaks of the density. To solve these problems, we propose a new clustering algorithm that divides the clustering problem into three steps: picking a good threshold on the sample density to separate the peaks, clustering the superlevel set at the chosen threshold, and classifying the remaining points. We explain the key details of these steps, and provide theoretical assurances on the performance. As an important application, we show how to apply this method to segment microstructure images by considering the images as a point-cloud of image patches. We present results on 2D microscopic images of various materials. (Received September 14, 2018)

1145-65-778 **Hengguang Li*** (li@wayne.edu), Department of Mathematics, Wayne State University, Detroit, MI 48202, and **Xun Lu**. *The finite element conditioning on a class of anisotropic meshes.*

New 3D anisotropic mesh algorithms were proposed for the finite element method to approximate elliptic equations with singularities. These algorithms are simple, intuitive, and impose less geometric constraints on the domain. The resulting mesh is generally anisotropic and the associated numerical approximation has optimal convergence. In this talk, we report new developments in these algorithms both in 2D and 3D, especially sharp estimates on the condition numbers of the finite element stiffness matrices from these meshes. (Received September 14, 2018)

1145-65-860 **Tyrus Berry*** (tberry@gmu.edu), **John Harlim** (jharlim@psu.edu), **Timothy Sauer** (tsauer@gmu.edu) and **Franz Hamilton** (fwhamilt@ncsu.edu). *Overcoming model and observation error in data assimilation using manifold learning.*

Data assimilation methods depend on specifying the correct model for both the underlying dynamics and the mapping to observations. However, many sources of error arise in practice, such as model misspecification, neglected phenomena, or numerical truncation effects. Such errors manifest themselves in the difference between the observations and the filter estimates and forecasts. If we can find functional relationships between the current state estimates and these errors, we can adjust the model to compensate for the errors. In this talk we explore methods of learning these functional relationships based on manifold learning. In particular, we will explore methods based on Takens delay embedding reconstruction combined with the Diffusion Maps algorithm for manifold learning and nonparametric regression. (Received September 16, 2018)

1145-65-924 **Lewei Zhao*** (fp5042@wayne.edu), 5200 Anthony Wayne Drive, Apt.Deroy#604, Detroit, MI 48202, and **Hao Pan** and **Zhimin Zhang**. *Some New Developments of Polynomial Preserving Recovery on Hexagon Pattern and Chervon Pattern.*

Polynomial Preserving Recovery (PPR) is a very popular post-processing techniques for finite element methods. In this article, we propose and analyze an effective linear element PPR on a new pattern so called Hexagon. By giving an interior estimates for discrete Green function and expansion analysis for the superconvergence theory , we prove that liner element PPR on this new pattern can reach $O(h^4|\ln h|^{\frac{1}{2}})$ superconvergence for recovering gradient of Possion problems in 2-d. In addition, we supplements the quadratic element PPR on the uniform grid of the Chervon pattern with an application in wave equation, which further verifies the superconvergence theory. (Received September 17, 2018)

1145-65-929 **Mingchao Cai*** (mingchao.cai@morgan.edu), Baltimore, MD 21251. *Preconditioners and solvers for Biot's model.*

Biot's model has been widely used in Biomechanics. For example, mathematical models of brain edema and cancellous bones are all Biot's model. In this presentation, we aim at solving Biot's model under a stabilized finite element discretization and the MAC Finite Difference discretization. To solve the resulting saddle point linear systems, some preconditioners and iterative methods are proposed. In the preconditioners, the Schur complement approximation is derived by using a Fourier analysis approach. These preconditioners are implemented exactly or inexactly using Multigrid or domain decomposition methods. For accelerating the convergence rate, Krylov subspace methods are used as outer iteration. Extensive experiments are given to justify the performance of the proposed preconditioners and the solvers. (Received September 17, 2018)

1145-65-948 **Alexander V Mamonov*** (mamonov@math.uh.edu), **Vladimir Druskin** (vdruskin@gmail.com) and **Mikhail Zaslavsky** (mzaslavsky@slb.com). *Inversion and imaging with acoustic waves via model order reduction.*

We introduce a framework for inversion and imaging with acoustic waves based on model order reduction. The reduced order model (ROM) is an orthogonal projection of the wave equation propagator on the subspace of discretely sampled time domain wavefield snapshots. It can be computed entirely from the measured waveform data using block Cholesky factorization. The use of the ROM is twofold.

First, the ROM can be used as a nonlinear "preconditioner" for full waveform inversion (FWI). Instead of conventional minimization of the least squares data misfit we propose to minimize the ROM misfit. Such objective is more convex and thus optimization is much less prone to common issues like getting stuck in local minima (cycle skipping), multiple reflection artifacts, slow convergence, etc.

Second, if a background kinematic model is available, the projected propagator can be backprojected to obtain an image of sound speed discontinuities. The ROM computation implicitly orthogonalizes the wavefield snapshots. This nonlinear procedure differentiates our approach from the conventional linear migration methods (Kirchhoff, RTM). It allows to resolve the nonlinear interactions between reflectors. Consecutively, the resulting image is almost entirely free of multiple reflection artifacts. (Received September 17, 2018)

1145-65-963 **Marianne Debrito**, **Annaliese Keiser*** (akeiser@bgsu.edu) and **Taima Younes**. *Efficiency of a Moving Mesh System with a Curvature-type Monitor and an Application to Burgers' Equation.* Preliminary report.

Moving Mesh Methods are adaptive techniques to approximate solutions to partial differential equations numerically. A moving mesh system consists of a discretized physical PDE that evolves in time together with a PDE that adapts the discretization mesh using a monitor function. We explore properties of the moving mesh system when the physical solution has a steep gradient and large curvature, depending on parameter ϵ, over a small interval in the domain. Using a curvature-type monitor, we prove an explicit dependence of the derivatives of mappings between the computational and physical domains on ϵ. In addition, we show a similar dependence for the mesh spacing, which is important in quantifying discretization errors. These results are verified numerically for a known physical solution. Numerical evidence also suggests a significant reduction in steep gradients when using this type of monitor. These estimates show an explicit reduction of the number of equations needed to approximate the physical PDE with the moving mesh. We can further control mesh spacing and steepness of derivatives by adjusting parameters in the monitor function. As an application, we use our moving mesh system to model Burgers' Equation, which satisfies the hypothesis of our theorem. (Received September 23, 2018)

1145-65-970 **Weidong Chen*** (weidong.chen@mnsu.edu). *Computation Of Two-Dimensional Fourier Transforms For Noisy Band-Limited Signals.*

The computation of the two-dimensional Fourier transform by the sampling points creates an ill-posed problem. In this presentation, we will cover this problem for the band-limited signals in the noisy case. We will present a regularized algorithm based on the two-dimensional Shannon Sampling Theorem, the two-dimensional Fourier series, and the regularization method. First, we prove the convergence property of the regularized solution according to the maximum norm. Then an error estimation is given according to the L^2-norm. The convergence property of the regularized Fourier series is given in theory, and some examples are given to compare the numerical results of the regularized Fourier series with the numerical results of the Fourier series. (Received September 17, 2018)

1145-65-978 **Efstathios Georgios Charalampidis*** (charalamp@math.umass.edu), 196 N Pleasant St, Apartment 4, Amherst, MA 01002. *Peregrine solitons and gradient catastrophes in continuum and discrete models: Theory and Computation.*

In this talk, we will discuss the dynamics of rogue waves in nonlinear Schrödinger (NLS) equations and discrete variants thereof. Initially, we will consider NLS equations with variable coefficients which can be converted into their integrable siblings by utilizing suitable transformations. Then, the Peregrine soliton will be fed to the transformation employed. Using direct numerical simulations, the formation of such soliton solutions will be presented. Subsequently, and in the realm of atomic Bose-Einstein Condensates (BEC), the IBVP with Gaussian wavepacket initial data for the scalar (NLS) will be discussed where some novel features will be presented. In particular, it will be shown that as the width of the relevant Gaussian is varied, large amplitude excitations strongly reminiscent of Peregrine solitons or regular solitons appear to form. This analysis will be complemented by considering the Salerno model interpolating between the discrete NLS (DNLS) and Ablowitz-Ladik (AL) models where similar phenomenology is observed. The findings presented in this talk might be of particular importance towards realizing experimentally extreme events in BECs. (Received September 17, 2018)

1145-65-1029 **Wei Zhu***, zhu@math.duke.edu, and **Qiang Qiu**, **Jiaji Huang**, **Robert Calderbank**, **Guillermo Sapiro** and **Ingrid Daubechies**. *LDMNet: Low Dimensional Manifold Regularized Neural Networks.*

Deep neural networks have proved successful when large training sets are available, but when the training data are scarce, their performance suffers from overfitting. Many existing methods of reducing overfitting are data-independent. Data-dependent regularizations are mostly motivated by the observation that data of interest lie close to a manifold, which is typically hard to parametrize explicitly. To resolve this, we propose the Low-Dimensional-Manifold-regularized neural Network (*LDMNet*), which incorporates a feature regularization method that focuses on the geometry of both the input data and the output features. In *LDMNet*, we regularize the network by encouraging the combination of the input data and the output features to sample a collection of low dimensional manifolds, which are searched efficiently without explicit parametrization. To achieve this, we directly use the manifold dimension as a regularization term in a variational functional. In the experiments, we show that *LDMNet* significantly outperforms widely-used regularizers. Moreover, *LDMNet* can extract common features of an object imaged via different modalities, which is very useful in real-world applications such as cross-spectral face recognition. (Received September 18, 2018)

1145-65-1068 **Minah Oh*** (ohmx@jmu.edu). *The Hodge Laplacian on Axisymmetric Domains.*

An axisymmetric problem is a problem defined on a three-dimensional (3D) axisymmetric domain, and it appears in numerous applications. An axisymmetric problem can be reduced to a sequence of two-dimensional (2D) problems by using cylindrical coordinates and a Fourier series decomposition. A discrete problem corresponding to the 2D problem is significantly smaller than that corresponding to the 3D one, so such dimension reduction is an attractive feature considering computation time. Due to the Jacobian arising from change of variables, however, the resulting 2D problems are posed in weighted function spaces where the weight function is the radial component r. Furthermore, formulas of the grad, curl, and div operators resulting from the so-called Fourier finite element methods are quite different from the standard ones, and it is well-known that these operators do not map the standard polynomial spaces into the next one. In this talk, I will present stability and convergence results of the mixed formulations arising from the axisymmetric Hodge Laplacian by using a relatively new family of finite element spaces that forms an exact sequence and that satisfies the abstract Hilbert space framework developed by Arnold, Falk, and Winther. (Received September 18, 2018)

1145-65-1101 **Yinlin Dong*** (ydong5@uca.edu), 201 Donaghey Avenue, Conway, AR 72035. *Weak Galerkin finite element method for Poisson's Equations.* Preliminary report.

We apply a new weak Galerkin (WG) finite element method with stabilization term to solve Poisson's equations. By introducing the discrete weak gradient, the WG method enables the trial and test functions to take separated values in the interior and on the boundary of each element. The method allows discontinuous piecewise polynomials with various degrees in the finite element space. Different combination of polynomial spaces leads to different formulations of WG, which makes the method highly flexible and efficient in practical computation. We will establish the optimal error estimates in both L^2 and H^1 norms. Numerical experiments will be presented for both structured and unstructured triangulations. (Received September 19, 2018)

1145-65-1112 **Jay Gopalakrishnan**, **Philip Lukas Lederer*** (philip.lederer@tuwien.ac.at) and **Joachim Schöberl**. *A mass conserving mixed stress formulation for incompressible flows.*

One of the main difficulties in computational fluid dynamics lies in the proper treatment of the incompressibility condition. A weak treatment of this constraint can lead to a locking phenomena if the viscosity is small and results in bad velocity approximations. Recent developments show that H(div)-conforming finite elements for the approximation of the velocity provide major benefits such as exact mass conservation, pressure-independent (locking free) and polynomial robust error estimates. By introducing a new variable which approximates the gradient of an H(div)-conforming velocity we derive a new mixed stress formulation of the incompressible Stokes equations. For the analysis a new function space, the H(curldiv), is defined, in which we can show well posedness.

In the discrete setting two different approaches lead to a stable analysis. We present the construction of proper Finite elements, discuss solvability and verify our method with several numerical examples implemented in NGSolve (www.ngsolve.org) with the new NGS-Py interface. We conclude the talk by a further motivation of the new mass conserving mixed stress formulation: the numerical treatment of a linearized R13 model. (Received September 19, 2018)

1145-65-1171 **Vladimir Delengov*** (delengov@gmail.com) and **Chiu-Yen Kao**. *Computing Eigenmodes of Laplace-Beltrami Operator by Using Radial Basis Functions.*

In this work, a numerical approach based on meshless methods is proposed to obtain eigenmodes of Laplace-Beltrami operator on manifolds, and its performance is compared against existing alternative methods. Radial Basis Function (RBF)-based methods allow one to obtain interpolation and differentiation matrices easily by using scattered data points. We derive expressions for such matrices for the Laplace-Beltrami operator via so-called Reilly's formulas and use them to solve the respective eigenvalue problem. Numerical studies of proposed methods are performed in order to demonstrate convergence on simple examples of one-dimensional curves and two-dimensional surfaces. (Received September 19, 2018)

1145-65-1173 **Jiequn Han***, jiequnh@princeton.edu. *Deep Learning-Based Numerical Methods for High-Dimensional Parabolic PDEs and Forward-Backward SDEs.* Preliminary report.

Developing algorithms for solving high-dimensional partial differential equations (PDEs) and forward-backward stochastic differential equations (FBSDEs) has been an exceedingly difficult task for a long time, due to the notorious difficulty known as the curse of dimensionality. In this talk we introduce the "deep BSDE method", to solve general high-dimensional parabolic PDEs and FBSDEs. Starting from the BSDE formulation, we approximate the unknown Z component by neural networks and design a least squares objective function based on the terminal condition to optimize parameters. Numerical results of a variety of examples demonstrate that the proposed algorithm is quite effective in high-dimensions, in terms of both accuracy and speed. We furthermore provide a theoretical error analysis to illustrate the validity and property of the objective function. (Received September 19, 2018)

1145-65-1215 **Vani Cheruvu*** (vani.cheruvu@utoledo.edu), Department of Mathematics and Statistics, The University of Toledo, Toledo, OH 43606, and **Shravan Veerapaneni**, **Eduardo Corona** and **Ryan Kohl**. *Spectra of Boundary Integral Operators Defined on the Unit Sphere for the Modified Laplace Equation.*

We consider a modified Laplace equation on a unit sphere. Spherical harmonics are used for the expansion of the unknown function. We show that on the unit sphere, both modified Laplace single and double layer operators diagonalize in spherical harmonic basis. The analytic expressions for evaluating the operators away from the boundary are also derived. Currently, we are working on the numerical aspects. In this talk, we present both the analytical and numerical results of our work. (Received September 20, 2018)

1145-65-1227 **L. Ridgway Scott*** (ridg@uchicago.edu), Department of Mathematics, University of Chicago, Chicago, IL 60637. *Recent advances for exactly incompressible elements.* Preliminary report.

Finite element approximations satisfying exact incompressibility conditions are now recognized as essential for certain flow simulations. We discuss two enhancements for algorithms based on what is known as the Scott-Vogelius method. One is known as the unified Stokes algorithm (USA) and projects the discontinuous pressure arising in Scott-Vogelius onto a continuous pressure space. The other enhancement relates to multi-grid solvers. It involves new smoothers that preserve the incompressibility condition and insure optimal convergence. (Received September 20, 2018)

1145-65-1239 **Constantin Bacuta** and **Jacob Jacavage*** (jjacav@udel.edu). *Preconditioning for mixed variational formulations.*

We consider a general approach to precondition and discretize boundary value problems written as primal mixed variational formulations. This approach connects the classical theory of symmetric saddle point problems with the theory of preconditioning symmetric positive definite operators. For the proposed discretization method, a discrete inf-sup condition is automatically satisfied by natural choices of test and trial spaces. In addition, bases are needed only for the test spaces and assembly of a global saddle point system is avoided. Efficient iterative solvers utilizing standard multilevel preconditioners are proposed. Applications include discretizations of second order PDEs, in which the coefficients may be discontinuous, and first order systems of parametric PDEs, such as the time-harmonic Maxwell equations. (Received September 20, 2018)

1145-65-1250 **L. Ridgway Scott*** (ridg@uchicago.edu), Department of Mathematics, University of Chicago, Chicago, IL 98040. *Automated Modeling with FEniCS.*

The FEniCS Project develops both fundamental software components and end-user codes to automate numerical solution of partial differential equations (PDEs). FEniCS and other automated software are catalyzing a change for PDEs similar to the one that Matlab did for linear algebra.

FEniCS enables users to translate scientific models quickly into efficient finite element code and also offers powerful capabilities for more experienced programmers. FEniCS is a disruptive force for both research and education related to PDEs. Both aspects will be discussed in this presentation.

FEniCS uses the variational formulation of PDEs as a language to define models and a rigorous basis for the finite element method. Variational formulations also provide a firm theoretical foundation for understanding PDEs. Combining theory with coding provides a way to teach PDEs and their numerical solution without requiring extensive prerequisites.

FEniCS also provides a productive platform for research. We will present examples where it has been used to answer questions that would have required months of programming using traditional techniques. (Received September 20, 2018)

1145-65-1286 **Snorre H Christiansen**, **Jun Hu** and **Kaibo Hu*** (khu@umn.edu), School of Mathematics, 206 Church St. SE, University of Minnesota, Minneapolis, MN 55455. *Nodal finite elements for de Rham complexes.*

There have been many discussions on the nodal finite element approximation of problems raised in fluid dynamics and electromagnetism. The C^0 Lagrange finite element has subtle stability issues as an approximation for vector fields on a general mesh since it does not naturally fit into a de Rham complex. In this talk, we modify the Lagrange vector by allowing discontinuity in the normal or tangential direction. This leads to partially discontinuous elements which fit into discrete de Rham complexes. As a result, canonical bases for the scalar Lagrange elements can be used for approximating vector fields. (Received September 20, 2018)

1145-65-1428 **Miandra Ann Ellis*** (mellis5@asu.edu) and **Rosemary Anne Renaut** (renaut@asu.edu). *Image deblurring using higher order Galerkin approximations with domain stretching.* Preliminary report.

Image deblurring may be modeled via the convolution $g(s) = \int K(s-t)f(t)dt$ for the shift invariant kernel operator $K(\cdot)$. Typical approaches for image deblurring apply a Galerkin method to discretize the integral equation, using the zeroth order indicator functions as a basis for the solution and the operator. This requires a basis of length N for a signal of N measurements in one dimension. The Chebyshev basis offers the potential to use a higher order basis with $n << N$ terms when applied using a Galerkin or collocation formulation. In this talk, initial results demonstrating validity of the use of a higher order basis for image deblurring will be presented. Results will be contrasted with those obtained using the standard techniques with an aim to find the technique which is most computationally efficient while maintaining accuracy and stability. Due to issues with the stability of the discretization of the Chebyshev operators, a standard domain stretching will be introduced to improve the conditioning of the formulation. Our interest in developing the method is motivated by the need to develop a computationally tractable algorithm for the solution of large-scale inversion problems. (Received September 21, 2018)

1145-65-1557 **Vladimir Druskin*** (vdruskin@wpi.edu), 00 Institute Rd, WPI-Stratton Hall, Worcester, MA 01609, and **Liliana Borcea** (borcea@umich.edu), **Alexander Mamonov** and **Mikhail Zaslavsky**. *Nonlinear processing of multi-scattering data via sparse data-driven reduced order models.*

Geophysical seismic exploration, as well as radar and sonar imaging, require the solution of large scale inverse problems for hyperbolic systems of equations. In this talk, I will show how model order reduction can be used to address some intrinsic difficulties of these problems. We consider ROMs that capture properties of the large problem that are essential for imaging and that can be realized via sparse graph-Laplacian networks. The ROMs are data-driven, i.e., they learn the underlying PDE problem from the transfer function. Here I will focus on one recent applications of this approach: A direct, nonlinear imaging algorithm in strongly heterogeneous media, where the ROM is used to manipulate the data in such a way that multiply scattered waves are separated from the single scattered ones. The algorithm, known as Data-to-Born map, transforms multi-scattering data to the single-scattering one. The latter can be effectively processed by any off-shelf linear algorithm. (Received September 23, 2018)

1145-65-1774 **Leo Rebholz*** (rebholz@clemson.edu) and **Alexander Linke**. *Pressure-induced locking in mixed methods for time-dependent (Navier–)Stokes equations.* Preliminary report.

A locking phenomenon is identified for classical inf-sup stable methods like the Taylor–Hood or the Crouzeix–Raviart elements by a novel, elegant and simple numerical analysis and corresponding numerical experiments, whenever the momentum balance is dominated by forces of a gradient type. More precisely, a reduction of the L^2 convergence order for high order methods, and even a complete stall of the L^2 convergence order for lowest-order methods on preasymptotic meshes is predicted by the analysis and practically observed. On the other hand, it is also shown that (structure-preserving) *pressure-robust* mixed methods do not suffer from this locking phenomenon, even if they are of lowest-order. (Received September 24, 2018)

1145-65-1831 **Bjørn Christian Skov Jensen**, **Adrian Kirkeby** and **Kim Knudsen*** (kiknu@dtu.dk). *Limited angle acousto-electric tomography with complete wave modelling.*

In acousto-electric tomography the goal is to reconstruct the interior conductivity distribution in a bounded domain. The data is in the form of boundary measurements of currents and voltages taken while the domain is penetrated by an externally generated acoustic wave. This leads to a coupled-physics inverse problem.

The problem is approached in two steps: first, we model carefully the acoustic wave and derive a framework for the reconstruction of the interior power density based on the corresponding boundary measurements; second, an optimization scheme using total variation regularization is used for the reconstruction of the conductivity distribution from the power density.

The reconstruction algorithm is implemented numerically and the feasibility, stability and efficiency is demonstrated on various numerical examples. In particular we address the limited angle problem, where only a small part of the boundary is accessible for measurements. (Received September 24, 2018)

1145-65-1885 **Samundra Regmi*** (samundra.regmi@cameron.edu), 2800 W Gore Blvd, Lawton, OK 73505, and **Ioannis K. Argyros**. *Majorizing Sequences for Iterative Methods with Applications.*

We present a new semi-local convergence analysis for Newton's method in order to approximate a locally unique solution of a nonlinear equation in a Banach space setting. Using tighter majorizing sequences than in earlier works, we extend the applicability of Newton's method in cases not covered before. Numerical examples show that the new results can be used to solve equations that the older results could not. (Received September 24, 2018)

1145-65-1901 **Simone Cassani***, 100 Institute Road, Worcester, MA 01609, and **Sarah D Olson**, 100 Institute Road, Worcester, MA 01609. *A hybrid cellular automaton model of cartilage regeneration.*

Articular cartilage (AC) is a connective tissue that covers articular joints to provide a surface that allows bones to slide over each other, and absorb shocks. AC is composed of a dense extracellular matrix (ECM), including fluid, a collagen network, and proteins, and chondrocytes (cells). Nutrients and oxygen are provided via diffusion through the ECM. Pathologies, injuries and normal wear and tear cause the erosion and damage of

AC. Cartilage is produced in vitro to be implanted at the site of the damage to restore normal functionality. A hybrid mathematical model is used to investigate the phenomena of AC growth in a tissue-engineered construct to elucidate the influence of different biological factors, such as scaffold porosity and cell velocity. The model couples a discrete approach for the chondrocytes, with a continuous approach for the other components of the matrix. The chondrocytes are described using an off-lattice cellular automaton model that accounts for biased movement, division, contact inhibition and death. The continuous components of the model, nutrients and porosity, are modeled consistently with the literature. The insight provided by the model are used to elucidate the outcomes of laboratory experiments involving tissue-engineered AC. (Received September 24, 2018)

1145-65-1906 **Christian Ratsch*** (cratsch@math.ucla.edu), 460 Portola Plaza, Suite 1158, Los Angeles, CA 90095-7121. *Mound Formation during Epitaxial Growth studied by Kinetic Monte Carlo and Island Dynamics Simulations.*

In this talk we will discuss how to model epitaxial growth using kinetic Monte Carlo (KMC) simulations as well as an Island Dynamics model that employs the level set method. We will focus on the formation of so-called mounds that result from the presence of a step edge barrier (that induces an uphill current). The slopes of these mounds are stabilized by a downward transport mechanism. We study two different downward transport mechanisms, referred to as downhill funneling and transient mobility. Our results show how the scaling exponents that are associated with mound formation depend on the model parameters. (Received September 24, 2018)

1145-65-1948 **Julia A Dobrosotskaya*** (julia.dobrosotskaya@case.edu), Case Western Reserve University, Dept. of Math., Appl. Math. and Statistics, 2049 Martin Luther King Jr. Drive, Cleveland, OH 44106. *Anisotropic diffuse interface functionals based on multiscale multidirectional representations.*

We consider Laplacian-like diffusive operators based on sparse representation systems such as shearlets and composite dilation wavelets in 2D. The directional sensitivity of these systems allow for adaptive design of anisotropic behavior in the diffuse interface set-up analogous of the Ginzburg Landau functionals. The associated energies approximate weighted perimeter functionals (regular or anisotropic TV) in the variational sense, with minimizers exhibiting sharp phase transitions and little interface blur. They can be effectively utilized in creating data adaptive variational techniques for multipurpose image processing. We illustrate the theoretical findings with examples of image inpainting, segmentation and supperresolution. (Received September 24, 2018)

1145-65-1975 **Zhiliang Xu*** (zxu2@nd.edu). *Central and Central Discontinuous Galerkin (DG) Schemes on Overlapping Cells of Unstructured Grids for Solving Ideal MHD Equations with Globally Divergence-Free Magnetic Field.*

In this talk, I will present new central and central DG schemes for solving ideal magnetohydrodynamic (MHD) equations while preserving globally divergence-free magnetic field on triangular grids. These schemes incorporate the constrained transport (CT) scheme of Evans and Hawley with central schemes and central DG methods on overlapping cells which have no need for solving Riemann problems across cell edges where there are discontinuities of the numerical solution. The schemes are formally second-order accurate with major development on the reconstruction of globally divergence-free magnetic field on polygonal dual mesh. Moreover, the computational cost is reduced by solving the complete set of governing equations on the primal grid while only solving the magnetic induction equation on the polygonal dual mesh. (Received September 24, 2018)

1145-65-2037 **Sean Ryan Breckling*** (sbreckli@nd.edu), IN, and **Daniele Schiavazzi** (dschiavazzi@nd.edu) and **Thomas Juliano** (tjuliano@nd.edu). *Unified Bayesian Networks for Uncertain Inputs and Partial Model Ensembles.*

We present a prototype system for probabilistic assessment of thermo-structural failure in hypersonic vehicles, based on a unified Bayesian network. A probabilistic characterization of failure in such systems presents significant challenges due to the complex dependence among a large number of uncertain parameters, the availability of an ensemble of models each describing a particular aspect of the underlying physics, and the presence of multiple mission-critical components like thermal protection system (TPS) and control surfaces. We start by considering an idealized model of the Space Shuttle orbiter, where parameters are assigned to the vehicle geometry, the flight trajectory, and TPS material properties. We use a simplified method to compute the heat flux and pressure load histories on the TPS surface and a two-dimensional plane strain characterization of its structural response. Failure is assessed based on thermal stress and maximum temperature in operation. Using a Bayesian network with discrete random variables, we perform inference using brute-force approaches and message passing. We also investigate how the results are affected by observations from pressure and temperature sensors. (Received September 24, 2018)

1145-65-2039 **Sibusiso Mabuza*** (smabuza@sandia.gov), Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM 87185, and **John N Shadid**, **Eric C Cyr**, **Thomas M Smith** and **Dmitri Kuzmin**. *Stabilized continuous finite element schemes for problems in plasma physics.*

We present finite element schemes for simulating ionized and magnetized gases. We consider iterative, linearity preserving, nodal variation limiting strategies for the stabilization of hyperbolic systems such as the MHD equations and multifluid plasma equations. These equations, are discretized using piece-wise linear continuous finite elements. The stabilization of the scheme follows the flux corrected transport paradigm by introducing some diffusion into the system, whose amount is regulated by solution dependent element and nodal limiters. The limiter is designed to be linearity preserving so to ensure that in smooth regions, second order convergence is observed for smooth solutions. The limiters are also designed such that they continuously dependent on data, guaranteeing solvability of the semi-discrete scheme. We consider a number of standard inviscid and viscous MHD examples in 1D,2D and 3D on unstructured quad and simplex meshes. We also consider two-fluid plasma (ions and electrons) problems. We show the verification and validation of the numerical scheme in this case and applications to very challenging problems. We also demonstrate the robustness of the scheme using various implicit,explicit and IMEX time integrators. (Received September 24, 2018)

1145-65-2172 **Prashant Athavale*** (prashant@clarkson.edu), 8 Clarkson Ave, Box 5815, Department of Mathematics, Potsdam, NY 13699, **Sheetal Dharmatti** (sheetal@iisertvm.ac.in), India, and **Aiswarya Sara Matthew** (aiswaryasaramathew@gmail.com), India. *An entropy-based algorithm for texture image inpainting.* Preliminary report.

Image inpainting is the problem of filling in the missing portion of an image. Numerous exemplar-based methods are proposed for inpainting images. However, inpainting of texture images is an especially tricky problem. Some methods propose separating an image into an oscillating part and structure part. We propose an exemplar-based method that is suitable for texture inpainting without separating the image into two parts. We achieve this by identifying the segment that the missing part belongs to. Then we use an entropy-based dissimilarity parameter for filling in the missing region pixel-by-pixel. (Received September 24, 2018)

1145-65-2175 **Yekaterina Epshteyn** and **Qing Xia*** (xia@math.utah.edu). *A Domain Decomposition Approach based on Difference Potentials Method for Chemotaxis Models in 3D.*

In this talk, I will present a domain decomposition approach based on Difference Potentials Method (DPM) for approximating the solution to the classical Patlak-Keller-Segel chemotaxis models in 3D. We employ DPM and uniform Cartesian meshes to handle sub-domains of complex geometric shapes, without loss of accuracy near the irregular boundaries of the sub-domains. As a result of using uniform meshes, fast Poisson solver based on FFT is employed for better efficiency of our numerical algorithms. In addition, our domain decomposition approach is capable of mesh adaptivity and is suitable for parallel computing, which further boosts the efficiency. Numerical results from 3D simulations will be given to demonstrate the significantly improved efficiency and similar accuracy of the domain decomposition approach, in comparison to the single domain approach. This is joint work with Y. Epshteyn. (Received September 24, 2018)

1145-65-2348 **Suzanne L. Weekes*** (sweekes@wpi.edu), 100 Institute Road, Worcester, MA 01609. *Numerical and Analytic Study of Dynamic Materials.*

An overview of work on wave propagation through dynamic materials will be given. Dynamic materials are spatio-temporal composites - materials whose properties vary in space and in time. Mathematically, we formulate the problem as linear, hyperbolic partial differential equations with spatio-temporally varying coefficients. The variability in the material constituents leads to effects that are unachievable through static (spatial-only) design. For example, with dynamic laminates we are able to screen portions of the material from the effects of a wave disturbance. With checkerboard geometry in space-time, we create pulse compression and energy accumulation, and recent work shows that these effects are structurally stable. (Received September 25, 2018)

1145-65-2410 **Shari Moskow*** (slm84@drexel.edu), **Liliana Borcea**, **Vladimir Druskin**, **Alex Mamonov** and **M. Zaslavsky**. *Reduced Order Models For Spectral Domain Inversion: Galerkin Equivalence And Generation Of Internal Data.* Preliminary report.

We generate reduced order Galerkin models for inversion of problems in Schrodinger form given data in the spectral domain for one and two dimensional problems. We show that in one dimension, after tridiagonalization, the Galerkin system is precisely the same as the three point staggered nite difference system on the corresponding spectrally matched grid. The orthogonalized basis functions depend only very weakly on the medium, and thus

the spectral data yields highly accurate internal solutions, which suggests some natural inversion procedures.
(Received September 25, 2018)

1145-65-2498 **Scott A Moe** (scott.moe@amd.com), Seattle, WA, **James A Rossmanith**, Ames, IA , and **David C Seal*** (seal@usna.edu), Department of Mathematics, 572C Holloway Road, Annapolis, MD 21402. *A high-order shock-capturing limiter for discontinuous Galerkin methods with applicability to Cartesian, curvilinear, and unstructured meshes.* Preliminary report.

The discontinuous Galerkin (DG) method is class of numerical methods that are state of the art for simulating mathematical models called hyperbolic conservation laws. Department of Defense applications for these models include high Mach number flows in aerospace applications, shallow water equations for storm surge models, Maxwell's equations for laser wave propagation and laser-induced plasma channels and space-weather plasma simulations relevant to support satellite communication infrastructure.

Hyperbolic PDEs often contain shocks and discontinuities in the exact solution, and therefore numerical methods need to address these issues. 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. Here, we present a novel shock capturing limiter for the for the DG method, which works by selecting local upper and lower bounds for the solution. Results for multiple dimensions, as well as problems that require positivity-preservation of the solution are included. (Received September 25, 2018)

1145-65-2612 **Zhen Chao*** (chaozhen@uwm.edu) and **Dexuan Xie**. *A modified preconditioned conjugate gradient method for a nonsymmetric elliptic boundary value problem.*

In this talk, we present a modified preconditioned conjugate gradient (mPCG) method for solving a second order nonsymmetric and indefinite elliptic boundary value problem. We first approximate the problem as a finite element linear system, and then reformulate it as a symmetric indefinite augmented linear system based on the least square approach. We next construct mPCG for solving this augmented linear system through introducing a singularity test and a novel preconditioner to deal with the singularity and convergence rate issues. As an application, we derive a fast mPCG for solving a steady state convection diffusion boundary value problem via a PCG-multigrid scheme for solving each related preconditoning linear system. We programmed this mPCG method in Python and Fortran based on the finite element library from the FEniCS project. Numerical results demonstrate the efficiency of this mPCG program in comparison to the commonly-used GMRES or MIN-RES methods. (Received September 25, 2018)

1145-65-2720 **Luan Vu Thai*** (vluan@smu.edu), Department of Mathematics, Southern Methodist University, Dallas, TX. *Exponential integrators for stiff PDEs and their application to atmospheric models.* Preliminary report.

In this talk, we first introduce exponential Rosenbrock methods, which are designed for large stiff PDEs. They are fully explicit and do not suffer from the stability restriction imposed by the CFL condition for the linear part. It has been also shown that these integrators can offer much higher accuracy than implicit/IMEX methods, and can offer significant computational savings, particularly for large systems where no efficient preconditioner is available. For the accuracy and efficiency purposes, we identify the three efficient schemes of orders 4 and 5 (exprb42, pexprb43, exprb53). Then we apply these schemes to a suite of four challenging tests problems performed with the shallow water equations on the sphere, which are commonly used to test and design atmospheric models. Moreover, we propose an efficient modification of one of state-of-the-art algorithms for the implementation of exponential integrators. Altogether, this allows the proposed schemes enable accurate solutions at much longer time-steps than previous methods including the widely used semi-implicit schemes, proving considerably more efficient as the desired accuracy decreases or as the problem nonlinearity increases. This offers a good potential for the new methods to be used in meteorological models. (Received September 25, 2018)

1145-65-2801 **Andreas C. Aristotelous*** (aaristotel@wcupa.edu). *Energy Stable DG-FE Schemes For Diffuse Interface Models.*

Cahn-Hilliard type equations coupled with fluid flow inspired from modeling tumor growth, biofilms, wound healing and other complex biological processes will be introduced. Discontinuous Galerkin Finite Element Methods for the numerical solution of the equations will be presented. For the underline schemes: solvability, energy stability, convergence and error estimates will be established where possible. Simulation results will be provided. (Received September 25, 2018)

1145-65-3028 **Andrea Arnold*** (anarnold@wpi.edu). *Estimating Structured, Time-Varying Parameters via Nonlinear Filtering.*

Many applications in modern day science involve unknown system parameters that must be estimated using little to no prior information. A subset of these problems includes parameters that are known to vary with time but have no known evolution model. We show how nonlinear sequential Monte Carlo filtering techniques can be employed to estimate time-varying parameters, while naturally providing a measure of uncertainty in the estimation. In particular, we show how structural characteristics of the time-varying parameters can be exploited in the estimation. Results are demonstrated on several applications from the life sciences. (Received September 26, 2018)

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1145-68-30 **Nektarios A Valous*** (nek.valous@nct-heidelberg.de), Im Neuenheimer Feld 460, 69120 Heidelberg, BW, Germany, **Rodrigo Rojas Moraleda** (rodrigo.moraleda@nct-heidelberg.de), Im Neuenheimer Feld 460, 69120 Heidelberg, BW, Germany, **Neha Pandey** (joonie2612@gmail.com), Im Neuenheimer Feld 205, 69120 Heidelberg, BW, Germany, **Dirk Jaeger** (dirk.jaeger@nct-heidelberg.de), Im Neuenheimer Feld 460, 69120 Heidelberg, BW, Germany, **Inka Zoernig** (inka.zoernig@nct-heidelberg.de), Im Neuenheimer Feld 460, 69120 Heidelberg, BW, Germany, and **Niels Halama** (niels.halama@med.uni-heidelberg.de), Im Neuenheimer Feld 460, 69120 Heidelberg, BW, Germany. *Visualization and separation of chromatic information in natural and medical images based on a quaternion algebra framework.*

Colors can be represented by vectors constructed by a linear combination of three primaries; in the perceptually nonuniform RGB color space the basic element i is chosen to describe red, j green, and k blue. Consequently, color pixels can be encoded by a linear combination of the three basis vectors in a hypercomplex algebra framework, e.g. quaternions. This encoding provides the opportunity to process color images in a geometric way, hence the quaternionic representation of color allows image analysis to be performed in a coherent manner. By conveniently rewriting the quaternionic representation of natural and medical images with simple algebraic operations, it is feasible to decompose an image into different spectral representations that can visualize and separate the contextual chromatic information. This pixel-based approach is computationally efficient thus taking advantage of parallel architectures in computing systems. The benefits of the proposed approach for medical images can be translated in two components: i) as a means for optimized manual assessment by clinicians (color visualization), and ii) as a key step of digitally separating chromatic regions of interest for further quantification in automated processing pipelines (color separation). (Received June 26, 2018)

1145-68-144 **Thomas Vidick*** (vidick@cms.caltech.edu), Pasadena, CA 91106. *Verifying quantum computations at scale: a cryptographic leash on quantum devices.*

Quantum computers are physical devices that leverage the laws of quantum mechanics to accomplish certain computations, such as the simulation of certain physical, chemical, or biological systems, in an exponentially more efficient way than can be achieved by the best classical methods. By its very nature, the outcome of such a computation cannot be predicted by a classical computer. Moreover, there is strong evidence that the outcome cannot even be verified by classical means. How can we, classical beings, tell if the quantum device produced the right prediction? What checks can be placed on the performance of devices whose computational power all but eludes us?

This question is made all the more urgent by recent advances in practical quantum devices. In this talk I will formulate the question precisely using the language of complexity theory, and present a recent resolution, by Urmila Mahadev, that combines the theory of interactive proofs with insights from cryptography and quantum information. I will not assume any background in complexity, cryptography, or quantum information, but instead aim to highlight how beautiful ideas from these areas combine to provide an insightful solution to a seemingly intractable problem. (Received August 08, 2018)

1145-68-154 **Christopher John Tralie*** (ctralie@alumni.princeton.edu). *Topological Periodicity Analysis in Multimedia Time Series.*

A large variety of multimedia data inference problems require analysis of repeated structures. In audio, for instance, understanding rhythm is an important preprocessing step in music information retrieval. In medical video analysis, there is interest in determining heart pulse rate in ordinary webcam videos, analyzing stereotypical repetitive motor motions in videos of autism spectrum disorder patients, and analyzing voice pathologies from

high speed videos of vocal folds. In this work, we show how the "shape" of time series can aid analysis in all of these applications. We present a unified sliding window framework in which periodic patterns show up as loops and quasiperiodic patterns show up as flat tori. We also show that some periodic processes with harmonic structures lie on loops which bound twisted spaces such as the Moebius strip, and quantifying these structures is applicable both to rhythm hierarchy analysis and detection of "biphonation" due to mucous in vibrating vocal folds. Finally, in addition to detecting and quantifying periodicity, we can parameterize periodic data, which we use both to analyze tempo/pulse rate and to create slow motion seamless templates of periodic time series and videos. (Received August 10, 2018)

1145-68-257 **Rachid Ait Maalem Lahcen** (rachid@ucf.edu), Department of Mathematics, University of Central Florida, Orlando, FL 32816, and **R. N. Mohapatra*** (ram.mohapatra@ucf.edu), Mathematics Department, University of Central Florida, Orlando, FL 32816. *Vulnerability Analysis of networks and Attack Graphs.*

he network infrastructure is the most critical technical asset of any organization. This network architecture must be useful, efficient, and secure. However, their cybersecurity challenges are immense as the number of attacks is increasing. Consequently, there is a need to have efficient tools to assess the risks, know the vulnerabilities, and find the solutions before the attackers exploit them. The challenges remain in integrating the vulnerability analysis tools in a holistic process that cyber defenders can use to detect an intrusion and respond quickly. Attack graphs are used in analyzing network security. In this talk, we present some instances of the use of attack graphs in analyzing vulnerability of a network/ (Received August 26, 2018)

1145-68-293 **Yu Ma*** (midsummer@berkeley.edu). *Tensor flattening approaches to estimate lower bound of small matrix multiplication tensor's border ranks.*

Matrix multiplication efficiency lies at the heart of every computer algorithm. Strassen's algorithm initiated a new field of complexity theory looking for improvements on this problem. One popular approach in recent years is to evaluate the border ranks of tensor representations of matrix multiplications, written as $M_{\langle n,m,l\rangle}$. Unfortunately, even small sized problems such as determining the tensor rank of $M_{\langle 3,3,3\rangle}$ has not yet been solved. This project presents a detailed overview and applications of a newly emerged method, tensor flattening, that has shown to successfully assist evaluating lower bound of the border rank of $M_{\langle n,n,n\rangle}$. Furthermore, we specifically looked into the merits and limitations of Young flattening, proposed by Landsberg in 2013, with preliminary computational and theoretical investigation of its applications on small scaled rectangular matrix multiplication tensors. We end with a discussion of the implications of these results as well as the potential for generalization to other complexity problems. (Received August 28, 2018)

1145-68-353 **Nicole Eikmeier*** (eikmeier@purdue.edu) and **David F. Gleich**. *Hypergraph Kronecker models for Networks.*

A Kronecker model for a network consists of a random draw from a matrix of edge probabilities arising from repeated Kronecker products between matrices. We explore a simple generalization of this model to generate a regular hypergraph by creating a tensor of edge probabilities via repeated tensor Kronecker products. A sample from this hypergraph distribution is then collapsed into a network model by treating each hyperedge as a motif, such as a triangle. We discuss efficient strategies to generate these networks and show there are surprising number of connections with topics across discrete mathematics, including Morton codes and ranking and unranking multiset permutations. We fit the HyperKron model to real-world networks, and demonstrate the model's flexibility with a complex application of the HyperKron model to networks with coherent feed-forward loops. (Received September 03, 2018)

1145-68-382 **Jiahan Du*** (dujiahan@berkeley.edu), 2318 Eighth Street, Berkeley, CA 94710. *On the rank of matrix multiplication tensors of medium size.* Preliminary report.

The multiplicative complexity of matrix multiplication for n by n matrices is an important topic in theoretical computer science, and in this paper I will use techniques developed by Alexander Sedoglavic in 2017 to produce new upper bounds for matrix multiplications of medium rank. I will begin by giving key definitions of algebraic complexity and tensor rank. Then I will revisit historical results obtained for upper bound and lower bound of the matrix multiplicative complexity from such authors as Winograd, Strassen, and Landsberg. Next, I'll explain the basic method developed by Sedglovic and how it can be useful in decomposing multiplication tensors and how it can be further improved on to have less loss of efficiency. Finally, I will give a comparison of all known lower and upper bounds with a summary of methods that have the potential to generate new asymptotically faster algorithms. (Received September 04, 2018)

1145-68-547 **Owen Levin*** (levin453@umn.edu). *Approximation Algorithms for Network Connectivity.* Preliminary report.

The problem discussed is to connect* a set of initially disconnected* points as quickly as possible. Assuming all points move at the same speed, this amounts to minimizing the maximum distance traveled. We give two new algorithms that outperform the state-of-the-art from the literature and a number of results bounding their optimality.

Let $d(p, q)$ denote the Euclidean distance between $p, q \in \mathbb{R}^2$. Then given P, a set of n distinct points in $\mathbb{R}^2$, define the r-disk graph, $G(P, r)$ to be the weighted graph with vertex set P and edges between all $p, q \in P$ with $d(p, q) \leq r$ with weights equal to $d(p, q)$.

* We call P *connected* when $G(P, 1)$ is a connected graph, and *disconnected* otherwise. (Received September 09, 2018)

1145-68-902 **Ellen Gasparovic*** (gasparoe@union.edu). *The Relationship Between the Intrinsic Cech and Persistence Distortion Distances for Metric Graphs.*

We will look at two persistence-based distances that one may define for metric graphs and discuss progress toward establishing their discriminative capacities. This is joint work with Maria Gommel, Emilie Purvine, Radmila Sazdanovic, Bei Wang, Yusu Wang, and Lori Ziegelmeier. (Received September 17, 2018)

1145-68-1183 **James Allen Fill*** (jimfill@jhu.edu), The Johns Hopkins University, Dept. Applied Math. & Stat., Whitehead Hall, 3400 N. Charles St., Baltimore, MD 21218-2682, and **Wei-Chun Hung** (whung6@jhu.edu), The Johns Hopkins University, Dept. Applied Math. & Stat., Whitehead Hall, 3400 N. Charles St., Baltimore, MD 21218-2682. *Asymptotic bounds on the tails of the limiting QuickSort density.*

The randomized algorithm `QuickSort` is one of the great algorithms in computer science, and its computational efficiency continues to be the subject of deep analysis. It is well known that the normalized number of comparisons required by `QuickSort` to sort a file of n keys converges in distribution, with the limiting distribution possessing a density f that is infinitely smooth and positive everywhere on the real line.

We give upper and lower asymptotic bounds for the left tail and for the right tail of f that are nearly matching in each tail. The bounds strengthen results from a paper of Svante Janson (2015) concerning the corresponding distribution function F—and we substantially improve Janson's right-tail upper bound on F, as well. Furthermore, we obtain similar bounds on absolute values of derivatives of f of each order.

Using the refined asymptotic bounds on F, we derive right-tail large deviation (LD) results for the distribution of the number of comparisons required by `QuickSort` that sharpen somewhat the two-sided LD results of McDiarmid and Hayward (1996). (Received September 19, 2018)

1145-68-1462 **Yusu Wang*** (yusu@cse.ohio-state.edu) and **Qi Zhao**. *Learning metric for persistence diagrams.* Preliminary report.

Persistent homology can summarize and characterize a given domain from different perspectives in a multiscale manner. It thus provides a natural way to represent various types of data. In the past several years, there have been many interesting approaches developed either to provide kernels for persistence-based summaries or to vectorize them, so as to make persistence-based summaries more friendly with machine learning frameworks. In this talk, I will describe our investigation and results on learning the appropriate metrics for persistence-based summaries, and applications. (Received September 22, 2018)

1145-68-1686 **Adam Case*** (adam.case@drake.edu), Dept. of Mathematics and Computer Science, Drake University, Des Moines, IA 50311, and **Jack H. Lutz** (lutz@iastate.edu), Department of Computer Science, Iowa State University, Ames, IA 50011. *Mutual Dimension and Random Sequences.*

If S and T are infinite sequences over a finite alphabet, then the *lower* and *upper mutual dimensions* $mdim(S : T)$ and $Mdim(S : T)$ are the lower and upper densities of the algorithmic information that is shared by S and T. In this talk we investigate the relationships between mutual dimension and *coupled randomness*, which is the algorithmic randomness of two sequences R_1 and R_2 with respect to probability measures that may be dependent on one another. For a restricted but interesting class of coupled probability measures we prove an explicit formula for the mutual dimensions $mdim(R_1 : R_2)$ and $Mdim(R_1 : R_2)$, and we show that the condition $Mdim(R_1 : R_2) = 0$ is necessary but not sufficient for R_1 and R_2 to be independently random. (Received September 23, 2018)

1145-68-1820 **Katie Rainey*** (krainey@spawar.navy.mil). *Functional Analysis of Deep Learning Classifiers.* Preliminary report.

Classification functions are central to most applications of machine learning. Recent advances in deep learning algorithms have shown impressive results on image recognition and other classification tasks, motivating researchers to apply such algorithms to all manner of problem domains. However, many practitioners fail to understand how the algorithms work, and in particular how they operate on a given dataset. In this talk I will discuss deep learning classifiers from the perspective of a mathematical function, to shed light on how the algorithms operate on data at a fundamental level. I will also discuss how understanding the domain and functional properties of a classifier is crucial to applying classifiers to defense applications, such as automatic detection of targets in overhead imagery. As advances in artificial intelligence find their way to more and more real-world applications, research into the underlying mathematical properties of algorithms is necessary to confidently deploy such systems in operational and safety-critical scenarios. (Received September 24, 2018)

1145-68-1878 **Don Stull*** (dstull@inria.fr). *The effective dimension of points on lines.*

In this talk, we will review recent advances on the dimension spectra of planar lines. The dimension spectrum of a line $L_{a,b}$ with slope a and intercept b is the set $\mathrm{sp}(L_{a,b})$ of all effective dimensions of the points $(x, ax+b)$ on $L_{a,b}$. This talk will focus on the conjecture of N. Lutz that, for every line $L_{a,b}$, $\mathrm{sp}(L_{a,b})$ contains a unit interval. We will discuss recent work settling this conjecture for certain classes of lines. This talk will also highlight the connections between the (effective) dimension spectra of lines, and well known conjectures in fractal geometry. (Received September 24, 2018)

1145-68-1902 **Hyunsun Lee*** (hlee@hpu.edu), **Yi Zhu** and **Brian Spain**. *Adaptive Data Dissemination for Wireless Ad Hoc Networks based on Stochastic Branching Process.*

In this study, we adapt a stochastic branching process to develop a routing method for wireless ad hoc networks. The stochastic branching model is often used to describe the beginning stage of a disease outbreak when the number of infected patients remains significantly smaller than the entire population. The network of individual contacts and transmissions are focused in the branching process model. The importance of the method is placed on the transmission rate from one individual to the next generation, which guides us to understand the statistical structure along the transmission path. The idea of proposed routing method is based on the similarities between epidemic and data dissemination. Our approach aims at balancing reachability, total node usage, and average branching factor in multi-hop data dissemination by locally regulating the transmission probability and adaptively selecting neighbor nodes. (Received September 24, 2018)

1145-68-1998 **Vladimir Braverman**, **Stephen R Chestnut**, **Nikita Ivkin**, **Jelani Nelson*** (minilek@seas.harvard.edu), **Zhengyu Wang** and **David P Woodruff**. *BPTree: an l_2 heavy hitters algorithm using constant memory.*

In the frequent items problem one sees a sequence of items in a stream (e.g. a stream of words coming into a search query engine like Google) and wants to report a small list of items containing all frequent items. We would like algorithms for this problem that use memory substantially sublinear in the length of the stream.

In this talk we describe a new state-of-the-art solution to this problem, called the BPTree. We make use of chaining methods to control the suprema of Rademacher processes to develop this new algorithm which has provably near-optimal memory consumption for the l2 heavy hitters problem, improving upon the CountSieve and CountSketch from previous work.

Based on joint work with Vladimir Braverman, Stephen Chestnut, Nikita Ivkin, Zhengyu Wang, and David P. Woodruff (Received September 24, 2018)

1145-68-2164 **Jorge Diaz*** (transcripciones@mail.com), P.O. Box #9021288, San Juan, PR 00902-1288, and **Christian Romero** (christian.romero1@upr.edu), Hogar Padre Venard, P.O. Box #9020274, San Juan, PR 00902-0274. *A Mathematical Model of Conciousness, with Applications to AI.* Preliminary report.

Let us consider a Venn diagram of three interconnecting structures: they stand for the brain, which processes thoughts; the cerebellum, which coordinates voluntary movements; and the medulla oblongata, which controls involuntary movements. The area that is shared by all three structures; the intersection of the three circles also represents the pons; and the Ego, according to Freud's theory of personality, may be thought to reside therein. The Id, which embodies our most basic instincts, may be thought to reside in those areas of the diagram that do not intersect with each other. The Superego, in contrast, may be thought to reside in the intersection of two of any of the three main components. (The Id and the Superego may be thought to be in constant turmoil.) We thus propose a schematic model of conciousness, based on Freud's theory of personality; and the basic gross anatomical structures of the encephalon, with their corresponding functions. While simple, the model appears to be essentially complete. If we extrapolate, we may propose that a computer network of three processors, connected in parallel, is sufficient to implement a system that exhibits conciousness; to the extent that the proposed hardware may be supported by appropriate software. (Received September 24, 2018)

1145-68-2375 **Giulia Isabella Pintea*** (pintea@simmons.edu), 54 Pilgrim Road, Boston, MA 02215, and **Daniel J Olszewski**, **Zhijian Yang** and **Chujun He**. *Using Quality-of-Life Scores to Guide Prostate Radiation Therapy Dosing.*

Since prostate cancer patients have high survival rates, an important factor in treatment is to avoid degradation in quality-of-life during and after treatment. The connection between the radiation a patient receives and his reported side effects has not been quantitatively analyzed. We use deep learning algorithms and statistical models to explore this relationship. We use interpolation methods to generate more data in order to leverage transfer learning. Using augmented data, we train a convolutional autoencoder network to obtain near-optimal starting points for weights of our final convolutional neural network (CNN). Our CNN analyzes the relationship between patient-reported quality-of-life and radiation dosage in the bladder and rectum. We also use analysis of variance and logistic regression to explore organ sensitivity to radiation and develop dosage thresholds for each organ region. Our findings show a connection between rectal radiation dosage and changes in quality-of-life. We identify regions of both the bladder and rectum that are highly correlated with changes in individual patient symptoms. Finally, we estimate radiation therapy dosage thresholds for the rectum to determine how high radiation therapy dosage needs to be in order to trigger collateral symptoms. (Received September 25, 2018)

1145-68-2471 **Michel Cukier*** (mcukier@umd.edu), University of Maryland, College Park, MD 20742, and **Yazdan Movahedi** and **Ilir Gashi**. *Cluster-based Vulnerability Assessment: Some Empirical Studies.*

It is critical for organizations to optimize their security resources allocations. Several of these resources are directly linked to software vulnerabilities. A method of accurately estimating the number of vulnerabilities in a given system is thus needed. This research focuses on the estimation of the number of vulnerabilities over a given period of time in a given product/system. In particular, we introduce a new approach that consists of clustering vulnerabilities by leveraging the text information within vulnerability records, and then simulating the mean value function of vulnerabilities by relaxing the monotonic intensity function assumption, which is often used in the studies that use software reliability models (SRMs) and nonhomogeneous Poisson process in modeling. This presentation will compare results obtained from our clustering approach versus results without applying clustering. In particular, we will apply these approaches to vulnerabilities of operating systems and web browsers. (Received September 25, 2018)

1145-68-2676 **Azubuike M. Okorie**, 1200 N. DuPont Highway, Dover, DE 19901, and **Taposh Biswas**, **Samuel K. Awidi** and **Sokratis Makrogiannis***, 1200 N. DuPont Highway, Dover, DE 19901. *Feature-Based Image Registration with Applications to Remote Sensing and Medical Imaging.*

Feature-based image registration techniques use mathematical models to align two images of the same scene, obtained either at different times, with different sensors, or from different viewpoints. The goal is to find point correspondences between the two images and to estimate a geometric transformation based on these points that will align the two images. The major components of feature-based registration techniques include feature detection, extraction and matching, and estimation of geometric transform. The literature in this field is rich; it includes algorithms that address either one or more of the components of feature-based registration techniques. Other published papers have combined techniques from each stage in specific application domains. In this work, we present and evaluate automated feature-based image registration methods for remote sensing and biomedical imaging. We perform systematic validation of these methods by calculating the root-mean squared error (RMSE) between ground truth (reference) transformations and transformations estimated by these methods, to evaluate the registration accuracy. Overall, our results showed that feature-based image registration methods have the potential to yield subpixel accuracy in the domains under consideration. (Received September 25, 2018)

1145-68-2729 **Laramie Paxton*** (realtimemath@gmail.com), 910 Summit Dr., Cheney, WA 99004. *A Survey of Liver Tumor Image Segmentation Techniques.*

With the incidence of liver cancer on the rise worldwide, researchers are working to develop automatic segmentation algorithms to aid medical experts in the detection and treatment process. However, there are many challenging aspects to this task, such as the low-contrast nature of the images, the wide variety of tumor shapes and volumes, and even the variety of liver size and structure. In this talk, we briefly survey the main methods

found in the literature, such as active contour, level set, graph cut, thresholding, region growing, and neural nets, so as to provide a concise introduction for new researchers or a short review for experienced image analysts. (Received September 25, 2018)

1145-68-2742 **Cliff Joslyn**, **Emilie Purvine*** (emilie.purvine@pnnl.gov) and **Mark Raugas**. *Towards a Functorial Approach to Dynamic Topic Modeling.* Preliminary report.

Clustering methods and topic modeling are standard tools within data science for understanding large corpora of documents. Algorithms such as DBSCAN and non-negative matrix factorization (NMF) are well-studied for a static data set and frequently used. Additional work has been done on incremental updates to the clustering or NMF result when a corpus is evolving dynamically. Our interest is related to these incremental updates but takes it a step further. In the spirit of prior work by Carlsson and Memoli we aim to formalize learning methods generally using category theory and sheaf theory in order to combine results from different methods or different corpora. In this talk we will survey the landscape, summarize our first steps towards this goal, and explain why we believe the language of categories, functors, and sheaves is beneficial for the problem. (Received September 25, 2018)

1145-68-3005 **James P Howard, II*** (james.howard@jhuapl.edu), 11100 Johns Hopkins Road, Laurel, MD 20723. *Blockchain Applications for Distributed Data.* Preliminary report.

Blockchain technology is a type of distributed database that uses a series of data blocks that are sequentially ordered, and secured with a series of successive cryptographic hashes. All holders of the database possess the entire database and can verify it by verifying the historical cryptographic hashes. In this presentation, we present a method for using blockchain databases to distribute domain name system data throughout a network, leading to a more resilient and stable system capable of withstanding concerted cyber attacks from well-funded adversaries. Beyond the method, we provide a working implementation that interacts seamlessly with the existing Internet naming system and provide examples of other mechanisms blockchain technology can secure critical infrastructure. (Received September 26, 2018)

70 ► Mechanics of particles and systems

1145-70-1491 **Sawyer Jack Robertson***, sawyerjack@ou.edu. *Kantorovich Duality and Optimal Transport Problems on Magnetic Graphs.*

Working first in the setting of finite combinatorial graphs, we explore Lipschitz function spaces, and give constructive results concerning norm-preserving extensions from certain subgraphs, as well as the identification of convex extreme points in the unit ball. We then move over to so-called magnetic graphs, which are equipped with a discrete analogue of a magnetic vector potential known as a signature. In this setting, we establish a Kantorovich-type duality result for 'signed' Lipschitz spaces, as well as the identification of the convex extreme points of the unit ball in this space. Finally, we apply this theory with the help of magnetic lift graphs to give some semi-constructive results concerning 'magnetic' optimal transport problems formulated on these graphs. (Received September 22, 2018)

1145-70-2403 **Robert Paul Volkin*** (rpv17@case.edu). *Entropy and L^p Convergence of the Pseudo-Inverses for CDFs of Solutions to the Radially Symmetric Aggregation Equation With Power Law Potential.* Preliminary report.

The aggregation equation with repulsive-attractive potential models the evolution of a (probability) density of particles that attract each other at long range but repel each other when close. These nonlocal interaction equations have a number of applications in biological and physical contexts. We numerically investigate the entropy and L^p convergence of the pseudo-inverses to the cumulative density functions for solutions to the aggregation equation. In the particular, we consider the radially symmetric case with power law potential. We demonstrate that when solutions are sufficiently close, they converge in the L^p sense to the exact equilibrium densities exponentially quickly.

This work is in collaboration with D. Balagué[1], A. Barbaro[1], and J. Carrillo[2].

(Received September 25, 2018)

1145-70-2553 **Alethea Barbaro***, CWRU Dept. of Math, Applied Math & Statistics, 10900 Euclid Ave, Cleveland, OH 44106-7058. *An interacting particle model for the Icelandic capelin.*

The capelin is a planktivorous fish that lives in the Northern oceans. In the sea around Iceland, the capelin stock undertakes migrations of hundreds of kilometers, bringing biomass from the Arctic down into the subarctic ecosystem. These migrations have been changing recently, as the marine environment changes. In this talk, I will describe the interacting particle model that we use to simulate and predict their yearly spawning migration. I will then describe several mathematical extensions of this work, and discuss how our work on the capelin fits within the broader picture of climate change. (Received September 25, 2018)

74 ► Mechanics of deformable solids

1145-74-306 **Maximilian K Rezek***, 2700 Reynolda Road, Apt. 503, Winston-Salem, NC 27106, and **John Gemmer**. *Isometric Immersions, Energy Minimization, Periodic Patterns, and the Geometry of Leaves.* Preliminary report.

In the non-Euclidean model of elasticity, growth is modeled by a Riemannian metric that encodes local changes in distance. In response to the growth, the sheet deforms to minimize an elastic energy. The elastic energy consists of the sum of the stretching and bending energy. Minimizers of the stretching energy consist of isometric immersions of the metric, while minimizers of the bending energy remain flat. The competition between bending and stretching selects a pattern in the sheet. In this talk, we will show that periodic patterns have the lowest energy for a large class of metrics. Qualitatively, our results agree with patterns observed in leaves and torn elastic sheets. (Received August 29, 2018)

1145-74-548 **G. A. Francfort***, LAGA, Universite Paris Nord, Avenue J.-B. Clement, 93430 Villetaneuse, France. *A two-dimensional labile aether arising out of homogenization.*

Homogenization in linear elliptic problems usually assumes coercivity of the accompanying Dirichlet form. In contrast with the scalar case, coercivity in linear elasticity is not ensured through mere (strong) ellipticity and a stronger notion of very strong ellipticity is usually assumed to hold.

Yet a homogenization process can still be performed, very strong ellipticity notwithstanding, for a class of two- phase mixtures giving rise to an overall behavior for which strict ellipticity can be lost.

That result is at the root of the construction of a two-dimensional medium which can propagate plane waves in a bounded domain with Dirichlet boundary conditions, a possibility which does not exist for the associated two-phase micro-structure at a fixed scale.

Equally striking is the realization that such a material blocks longitudinal waves in the direction of lamination, thereby acting as some kind of two-dimensional aether in the sense of e.g. Cauchy or Maxwell. (Received September 09, 2018)

1145-74-1383 **Graeme Milton**, **Mark Briane** and **Davit Harutyunyan*** (harutyunyan@math.ucsb.edu), University of California Santa Barbara, Department of Mathematics, South Hall, Room 6607, Santa Barbara, CA 93106. *On the possible effective elasticity tensors of 2 and 3 dimensional printed materials.*

In this talk we present a partial characterization of the set of effective elasticity tensors of metamaterials built from a stiff material and void in given volume fractions. The sought set of effective tensors is completely characterized through minimums of sums of energies, involving a set of applied strains, and complementary energies, involving a set of applied stresses, we provide descriptions of microgeometries that in appropriate limits achieve the minimums in many cases. In these cases the calculation of the minimum is reduced to a finite dimensional minimization problem that can be done numerically. Each microgeometry consists of a union of walls in appropriate directions, where the material in the wall is an appropriate p-mode material, that is easily compliant to $p \leq 5$ independent applied strains, yet supports any stress in the orthogonal space. This is joint work with Graeme Milton and Mark Briane (Received September 21, 2018)

1145-74-1900 **Hua Chen*** (chenhua@udel.edu), Ewing 108, Department of Mathematical Sciences, University of Delaware, Newark, DE 19706, and **Robert P Gilbert** and **Philippe Guyenne**. *A Biot model for the determination of material parameters of cancellous bone from acoustic measurements.*

A numerical investigation is presented for the feasibility of determining material parameters of cancellous bone by acoustic interrogation in two dimensions. A mathematical formulation is proposed for the *in vitro* experiment where a bone sample is immersed in a rectangular water tank. Modified Biot's equations for cancellous bone are coupled with a boundary integral equation for the water pressure. Cancellous bone is described as an isotropic and homogeneous medium with constant material parameters. An explicit expression for the Green's function is derived in the form of a double series. Well-posedness is established for a variational formulation of this nonlocal boundary value problem. Sensitivity and recovery tests are performed for frequencies in the ultrasonic range,

and the results show that such parameters as bone porosity can be determined with reasonable accuracy. The inversion procedure is based on direct minimization of an objective function involving the pressure field measured at locations near the bone sample. (Received September 24, 2018)

1145-74-2983 **Charles L Talbot*** (ctalbot@live.unc.edu), University of North Carolina at Chapel Hill, Phillips Hall, Department of Mathematics, Chapel Hill, North Carolina 27514, Chapel Hill, NC 27514. *A Hybrid Finite Element Method for Nonlocal Models of Mechanics and Failure of Biological Tissue.*

Nonlocal models and associated hypersingular integral operators have been widely adopted in disciplines ranging from machine learning (nonlocal neural networks) to fracture mechanics (Peridynamics), and continue to inspire work in pure and applied mathematics. In particular, myriad integral reformulations of classical Continuum Mechanics have been developed for representing physics of material failure at multiple scales, predominantly in the context of brittle materials characterized by rapid catastrophic propagation and branching of discontinuities. We expand on the recent notion of the asymptotic local compatibility of nonlocal numerical schemes, with an emphasis on conditions in the context of hybrid mesh-free methods and the Finite Element Method. We emphasize the Discontinuous Galerkin finite element method and fluid-structure interaction in the context of Biological soft tissues, and construct a hybrid Nonlocal Finite Element method that reduces to a Discontinuous Galerkin method in the local limit, and is amenable to multiscale descriptions of discontinuous vector fields. We extend this to a novel scheme that incorporates adaptivity through the nonlocal length scale, and demonstrate how the scheme consistently recovers, across a range of nonlocal parameters, classical results from common benchmark tests in the context of nonlinear elasticity. Finally, we apply the Nonlocal Finite Element Method to a case of rupture in a biological tissue described by the Holzapfel-Gasser-Ogen material model with experimental data. (Received September 26, 2018)

76 ► Fluid mechanics

1145-76-224 **Karoline Disser*** (kdisser@mathematik.tu-darmstadt.de), Fachbereich Mathematik, Schlossgartenstr. 7, 64289 Darmstadt, Germany. *Analysis of fluids with non-smooth viscosities.*

We consider fluid models with a viscosity parameter that may be time-, space- and/or velocity-dependent. In particular, we look at cases in which the dependence is non-smooth. (Received August 22, 2018)

1145-76-403 **Chengcheng Tao*** (chengcheng.tao@netl.doe.gov), 626 Cochrans Mill Road, P. O. Box 10940, Pittsburgh, PA 15236, and **Barbara Kutchko** and **Mehrdad Massoudi**. *Flow of cement slurry in a vertical pipe.*

In this presentation, we study the fully developed flow of a cement slurry in a vertical pipe and explore the effects of concentration on the shear viscosity. A brief discussion of the constitutive relations for the viscous stress tensor and the diffusion flux vector is presented. The one-dimensional forms of the governing equations and the boundary conditions are made dimensionless and solved numerically. A parametric study is performed to present the results by varying the dimensionless numbers. (Received September 05, 2018)

1145-76-832 **Eitan Tadmor*** (tadmor@math.umd.edu), Department of Mathematics, University of Maryland, College Park, MD 20742. *The emergence of higher-order structures in hydrodynamic flocking.*

We discuss the large-time behavior of different hydrodynamic models for collective dynamics driven by alignment. In particular, we address the central question how short-range interactions lead, over time, to the emergence of flocking in one- and multi-species dynamics. (Received September 15, 2018)

1145-76-1149 **Young Ju Lee*** (yjlee@txstate.edu), Texas State University, San Marcos, TX , and **Hengguang Li** (li@wayne.edu), Wayne State University, Detroit, MI. *Locally conservative finite elements for axisymmetric Stokes equation.*

In this talk, we shall consider the mixed finite element approximation of the axisymmetric Stokes problem (ASP) on a bounded polygonal domain in the rz-plane. Standard stability results on mixed methods do not apply due to the singular coefficients in the differential operator and due to the singular or vanishing weights in the associated function spaces. We develop new finite element analysis in these weighted spaces, and propose macroelement conditions that are sufficient to ensure the well-posedness of the mixed methods for the ASP. These conditions are local, relatively easy to verify, and therefore will be useful for validating the stability of a variety of mixed finite element methods. These new conditions can not only re-verify existing stable mixed methods for the ASP, but also lead to the discovery of new stable conservative mixed methods. In particular, we report newly discovered, locally conservative finite elements for axisymmetric Stokes equation, numerical test results that confirm the theory and applications. (Received September 19, 2018)

1145-76-1327 **Buddhika Priyasad***, Department of Mathematical Sciences, The University of Memphis, Memphis, TN 38152, and **Irena Lasiecka** and **Roberto Triggiani**. *Local uniform boundary stabilization of the 3D Navier-Stokes equations by finite dimensional localized tangential feedback controls.*

Present literature contains the solution of the uniform boundary stabilization, near an equilibrium solution, of the Navier-Stokes equations by means of localized tangential feedback controls. However, weather such controls. However, whether such controls can be taken to be finite dimensional in the 3D case was an open problem. We present a solution to this problem. (Received September 21, 2018)

1145-76-1344 **Kazuo Yamazaki*** (kyamazak@ur.rochester.edu), 1017 Hylan Hall, Department of Mathematics, University of Rochester, Rochester, NY 14627. *Well-posedness and ergodicity of three-dimensional Hall-magnetohydrodynamics system.*

The Hall-magnetohydrodynamics system (Hall-MHD) plays an important role in astrophysical plasmas, star formation and magnetic re-connection. Ergodicity issues of the 2-d Navier-Stokes equations has caught much attention in the last decade. However, the Hall-MHD system has a very singular structure and mathematical analysis on this system has been delayed until very recently; in particular, the Navier-Stokes equations is semi-linear while the Hall-MHD system is quasilinear. In this talk we describe some ergodicity results comparing the case of the standard MHD system and the Hall-MHD system. For the former system, we are able to prove irreducibility, existence of a Markov selection, weak-strong uniqueness, and that Markov solution has the strong Feller property. Consequently it is deduced that if the MHD system is well posed starting from one initial data, then it is well posed starting from any initial data, verifying a sharp contrast to the deterministic case in which the well posedness for all time with small initial data is well known. For the latter system, we were able to prove only the first three results due to the singularity of the Hall term; thus, the strong Feller property of the 3-d Hall-MHD system is an open problem. (Received September 21, 2018)

1145-76-1406 **Sarah Elizabeth Ritchey Patterson*** (ser39@duke.edu), 120 Science Drive, Durham, NC 27710. *Extensions of the Immersed Interface Method to Open Interfaces and Hemodynamic Models.*

The Immersed Interface Method (IIM) can be used to numerically solve fluid-structure interaction problems where an infinitely thin boundary or interface is immersed in a fluid. Deviating the interface from its resting position generates a boundary force that is singularly supported on the interface. Due to this singular force, the pressure and the velocity gradient may not be continuous across the interface. The IIM incorporates these jumps in pressure and velocity into the finite difference approximations of the spatial derivatives in the discretized Navier Stokes equation.

The IIM was designed for closed interfaces. Therefore, when creating hemodynamic models, the blood vessel are often represented as a tube with capped ends. Flow is created by adding a fluid source and sink to opposing ends of the tube. This closed-tube model is not ideal since around the source and sink, the fluid does not behave like fluid flowing in a vessel. This talk will discuss novel extensions of the IIM to open interfaces which can provide a more natural fluid profile. (Received September 21, 2018)

1145-76-1610 **Stephanie A. Blanda*** (blanda@lvc.edu). *Interfacial Waves Between Two Fluids With a Shear Flow.*

The generation of waves by wind has long been a topic of interest. However, it has only been in the past 50 years that significant progress has been made in understanding the effect of wind on water waves. Despite this progress, there is still much we do not understand about the interaction. Here, we focus on the previously ignored effect of viscosity on the overall growth rate of waves. We consider the coupled air/water system as a viscous 2-layer system. In this talk, we describe the derivation of the equations for the linear theory dealing with the interface of two immiscible, incompressible, viscous fluids under an unsteady base flow with a surface current and discuss the numerical methods we have used to solve the resulting 19×19 system of equations. In addition, we provide a numerical estimate for the growth rate of the waves, as well as energy estimates for the wind-wave system. (Received September 23, 2018)

1145-76-1675 **Dania Sheaib*** (dania.sheaib@ou.edu). *Linear Stability Analysis of a Hydrodynamic Problem in the Absence of Dissipation.*

Our interest in hydrodynamic problems stems from modeling the turbulent flow found in the atmosphere and studying the onset of convective patterns caused mainly by the interactions of solar radiation with the Earth's surface. One of the most studied convection phenomena is the Rayleigh-Benard convection occurring in a fluid placed between horizontal parallel plates in the gravitational field in which a temperature gradient is always maintained. The literature shows that when the temperature difference across the fluid exceeds a critical value, the rest state becomes unstable and the fluid breaks into convective flow cells that occur periodically in space. Although our problem seems very similar to the Rayleigh-Benard setting, mathematical and numerical results show that in the absence of dissipation the model is stable and the fluid is incapable of producing convective patterns no matter how much we increase the temperature of the bottom plate. In this talk, we will describe the governing equations and boundary conditions and explain how they differ from the Rayleigh-Benard set up. Then we will present mathematical results concerning the linear stability analysis of the problem and as time permits introduce a numerical approach that helped us build intuition about our problem. (Received September 23, 2018)

1145-76-1776 **Xiaolin Wang*** (xiaolinwang@seas.harvard.edu), **Chris H Rycroft** and **Ken Kamrin**. *An Eulerian method for mixed soft and rigid body interactions in fluids.*

Fluid–solid interaction problems are encountered in many engineering and biological applications, but are challenging to simulate due to the coupling between the two material phases. Typically, solids are simulated using a Lagrangian approach with a grid that moves with the material, whereas fluids are simulated using an Eulerian approach with a fixed spatial grid, requiring some type of interfacial coupling between the two different perspectives. Here, we present a fully Eulerian method for simulating structures immersed in a fluid. By introducing a reference map variable to model finite-deformation constitutive relations in the structures on the same grid as the fluid, the interfacial coupling problem is highly simplified. The method is particularly well suited for simulating soft, highly-deformable materials and many-body contact problems. We also extend the technique to simulate rigid solids in an incompressible fluid, using a projection step formulated as a composite linear system that simultaneously enforces the rigidity and incompressibility constraints. Several examples including single deformable/rigid objects, multiple objects and soft-rigid combinations will be presented. (Received September 24, 2018)

1145-76-2133 **Francesca Bernardi*** (bernardi@math.fsu.edu), **Roberto Camassa**, **Gabrielle M Hobson** and **Richard M McLaughlin**. *Diffusion of Passive Tracers Advected by Laminar Shear Flow in Triangular Capillary Pipes.*

We investigate the dispersion of a passive tracer in laminar shear flow through triangular capillary pipes. We show through simulation and experiments how the longitudinal asymmetry of the tracer distribution changes in time. We observe a change in the longitudinal concentration profile from back-loaded to front-loaded, corresponding to a sign-change in the (cross-sectionally averaged) skewness. Future directions will be discussed. (Received September 24, 2018)

1145-76-2185 **Guoyi Ke*** (gke@lsua.edu), Mathematics and Physical Sciences, Louisiana State University of Alexandria, 8100 Hwy 71 S, Alexandria, LA 71302-9119, **Sara Calandrini** (sara.calandrini@ttu.edu), Department of Mathematics and Statistics, Texas Tech University, 1108 Memorial Circle, Lubbock, TX 79409, and **Eugenio Aulisa** (eugenio.aulisa@ttu.edu), Department of Mathematics and Statistics, Texas Tech University, 1108 Memorial Circle, Lubbock, TX 79409. *A new preconditioning technique for fluid-structure interaction problems with applications in biomechanics.*

In this work, we investigate preconditioning techniques for Krylov subspace algorithms to solve fluid-structure interaction (FSI) linear systems arising from finite element discretizations. An outer Krylov subspace solver preconditioned with a geometric multigrid (GMG) algorithm is used, where for the multigrid level sub-solvers, a field-split (FS) preconditioner is investigated. The block structure of the proposed FS preconditioner derives from using the physical variables as splitting strategy. To solve the subsystems originated by the FS preconditioning, an additive Schwarz (AS) block strategy is employed. The proposed field-split preconditioner is tested on biomedical FSI applications. Both 2D and 3D simulations are carried in consideration of aneurysm and venous valve geometries. The performances of the FS preconditioner are compared with those of a second preconditioner of pure domain decomposition type. (Received September 25, 2018)

1145-76-2236 **Michael S Jolly** (msjolly@indiana.edu) and **Yu Cao*** (cao20@iu.edu). *Bounds on the attractor for the 2D Rayleigh-Bénard problem.* Preliminary report.

We find regions that bound the global attractor of the Rayleigh-Bénard problem in the EZ-plane, where E is a sum of squared L^2 norms of velocity and temperature and Z is a similar sum, but for gradient norms. This is done for both no-slip and free-slip boundary conditions, with modest improvement for the overall gradient norm bounds on the global attractor. We then find invariant regions in the 3-space spanned by enstrophy, palinstrophy and the gradient norm of temperature in the free-slip case. (Received September 25, 2018)

1145-76-2276 **Quentin Robinson*** (qrobinson5@nccu.edu). *Frequency of Upstream propagating soliton generation in the forced Korteweg-de Vries Equation.* Preliminary report.

We explore ways in which information gained from various approximations to the forced Korteweg-de Vries (fKdV) equation predict the behavior of the solution of the full equation. We find an exact, closed-form solution to the dispersionless, nonlinear approximation to fKdV using an appropriate forcing function and determine the amplitude and propagation speed of the shocks obtained from the same approximation. We determine a critical Froude number parameter value above which stationary solutions exist and examine their stability. We use WKB analysis as an application of inverse scattering theory to determine a relationship between the amplitude of the shock in the dispersionless approximation to fKdV and the amplitude of the upstream propagating solitary waves generated by the full equation. All of this information together provides a means of predicting which combinations of parameter values will result in the generation of upstream propagating solitons as well as a means of predicting the frequency of soliton generation. (Received September 25, 2018)

1145-76-2438 **Nguyenho Ho*** (nho@bridgew.edu), 7 north border rd, Stoneham, MA. *Swimming Near a Solid Wall in a Brinkman fluid.* Preliminary report.

The incompressible Brinkman equations are used to describe a fluid with sparse stationary obstacles, which is controlled by a resistance parameter. Here, we study an infinite-length swimming sheet near a solid wall. Using small amplitude analysis, to the second-order solution, we obtain the nondimensional swimming speed, the mean pressure drag, and the mean viscous drag. We also derive the propulsive velocity using lubrication theory approach. The outcomes are analyzed to see the effects of the resistance parameter on the overall swimming behavior. A numerical study is also presented to compare the analytical results with the finite-length swimmers obtained from simulating data. (Received September 25, 2018)

1145-76-2603 **Kaitlyn Hood*** (kthood@mit.edu), **M.S. Suryateja Jammalamadaka** and **A. E. Hosoi**. *Rake or Sieve: modelling flow past an array of rigid hairs.*

The Navier-Stokes equations (NSE) represent a balance between viscous, pressure, and inertial stresses. While inertia is typically considered an obstacle to engineering flows, here we model a system that exploits inertia to achieve a desired flow. In particular, crustaceans have appendages with an array of rigid hairs covered in chemoreceptors, used to sense and track food. By changing the speed of flow past the hairy surface, and thereby manipulating the Reynolds number (Re) of the flow, crustaceans directly influence the flow behavior. Flow acts either as a rake – diverting flow around the hair array, or as a sieve – penetrating into the hair array. In our experiments, we uncover a third transitional phase: deflection – where the flow partially penetrates the hair array and is deflected laterally. We model the flow around a rigid cylinder in order to determine the depth of a boundary layer on a single hair, and find that as Re increases, the depth of the boundary layer decreases. From this model, we develop a design principle for constructing hair arrays that exhibit each flow phase. (Received September 25, 2018)

1145-76-2615 **Yong Yang*** (yyang@wtamu.edu), West Texas A&M University, WT Box 60787, Canyon, TX 79016. *Modal analyses on transitional boundary layer.*

A direct numerical simulation (DNS) by finite difference method is carried out to reveal the coherent structures in transitional boundary layer over a flat plate. A sixth order compact scheme is used in spatial discretization and a third order TVD Runge-Kutta scheme is adopted in time marching. The adiabatic and the non-slipping conditions are enforced at the wall boundary on the flat plate. On the far field and the outflow boundaries, the non-reflecting boundary conditions are applied. The Jacobian coordinate transformation is employed from physical domain to computational domain and the Message Passing Interface (MPI), together with domain decomposition, is utilized to accomplish the parallel computation. Based on the data-set obtained by DNS, the proper orthogonal decomposition (POD) and dynamic mode decomposition (DMD) are performed on a subdomain of the numerical data to extract dynamic information from snapshots of transitional flow. The extracted modes can be used to determine the most energetic structures and to describe the underlying physical mechanisms. By investigating the most principal mode of the flow field, the streamwise vortices are found to play significant roles in transitional boundary layer. (Received September 25, 2018)

1145-76-2683 **Animikh Biswas*** (abiswas@umbc.edu). *Determining map for statistical data assimilation and applications.* Preliminary report.

Based on a down-scaling data assimilation algorithm which employs a nudging term on the coarse scales, for observations discrete in time and possibly contaminated with a random error, we construct a *determining map* of coarse scale trajectories and investigate its properties. This map is then used to develop a down-scaling statistical data assimilation scheme for dissipative systems, where the coarse scale statistics of the systems are obtained from measurements. We also discussion some computational strategies for statistical solutions of the Navier-Stokes equations by employing the data assimilation map. (Received September 25, 2018)

1145-76-2792 **Yuanyuan Feng*** (yuanyuaf@andrew.cmu.edu), 6113 Wean Hall, 5000 Forbes Avenue, Pittsburgh, PA 15213. *Dissipation enhancement by mixing.*

Diffusion and mixing are two fundamental phenomena that arise in a wide variety of applications ranging from micro-fluids to meteorology, and even cosmology. In incompressible fluids, stirring induces mixing by filamentation and facilitates the formation of small scales. Diffusion, on the other hand, efficiently damps small scales and the balance between these two phenomena is the main subject of our investigation. I will talk about the interaction between diffusion and mixing in both continuous, and discrete time setting. In discrete time, we consider a mixing dynamical system interposed with diffusion. In continuous time, we consider the advection diffusion equation where the advecting vector field is assumed to be sufficiently mixing. The main results of this talk is to estimate the dissipation time and energy decay based on assumption quantifying the mixing rate. (Received September 25, 2018)

1145-76-3031 **Anh Bui*** (abui@smith.edu), Smith College, Department of Mathematics and Statistics, 44 College Lane, Northampton, MA 01063. *An investigation of different hydrological models.*

Hydrologists use different mathematical models to simulate estimates of high flows. SWAT is an important but complicated hydrologic model used to examine the effects of land-use scenarios on high flows in New England. Recent work by Guswa, Meyer, and Hamel simplified SWAT by using the NRCS curve number method combined with an exponential distribution of rainfall. The goal of this project is to investigate the utility of Guswa, Meyer, and Hamel's model by comparing estimates of high flows with results from SWAT. We describe results comparing the relative accuracy of this new model with the SWAT model. (Received September 26, 2018)

78 ► Optics, electromagnetic theory

1145-78-401 **Leonidas Mindrinos*** (leonidas.mindrinos@ricam.oeaw.ac.at), Altenberger Strasse 69, 4040 Linz, Austria. *Reconstructing the optical properties of a medium from the coupled physics PAT/OCT system.*

We consider the inverse problem of reconstructing the electric susceptibility of a sample placed in a multi-modal PAT/OCT system. The dielectric medium is characterized by the frequency dependent electric susceptibility and the Grüneisen parameter. We present a reconstruction method for recovering both parameters from multi-frequency measurements under the Born approximation. The combined system is equivalently transformed to a Fredholm type integral equation whose unique solvability depends on the PAT data. We present numerical examples for simulated data. This is a joint work with P. Elbau and O. Scherzer. (Received September 05, 2018)

1145-78-531 **Johannes Familton*** (jfamilton@bmcc.cuny.edu), BMCC CUNY, Mathematics Dept, 199 Chambers Street, New York, NY 10007, and **Richard Friedberg**. *Maxwell, Clifford, and Hestenes.*

Since Maxwell first wrote his equations they have been rewritten in many different ways. Maxwell himself first wrote them as components (1862-1865) and then in quaternions (1873). In this talk we will look at the 4D Clifford algebra formalism and how it has been used in Hestenes' version of Geometric Algebra to derive Maxwell's equations. (Received September 08, 2018)

1145-78-1077 **Alexey Sukhinin*** (alexey.sukhinin@ndsu.edu). *Topologically-mixed vector soliton instability.* Preliminary report.

Solitons having different topological charges were obtained from the system of (2D+1) coupled Nonlinear Schrodinger Equations with focusing nonlinearity. In this talk, I will discuss their dynamics and stability properties. The role of the winding number and intersecting area between two localized profiles will be discussed as well. (Received September 18, 2018)

1145-78-1804 **Peter A Muller*** (mullerp@rowan.edu). *Electrical Impedance Tomography: Two Direct Image Reconstruction Methods.*

Electrical impedance tomography (EIT) is an imaging modality that measures currents and voltages on the surface of a body to image the electrical conductivity within the body. Image reconstruction in EIT is a severly ill-posed, nonlinear inverse problem. In this talk, I will present two direct reconstruction methods based on complex geometrical optics solutions: Calderón's method and Nachman's D-bar method. Both methods provide a point-wise reconstruction of the image. Calderón's method is a linearized approach while the D-bar method solves the fully non-linear inverse problem. I will present both methods and improvements to them that address clinical concerns for this medical imaging technique. (Received September 24, 2018)

1145-78-2363 **Vadim A Markel*** (vmarkel@pennmedicine.upenn.edu), 603W Goddard Laboratories, 3710 Hamilton Walk, Philadelphia, PA 19104. *Investigation of the super-resolution phenomenon in nonlinear inverse problems.*

It is well known that the spatial resolution of images obtained by solving the linearized inverse scattering problem is restricted by the so-called diffraction limit. However, multiple scattering results in nonlinearity of the inverse problem. In this case, the above limit on the spatial resolution of images cannot be proved as easily.The limit of spatial resolution in nonlinear inverse scattering problems is still an open question. I will consider several exactly solvable toy problems in which spatial resolution can be defined precisely and then investigated. (Received September 25, 2018)

1145-78-2642 **Daniel T Onofrei***, donofrei79@gmail.com. *Exterior acoustic and electromagnetic control through active surface sources.*

In this talk we will present our recent results concerning the active control of Helmholtz and Maxwell equations in prescribed exterior disjoint regions (possiblly including the far field) by using optimally chosen surface sources. We will briefly present the theoretical ideas and then show and discuss relevant simulations for acoustics and electromagnetism in homogenous isotropic media possiblly including scatterers. Applications to field synthesis in the presence of obstacles, characterization of almost non-radiating sources with controlable near fields, or scattering cancellation will be also discussed. (Received September 25, 2018)

81 ► Quantum theory

1145-81-24 **Salvador Elias Venegas-Andraca*** (salvador.venegas-andraca@keble.oxon.org), ITESM CEM, Carretera Lago de Gpe. Km. 3.5, Col. Margarita Maza de Juarez, 52926 Atizapan de Zaragoza, EdoMex, Mexico. *Quantum Annealing-Based Algorithms, Quantum Machine Learning and Quantum Walks.*

Research on quantum computation heavily focuses on building and running algorithms which exploit the physical properties of quantum computers. The existence of quantum technology for developing quantum algorithms to solve combinatorial optimization problems has boosted the interest of the scientific and engineering communities to think of novel applications of quantum algorithms in fields like Machine Learning.

The first part of this talk will be focused on presenting the quantum annealing model of quantum computation, succinctly compared with other models of quantum computation. Then, we shall proceed to present a general structure of quantum annealing-based algorithms, followed by an example of this kind of algorithms for solving instances of the Minimum Multicut problem and a concise overview of the emergent field of Quantum Machine Learning and its links with quantum annealing-based algorithms. We will finish our talk by presenting and analysis of the similarities of the quantum annealing model of computation and quantum walks.

This talk is mostly based on **S.E. Venegas-Andraca, W. Cruz-Santos, C. McGeogh and M. Lanzagorta. A cross-disciplinary introduction to quantum annealing-based algorithms. Contemporary Physics 59(02), pp. 174–196 (2018)**. (Received June 11, 2018)

1145-81-161 **Radhakrishnan Balu*** (radhakrishnan.balu.civ@mail.mil). *Quantum Structures from Association Schemes.* Preliminary report.

Starting from an association scheme and the corresponding Bose- Mesner algebra we construct quantum Markov chains (QMC), their entangled versions, and interacting Fock spaces (IFS). (Received August 13, 2018)

1145-81-165 **Yutaka Shikano*** (yutaka.shikano@keio.jp), 3-14-1 Hiyoshi, Kohoku, Yokohama, Kanagawa 223-8522, Japan. *On Quantum Phase Estimation Algorithm in Quantum Chemistry Calculation.* Preliminary report.

The electronic ground state of molecules can be calculated by the quantum computer via the quantum phase estimation algorithm. This algorithm is now attracted as the useful application of quantum computers. Recently, the superconducting-qubit type and optical-type quantum computers can computer the small-size molecules. We discuss the detailed analysis on quantum estimation method in quantum chemistry calculation. We show the relationship between the error of the algorithm itself and the gate complexity.

This work is collaborated with Shintaro Niimura, Aruto Hosaka, and Fumihiko Kannari. (Received August 14, 2018)

1145-81-167 **Juan Arturo Silva-Ordaz*** (arturo.silva@quantumworks.io), Tecnologico de Monterrey, Campus Estado de Mexico, Departamento de Computacion, 52926 Atizapan de Zaragoza, EdoMex, Mexico, and **Salvador E Venegas-Andraca** (salvador.venegas-andraca@keble.oxon.org), Tecnologico de Monterrey, Escuela de Ingenieria y Ciencias, Av. Eugenio Garza Sada 2501, Col Tecnologico, 64849 Monterrey, NL, Mexico. *A concise review of digital simulation software platforms of quantum algorithms.*

A central goal in quantum computing is the development of quantum hardware and quantum algorithms in order to analyze challenging scientific and engineering problems. One of the main problems that scientists and engineers face when learning and working on the development of quantum algorithms is the counterintuitive behavior of quantum mechanical systems. For this reason, together with the need to test experimental proposals before implementing them, building powerful classical computer platforms for the simulation of quantum systems is crucial in order to develop intuition about the behavior of quantum systems used for computational purposes, as well as to realize the approximate behavior of practical implementations of quantum algorithms.

In this talk, we present a succinct introduction to the mathematics and computational complexity of quantum algorithm simulation on digital systems. We then proceed to analyze several advanced platforms for digital simulation of quantum algorithms with a strong emphasis on IBM Q platform. (Received August 14, 2018)

1145-81-486 **Jake Farinholt*** (jacob.farinholt@navy.mil) and **Samuel Mendelson** (samuel.mendelson@navy.mil). *Adiabatic Quantum Computing and Graph Theory.*

Adiabatic Grover's Algorithm generally assumes the problem Hamiltonian is diagonal in the computational basis. In this talk, we will show how to reinterpret Grover's search algorithm as a Graph Theory problem, and conversely, we will show how to build the problem Hamiltonian for various graph search problems directly from the Graph Laplacian. Finally, we analyze the performance of the adiabatic algorithms under various graph constraints and provide evidence to suggest that the performance improves with the number of edges. We rigorously prove that the graph search algorithm is exactly Grover's algorithm when the graph is complete. (Received September 07, 2018)

1145-81-539 **Radhakrishnan Balu***, 2800 Powder Mill Rd, Adelphi, MD 20783. *Kinematics and Dynamics of Quantum Walks in terms of Systems of Imprimitivity.*

We build systems of imprimitivity (SI) in the context of quantum walks and provide geometric constructions for their configuration space. We consider three systems, an evolution of unitaries from the group SO3 on a low dimensional de Sitter space where the walk happens on the dual of SO3, standard quantum walk whose SI live on the orbits of stabilizer subgroups (little groups) of semidirect products describing the symmetries of 1+1 spacetime, and automorphisms (walks are specific automorphisms) on distant-transitive graphs as application of the constructions. (Received September 09, 2018)

1145-81-557 **Chaobin Liu*** (cliu@bowiestate.edu), Department of Mathematics, Bowie State University, 14000 Jericho Park Road, Bowie, MD 20715. *From open quantum walks to unitary quantum walks.* Preliminary report.

We present an idea to transform an open quantum walk into a unitary quantum walk on lattices or on finite graphs. This approach generalizes the theoretical framework introduced by Szegedy for quantizing Markov chains to the domain of open quantum walks (or quantum Markov chains). For the unitary quantum walks formulated in this paper, we define the probability and the average of probability over time of finding the walker at a node, then derive its asymptotic probability distribution. (Received September 09, 2018)

1145-81-680 **Anna Vershynina*** (anna@math.uh.edu), Philip Guthrie Hoffman Hall, Department of Mathematics, University of Houston, Houston, TX 77204. *How fast can entanglement be generated in quantum systems?*

We investigate the maximal rate at which entanglement can be generated in bipartite quantum systems. The goal is to upper bound this rate. All previous results in closed systems considered entanglement entropy as a measure of entanglement. I will present recent results, where entanglement measure can be chosen from a large class of measures. The result is derived from a general bound on the trace-norm of a commutator, and can, for example, be applied to bound the entanglement rate for Renyi and Tsallis entanglement entropies. At the end I will quickly review the generalization of the problem to open systems. (Received September 12, 2018)

1145-81-1229 **Travis B Russell*** (travis.russell@usma.edu). *Quantum correlation sets and quantum communication.* Preliminary report.

A quantum correlation is a kind of probability distribution that can be achieved with quantum technology but cannot be achieved by classical probabilistic means. The study of quantum correlations goes back to debates between Albert Einstein and his contemporaries during the formative years of quantum mechanics, yet there are many questions about quantum correlations that remain unanswered to this day. In this talk, we introduce the idea of quantum correlations for a general audience and discuss some connections with positive semidefinite programming, operator algebras and cybersecurity. (Received September 20, 2018)

1145-81-1527 **Zhengfeng Ji**, **Debbie Leung*** (wcleung@uwaterloo.ca) and **Thomas Vidick**. *Bell inequality that cannot be maximally violated with finite amount of entanglement.* Preliminary report.

We present a Bell inequality on three systems with very few measurement settings and outcomes, such that no finite amount of entanglement distributed among these systems can lead to a maximum violation of the Bell inequality. This result is based on the coherent state exchange game introduced in arXiv:0804.4118, which in turns is based on embezzlement of entanglement due to van Dam and Hayden (arXiv:quant-ph/0201041).

Joint work with Zhengfeng Ji and Thomas Vidick, arXiv:1802.04926 . (Received September 22, 2018)

1145-81-1955 **Jean Bourgain**, **Svetlana Jitomirskaya** and **Ilya Kachkovskiy*** (ikachkov@msu.edu). *Localization and delocalization for interacting quasiperiodic particles.* Preliminary report.

We show that a system of two interacting 1D discrete quasiperiodic particles demonstrates Anderson localization at large disorder assuming that the single-particle potential does not have cosine-type symmetries. In case of symmetries, our methods show localization away from zero energy.

We also study the regime of fixed disorder and strong interaction, at the energy region corresponding to particles being bound together forming a 1D quasiparticle ("droplet"). We show that droplet states can be localized or de-localized, depending on the quasiperiodic phase difference and symmetries of the potential.

The talk is based on joint works with J. Bourgain and S. Jitomirskaya. (Received September 24, 2018)

1145-81-2024 **James D Whitfield*** (james.d.whitfield@dartmouth.edu), Dartmouth College, 6127 Wilder, Room 248, Hanover, NH 03755. *Quantum Measurement Problem.*

Measurement is at the heart of quantum mechanics and consequently also at the core of quantum simulation on quantum computers. This rapidly evolving field has recently produced a glut of publications with wide ranging claims from both academic and industrial groups. This makes the literature difficult to navigate and find common threads.

In this talk, I will use measurement to underline common themes and ground the literature in a common reality. We highlight the usefulness of phase estimation even for noisy intermediate quantum computers and clarify that variational quantum simulation methods are an extension of phase estimation rather than a replacement. (Received September 24, 2018)

1145-81-2168 **Colleen Delaney*** (cdelaney@math.ucsb.edu) and **Eric Samperton** (eric@math.ucsb.edu). *Towards fusion rules for permutation extensions of modular tensor categories.* Preliminary report.

Although G-extensions of modular tensor categories $\mathcal{C}$ are classified by the work of Etingof, Nikshych, and Ostrik, this classification doesn't yield explicit constructions of G-crossed fusion, associativity, and braiding.

One would expect that particularly simple examples of G-extensions are permutation extensions, where $G = S_n$ acts on the Deligne product of modular tensor categories $\mathcal{C}^{\boxtimes n}$. However, even in this case it was only recently shown by Gannon and Jones that these extensions exist.

I will share some recent progress on the structure of fusion rules for permutation extensions. This talk is based on work in progress joint with Eric Samperton. (Received September 24, 2018)

1145-81-2383 **Michael A. Maroun*** (marounm@gmail.com). *Estimates of Pure Point Spectra and Spectral Functions for a Lowest-order Hamiltonian as an Unbounded Self-Adjoint Operator formed from the sum of a Gravitational and a Harmonic Dark Potential.*

The nature of gravity and its interaction with light is possibly greatly different than its standard interaction within Einstein's theory of gravitation. This is most notably due to the presence of a dark sector. The measurement of the expanding but accelerating rate of expansion of the universe together with galactic masses that do not correspond to stellar or blackhole concentrated mass observations, strongly suggests the presence of a dark sector or fifth force of nature. An expading universe can be approximated by envisioning springs at each point in space. The quantum pure point spectrum for such a system in the presence of the standard gravitational potential, as well as the corresponding spectral functions are investigated. The constants parameters can be fit to actual observation data to give a rough approximation of the dark sector and hence a pure point spectral distribution with which to search for. (Received September 25, 2018)

1145-81-2440 **Zachary Cline*** (zcline@temple.edu), Department of Matematics, Temple University, 1805 N Broad Street, Philadelphia, PA 19122. *On actions of Drinfel'd doubles on finite dimensional algebras.*

Let q be an n^{th} root of unity for $n > 2$ and let $T_n(q)$ be the Taft (Hopf) algebra of dimension n^2. In 2001, Susan Montgomery and Hans-Jürgen Schneider classified all non-trivial $T_n(q)$-module algebra structures on an n-dimensional associative algebra A. They further showed that each such module structure extends uniquely to make A a module algebra over the Drinfel'd double of $T_n(q)$. We explore what it is about the Taft algebras that leads to this uniqueness, by examining actions of (the Drinfel'd double of) Hopf algebras H "close" to the Taft algebras on finite-dimensional algebras analogous to A above. Such Hopf algebras H include the Sweedler (Hopf) algebra of dimension 4, bosonizations of quantum linear spaces, and the Frobenius-Lusztig kernel $u_q(\mathfrak{sl}_2)$. (Title and abstract are subject to change.) (Received September 25, 2018)

1145-81-2492 **George Androulakis** and **Duncan Wright*** (dw7@email.sc.edu). *Dynamical Entropy of Quantum Walks.* Preliminary report.

Variants of quantum dynamical entropy will be introduced and applied to unitary quantum random walks. In particular, we will show that the quantum dynamical entropy is nonlinear in the time interval between successive measurements of a quantum dynamical system, in contrast to Kolmogorov-Sinai dynamical entropy for classical dynamical systems. Applications to quantum computing will also be discussed. (Received September 25, 2018)

1145-81-2509 **Erica K Swindle*** (erica_swindle@baylor.edu), Department of Mathematics, Baylor University, One Bear Place #97328, Waco, TX 76798. *Spectral Properties of Quantum Circulant Graphs.*

We investigate the spectral properties of quantum circulant graphs. Circulant graphs are the Cayley graphs of cyclic groups, and in the quantum graph the edges are intervals equipped with the negative Laplace or Schrodinger operator. Quantum graphs are a widely studied model of quantum mechanics in a system with complex geometry and the quantum circulant graph model shares important features with the prototypical star graph model. The spectrum of a quantum circulant graph is encoded in a secular equation. This equation takes two forms depending on whether the metric respects the cyclic symmetry of the graph. (Received September 25, 2018)

1145-81-2575 **Alexander K Wiedemann*** (akw@math.sc.edu) and **George Androulakis**. *GKSL Generators and Digraphs: Computing Invariant States.*

In recent years, digraph induced generators of quantum dynamical semigroups have been introduced and studied, particularly in the context of unique relaxation. In this talk we consider a general class to which these generators belong which allows for additional interaction coefficients but still preserve their main structural properties. To this end we provide a characterization of when the Gorini-Kossakowski-Sudarshan-Lindblad (GKSL) equation defines a proper generator when allowed arbitrary Lindblad operators (in particular, they need not be traceless as demanded by the GKSL Theorem(s)).

Within this general class, when the basis of the underlying Hilbert space is given by the eigenbasis of the Hamiltonian, e.g. the generic semigroups, we explicitly compute all invariant states of the semigroup; further, given the digraph's (Laplacian) eigenvalues, one can also explicitly compute all eigenvalues of the semigroup, and thereby recover exact rates of relaxation.

Finally, we consider the converse construction to show that every generator naturally gives rise to a digraph, and that under certain assumptions the properties of this digraph can be exploited to gain knowledge of both

the number and the structure of the invariant states of the corresponding semigroup. (Received September 25, 2018)

1145-81-2744 **Archismita Dalal**, **Seyed Shakib Vedaie**, **Radhakrishnan Balu** and **Barry Cyril Sanders*** (sandersb@ucalgary.ca), , Canada. *Machine-learning-assisted search for a quantum-annealing speedup.* Preliminary report.

Quantum annealing could enable quantum-enhanced speedup for certain computational problems. Quantum annealers are designed to find the ground state of an Ising Hamiltonian, which encodes the solution of the NP-Hard problem called weighted MAX-2-SAT. This computational problem can be equivalently expressed as a quadratic unconstrained binary optimization problem over Boolean variables and hence mapped to the hardware graph for qubit connectivity of the quantum annealer (Chimera graph for D-Wave's current architecture). We seek to develop an intelligent search for a quantum-annealing speedup over the weighted MAX-2-SAT language using machine learning. If successful, quantum annealers will then be known to provide a genuine quantum-computational advantage. Our aim is to devise an autonomous approach to search for a quantum-annealing speedup. Through this approach, a set of problem instances, of varying size, are methodically searched, and a set of tests is performed for comparing quantum annealing against various classical algorithms such as simulated annealing and quantum Monte Carlo. We make this search "intelligent" by devising a suitable reward function for problem instances so that the autonomous agent learns from experience and thus rapidly finding promising problems. (Received September 25, 2018)

1145-81-2812 **John Z. Imbrie*** (imbrie@virginia.edu), Department of Mathematics, P. O. Box 400137, Charlottesville, VA 22904-4137. *Eigenvalue separation in disordered quantum systems.*

Degeneracies (or near-degeneracies) create difficulties in understanding the behavior of quantum systems. In the case of disordered quantum systems such as the Anderson model, degeneracies provide avenues for long-range tunneling, and hence are a barrier to localization. I will discuss a method (the energy-following procedure) for tracking eigenvalues of the Anderson model Hamiltonian through a sequence of successive approximations. The rate at which eigenvalues separate in this procedure controls the statistics of separation of nearby eigenvalues. The method is a key part of the proof of localization for discrete disorder distributions. (Received September 25, 2018)

1145-81-3021 **Svetlana Jitomirskaya** and **Xiaowen Zhu*** (5xiaowz@uci.edu), 1421 Verano Place, Irvine, CA 92617. *A short proof of Anderson localization for the 1-d Anderson model.*

The proof of Anderson localization for 1D Anderson model with arbitrary (e.g. Bernoulli) disorder, originally given by Carmona-Klein-Martinelli in 1987, is based on the Furstenberg theorem and multi-scale analysis. This topic has received a renewed attention lately, with two recent new proofs, exploiting the one-dimensional nature of the model. At the same time, in the 90s it was realized that for one-dimensional models with positive Lyapunov exponents some parts of multi-scale analysis can be replaced by considerations involving subharmonicity and large deviation estimates for the corresponding cocycle, leading to nonperturbative proofs for 1D quasiperiodic models. Here we present a proof along these lines, for the Anderson model. We also include a proof of dynamical localization based on the uniform version of Craig-Simon that works in high generality and may be of independent interest. It is a joint work with S. Jitomirskaya. Our entire proof of spectral localization fits in three pages and we expect to present almost complete detail during the talk. (Received September 26, 2018)

82 ► Statistical mechanics, structure of matter

1145-82-84 **Assane Lo*** (assanelo@uowdubai.ac.ae), University of Wollongong in Dubai, Block 15, Knowledge Park, PO Box 20183, Dubai, UAE, Dubai, United Arab Emirates. *Direct Methods for Investigating Phase Transitions in Classical Models of Kac Type.*

Phase transitions and critical points correspond to mathematical singularities in the thermodynamic potentials and other thermodynamic quantities which are related to appropriate derivatives of the free energy. For example, at the critical point of a ferromagnetic system, the spontaneous magnetization vanishes and the susceptibility diverges. It is therefore central to develop methods for calculating the thermodynamic potentials and their derivatives. We consider classical continuous models of Kac type and discuss hypotheses on the source term that will result in a direct proof of the analyticity of the free energy without using the truncated correlations.
(Received July 25, 2018)

1145-82-666 **Ira B. Schwartz*** (ira.schwartz@nrl.navy.mil), US Naval Research Laboratory, Code6792, Washington, DC 20375, and **Klimka Szwaykowska** (klimka@gmail.com), **Thomas W. Carr** (tcarr@smu.edu), **Jason Hindes** (jason.hindes.ctr@nrl.navy.mil) and **Leah B. Shaw** (lbshaw@wm.edu). *Large fluctuations, rare event prediction and control in complex networks.*

Noise-induced large fluctuations occur in systems across many fields and over many length scales. They range from desynchronization in power-grid networks and switching patterns in autonomous drone swarms at the macro-scale to alternating coupled neurons used to model perception at the micro-scale. An important class of dynamical systems that model such noise-induced behavior are networks with heterogeneous topological properties and local parameters. Importantly, noise-induced large fluctuations can give rise to dramatic events such as extinction of networked epidemics and species, switching between different collective network states, and/or complete collapse of network functionality and structure.

In this talk, I will review some of our recent general results in noise-induced fluctuations in complex networks. In particular, I will discuss how these results lead to new scalings of the probability occurrence of rare, large fluctuations in: mixed-reality coupled systems with asymmetric noise, switching and control of large fluctuations in complex networks, and large fluctuations to extinction in adaptive networks. My main collaborators for this work are: Jason Hindes, Klimka Szwaykowska, Thomas Carr and Leah Shaw. (Received September 12, 2018)

1145-82-1540 **Houssam Abdul-Rahman*** (houssam@math.arizona.edu), 617 N. Santa Rita Ave., Tucson, AZ 85721. *Dynamical Entanglement of disordered harmonic oscillators.* Preliminary report.

We consider the dynamics of quantum harmonic oscillator systems with disorder under the general assumption of eigencorrelator localization of the associated one-particle Hamiltonian. We show that starting from products of gaussian states (thermal and/or ground states) of local oscillators Hamiltonians, the averaged entanglement of the time-evolved states follows an area law with a pre-factor that grows linearly in time. (Received September 23, 2018)

1145-82-1653 **Bruno Nachtergaele**, **Robert Sims** and **Amanda Young*** (amyoung@math.arizona.edu). *Lieb-Robinson bounds and conditional expectations for lattice fermion systems.*

Lieb-Robinson bounds have proved a powerful tool for expressing locality properties of both static and disordered quantum spin systems. In this talk, we consider (static) lattice fermion systems, and discuss how to obtain Lieb-Robinson bounds in this context. One of the main difficulties in this setting is that spatially separated observables do not necessarily commute as they do in the tensor product structure of quantum spin systems. In addition, we will describe a class of conditional expectations that can be used to well-approximate dynamically evolved observables by strictly local ones. (Received September 23, 2018)

1145-82-1737 **Bruno Nachtergaele***, Department of Mathematics, University of California, Davis, Davis, CA 95616, and **Jake Reschke**. *Slow transport in some one-dimensional disordered many-body systems.* Preliminary report.

We study the Heisenberg dynamics of a class of quantum spin chains with finite-range interactions that include disorder and obtain bounds on the propagation of signals in such systems. (Received September 24, 2018)

1145-82-1782 **Houssam Abdul-Rahman**, **Christoph Fischbacher*** (cfischb@uab.edu) and **Gunter Stolz**. *Recent Progress on the Quantum XXZ Spin Model on General Graphs.*

We report on recent progress on the XXZ quantum spin model defined on general graphs. After reviewing its general definition, we discuss Combes-Thomas bounds from which we derive estimates on the structure of eigenfunctions and on spectral projections. We use this to show bounds on entanglement entropy in various situations. (Received September 24, 2018)

1145-82-2184 **Rajinder Singh Mavi*** (mavir@ripon.edu), 300 Seward Street, Ripon, WI 54972, and **Rodrigo Matos** and **Jeffrey Schenker**. *Dynamical and spectral properties of random Schrodinger operators with strongly correlated potentials.* Preliminary report.

We consider a random Schrodinger operator with strongly correlated potentials at arbitrarily large distances. We will study the dynamical and spectral properties of the Hamiltonian. We apply our results to an Anderson localized polaron, which is the motivation of our study. (Received September 25, 2018)

1145-82-2384 **Robert Sims*** (rsims@math.arizona.edu), **Houssam Abdul-Rahman** and **Gunter Stolz**. *Low Energy Localization Properties of Disordered Harmonic Oscillators.*

We review some recent results on disordered harmonic oscillator models. In particular, at fixed disorder, we prove zero velocity Lieb-Robinson bounds, quasi-locality estimates for the dynamics, and exponential decay of dynamic correlations in eigenstates. The main stress here is that we do not require the model to be in the fully many-body localized phase. (Received September 25, 2018)

1145-82-2693 **Matthew Cha*** (chamatth@msu.edu), **Rodrigo Matos**, **Jeffery Schenker** and **F Zak Tilocco**. *On ground states and excitations in certain disordered quantum spin chains.* Preliminary report.

We study the ground states and low-energy excitations of disordered quantum spin chains. In some cases, disorder effects have been linked to manifestations of dynamical localization, such as by zero-velocity Lieb-Robinson bounds. Assuming such zero-velocity bounds and mild uniqueness assumptions for the finite volume ground state we show uniqueness of the infinite volume ground state. In the Ising and XXZ spin chains there is no unique ground state. Instead there a manifold of domain wall type excitations, called kink/anti-kink states, that appear as ground states in the infinite volume limit. We investigate the localization properties of domain wall excitations in the disordered quantum Ising model. (Received September 25, 2018)

83 ► Relativity and gravitational theory

1145-83-415 **Steven Carlip***, Physics Department, 1 Shields Avenue, UC Davis, Davis, CA 95616. *Quantum fluctuations, light, and the small scale structure of spacetime.*

Quantum fluctuations of the stress-energy tensor almost certainly cause light rays to converge very rapidly at distances a bit above the Planck scale. I will explain why this is true, and offer some speculations about general implications for the small scale structure of spacetime. (Received September 05, 2018)

1145-83-1103 **Marcus C. Werner*** (werner@yukawa.kyoto-u.ac.jp), Kitashirakawa Oiwakecho, Sakyoku, Kyoto, 606-8502, Japan. *New developments in optical geometry.*

In general relativity, optical geometry is defined as 3-manifold whose geodesics correspond to spatial light rays, thus providing a geometrical description for the gravitational lensing effect. In this talk, I will discuss the background and introduce recent developments in this field, some of which grew out of the AMS MRC 'The Mathematics of Gravity and Light'. This includes a theorem on the isoperimetric problem in the Riemannian optical geomtry of static spacetimes (with Henri Roesch), and the application of the so-called Gauss-Bonnet method to the Randers-Finsler optical geometry of stationary spacetimes (with Nishanth Gudapati). I will also describe recent work on the geometrical phase in optical geometry (with Sosuke Noda) and the gravitational analogue of the magneto-electric effect (with Gary Gibbons). (Received September 20, 2018)

1145-83-1104 **Volker Perlick*** (perlick@zarm.uni-bremen.de), ZARM, University of Bremen, 28359 Bremen, Germany, and **Oleg Yu. Tsupko** and **G. S. Bisnovatyi-Kogan**. *Influence of a plasma on the shadows of black holes.*

If a black hole, or another compact dark object, is seen against a backdrop of light sources the observer sees a black disc in the sky which is known as the "shadow". In this talk I discuss how the boundary curve of the shadow is analytically determined for (a) spherically symmetric objects and (b) a Kerr black hole. It is assumed that the light rays are influenced by a plasma, i.e., they are not lightlike geodesics but rather solutions to a set of Hamilton's equations that involves the plasma density. The plasma is assumed pressureless ("cold") and non-magnetised. (Received September 19, 2018)

1145-83-1115 **Carla Cederbaum*** (cederbaum@math.uni-tuebingen.de). *Static, equipotential photon surfaces have no hair.*

The Schwarzschild spacetime is well-known to possess a unique "photon sphere" – meaning a cylindrical, timelike hypersurface P such that any null geodesic initially tangent to P remains tangent to P – in all dimensions. We will show that it also possesses a rich family of spatially spherically symmetric "photon surfaces" – general timelike hypersurfaces P such that any null geodesic initially tangent to P remains tangent to P. This generalizes a result of Foertsch, Hasse, and Perlick from $2+1$ to higher dimensions.

Moreover, we investigate the existence and properties of photon surfaces in a large class of static, spherically symmetric spacetimes. We show that they are (almost) necessarily rotationally symmetric.

We will also present a general theorem that implies that any static, vacuum, asymptotically flat spacetime possessing a so-called "equipotential" photon surface must already be the Schwarzschild spacetime. The proof of the theorem uses and extends Riemannian geometry arguments first introduced by Bunting and Masood-ul-Alam in their proof of static black hole uniqueness. It holds in all dimensions $n+1 \geq 3+1$.

Part of this work is joint with Gregory J. Galloway. (Received September 19, 2018)

1145-83-1121 **Pedro Vieira Pinto da Cunha***, Departamento de Fisica, CIDMA, University of Aveiro, 3810-193 Aveiro, Portugal, and **Emanuele Berti** and **Carlos Herdeiro**. *Light ring stability in ultra-compact objects.*

The following theorem is proven: axisymmetric, stationary solutions of the Einstein field equations formed from classical gravitational collapse of matter obeying the null energy condition, that are everywhere smooth and ultracompact (i.e., they have a light ring, or a.k.a. circular photon orbit) must have at least two light rings, and one of them is stable. It has been argued that stable light rings generally lead to nonlinear spacetime instabilities. Thus this result implies that smooth, physically and dynamically reasonable ultracompact objects are not viable as observational alternatives to black holes whenever these instabilities occur on astrophysically short time scales. The proof of the theorem has two parts: (i) We show that light rings always come in pairs, one being a saddle point and the other a local extremum of an effective potential. This result follows from a topological argument based on the Brouwer degree of a continuous map, with no assumptions on the spacetime dynamics, and hence it is applicable to any metric gravity theory where photons follow null geodesics. (ii) Assuming Einstein's equations, we show that the extremum is a local minimum of the potential (i.e., a stable light ring) if the energy-momentum tensor satisfies the null energy condition. (Received September 19, 2018)

1145-83-1135 **Henri P Roesch*** (roesch@math.columbia.edu), 2990 Broadway, New York, NY 10027, and **Marcus C Werner**. *Optical Geometry and the Isoperimetric Problem.* Preliminary report.

Einstein's theory of General Relativity predicts the bending of light trajectories between a distant source and an observer around a distribution of matter, or a gravitational lens, suspended in space-time. In static, spherically symmetric space-times, the geometry of these light trajectories can be described by a conformal rescaling of the space-time metric, called its Optical Geometry. In this talk, we discuss recent work on the Isoperimetric Problem in optical geometry and the implications for its gravitational lens. In particular, adapting a theorem of Hubert Bray, we give a proof of the Isoperimetric Problem for the Schwarzschild lens. (Received September 19, 2018)

1145-83-1799 **Robert J Abramovic*** (rabramo2@gmail.com). *Integrating Factors for Dirac-Schrodinger Operators and Positive Mass Theorems Outside Horizon(s).* Preliminary report.

A Dirac-Schrodinger operator is simply the Dirac operator plus a zeroth order endomorphism of the spinor bundle. Using an expression for this endomorphism in terms of a basis of the Clifford algebra on the tangent bundle, we will investigate when an integrating factor exists for the associated Dirac-Schrodinger operator. Not only will this allow us to prove existence to solutions of Dirac-Schrodinger equations, but it will also provide a way to obtain a lower eigenvalue bound to Dirac-Schrodinger operators via the Hijazi-Bar argument. This will provide the framework to prove positive mass theorems outside horizon(s) that generalize a result of M. Herzlich to include the non-time symmetric case and charge, as well as holding for a Riemannain manifold of arbitrary dimension. (Received September 24, 2018)

1145-83-1960 **Arlie O Petters*** (arlie.petters@duke.edu). *Cosmic Shadows, Other Worlds, and a Fifth Dimension.*

The gravitational fields of stars, black holes, and galaxies act on light propagating near them, casting shadow patterns in space. Such optical phenomena have wide-ranging physical applications, including detecting extrasolar planets and testing for a fifth dimension of the universe. Assuming no background in astrophysics or cosmology, this talk will take you on a mathematical journey unveiling the intriguing properties of these beautiful shadow patterns and exploring the possibility of a fifth dimension. (Received September 24, 2018)

1145-83-1987 **Frederic P. Schuller*** (fps@aei.mpg.de). *Constructive Gravity – How to unlock the hidden information about gravity that is encoded in a matter action.*

Constructive gravity allows to calculate the Lagrangian for gravity – rather having to postulate it – provided one previously prescribes the Lagrangian for all matter fields that are assumed to inhabit the spacetime. Even if these matter field dynamics employ a tensorial background geometry that is more refined than a Lorentzian metric, it is precisely this refined geometry that is given dynamics. This result is built on key observations of the original geometrodynamics program and on significant new results, employing an intricate interplay of the modern theory of partial differential equations, convex analysis and algebraic geometry.

We explain the physical and mathematical foundations of the constructive gravity program and show how one can now answer some questions about gravity that previously could not be addressed. In particular, we will present results on the systematic search for vacuum birefringence. (Received September 24, 2018)

1145-83-2135 **Sougata Dhar** and **Jessica Stewart Kelly***, jessica.kelly@cnu.edu, and **Arlie Petters**. *A Refinement for the Upper Bound on the Number of Cusps in the Case of Single-Plane Microlensing.*

For a single-plane lensing map η with deflection potential Ψ, which maps an observation position in the lensing plane to the source plane, the set of observation points (set of x-values) from the lensing plane for which $\det[\mathrm{Jac}\eta](x) = 0$ have infinite magnification and form a critical curve. Corresponding to the critical curve are the light source locations in the source plane; this set is the caustic set. While critical curves are smooth, the associated caustic curves contain folds and cusps. Several special features—beak-to-beak, elliptic umbilic, and swallowtail metamorphoses—can appear in the caustic curve. For the case of beak-to-beak and elliptic umbilic metamorphoses, an upper bound has been established for the maximum number of occurrences. It remains to improve the estimate for the maximum number of cusps and hence swallowtail metamorphoses in the case of single-plane microlensing. In this talk, we will discuss an application of the resultant theorem and how its use improves this upper bound estimate on the number of cusps. (Received September 24, 2018)

1145-83-2652 **Arthur E. Fischer*** (`aef@ucsc.edu`). *Friedmann's Equation and the Creation of the Universe.*

In this paper we present *mathematical evidence* that the beginning of the universe did not occur at the big bang with the universe in a state of infinite density, but occurred at $t = -\infty$ with the universe in a state of infinite dilution. We show the essential importance played by the *native quadratic structure* of a generic Friedmann's equation

$$\dot{a}^2 = F(a)$$

in the time derivative $\dot{a}$ in arriving at this conclusion and show how this quadratic structure, together with the accompanying *time-reversal symmetry* of Friedmann's equation, has profound physical consequences in building Friedmann models of the universe. We conclude that classical cosmological models can be *extrapolated backwards through the big bang* into the infinite past and thus that viable cosmological models based on the native quadratic form of Friedmann's equation, and thus on Einstein's equations, show that global spatial singularities need not signal an end to spacetime. Thus, classical big bang cosmological models based on Friedmann's equation, without the need for quantum gravity, when globalized to all-time models, show that the universe did not begin at the big bang. Thus encoded in Friedmann's equation is previously undiscovered information about how the universe began. (Received September 25, 2018)

1145-83-2672 **Deborah A Konkowski*** (`dak@usna.edu`), Department of Mathematics, 572C Holloway Road, U.S. Naval Academy, Annapolis, MD 21012, and **Thomas M Helliwell** and **J Williams**. *Classical and quantum singularities in self-similar solutions of Einstein's equations.*

In classical general relativity incomplete causal geodesic paths in maximal spacetimes indicate classical singularities. Such singularities are ubiquitous in relativistic spacetimes as Hawking and Penrose showed in their famous singularity theorems of the mid-twentieth century. A major question of this century is whether classical singularities will be erased in a full quantum version of general relativity. No single quantum gravity theory has primacy, however; versions of loop quantum gravity and string theory are in the forefront at this time. A more modest approach is to replace classical geodesic paths with quantum wave packets and look to see if there is a unique, well-defined quantum evolution. That is our method, one based on a paper by Horowitz and Marolf, following earlier work by Wald. One examines a quantum wave operator, in this case the relativistic Klein-Gordon operator, and sees if it is essentially self-adjoint. Here a particularly interesting family of self-similar spacetimes with timelike curvature singularities is investigated. We find, using Weyl's limit point-limit circle criterion, that for asymptotically power-law metrics the wave operator is not essentially self-adjoint. They are quantum mechanically singular. (Received September 25, 2018)

85 ► Astronomy and astrophysics

1145-85-2609 **Charles R. Keeton*** (keeton@physics.rutgers.edu), Department of Physics & Astronomy, 136 Frelinghuysen Road, Piscataway, NJ 08854. *An astrophysical perspective on the mathematics of gravity and light.*

Gravitational lensing provides a beautiful connection between astrophysics and mathematics. I will show examples of connections that involve catastrophe theory, complex analysis, the Poincare-Hopf index theorem, and stochastic processes. I will strive to explain how astrophysical applications both motivate and benefit from deep study of the mathematics of gravity and light. (Received September 25, 2018)

86 ► Geophysics

1145-86-2202 **Kayo Ide*** (ide@umd.edu), Department of Atmospheric and Oceanic Science, College Park, MD 20742. *Fitness of the ensemble approach in ensemble-var data assimilation system.*

In ensemble-var data assimilation, ensemble is used in the two ways. One is to provide the dynamically-estimated prior (background) error covariance information for the analysis process. The other is to propagate the posterior (analysis) uncertainty information during the model forecast. While both are critical to the performance of ensemble data assimilation system, quite often the emphasis is placed on more on the former. This talk will focus on the latter. We propose a practical procedure to evaluate the fitness of the ensemble approach in place for the approximation to the tangent linear and adjoint model. We also present a simple diagnostics tool to evaluate its spread in the relative sense with respect to the observation error covariance and the necessity of the inflation. We apply them to the current NOAA operational hybrid 4DEnVar global data assimilation system and discuss the applicability and fitness of the ensemble approach to the hybrid system. (Received September 26, 2018)

1145-86-2541 **Alfredo N. Wetzel*** (alfredo.wetzel@wisc.edu), **Leslie M. Smith** and **Samuel N. Stechmann**. *Discontinuous Fronts as Exact Solutions to Precipitating Quasi-Geostrophy.*

Atmospheric fronts may be idealized as boundaries between two air masses with different temperature, density, moisture, etc. In this presentation, we discuss exact discontinuous solutions of a simplified model for moist mid-latitude synoptic atmospheric flows: the precipitating quasi-geostrophic (PQG) equations. These simple discontinuous fronts extend the celebrated Margules' front slope formula to the case of propagating moist fronts and require both rainfall and a phase change of water at the front interface to exist. The fronts propagate at speeds related to the rainfall velocity, temperature/wind jump magnitudes, and front geometry. To assess the realism of these fronts, we use rough estimates of relevant physical parameters to show that cold, warm, and stationary fronts are sensibly captured by the model. (Received September 25, 2018)

1145-86-2644 **Chung-Nan Tzou*** (ctzou@wisc.edu), 402 N Eau Claire Ave, Apt 115, Madison, WI 53705, and **Samuel Stechmenn**. *Numerical Methods for Potential Vorticity Inversion with Phase Changes.*

The precipitating quasigeostrophic (PQG) equations have been recently derived as an asymptotic limit of mid-latitude atmospheric dynamics, with the effects of clouds and phase changes of water included. One key part of the PQG equations is a nonlinear elliptic partial differential equation (PDE) with interface jumps, where the interface is the edge of a cloud, and its location is actually unknown and is discovered as part of the solution process. This interface location nonlinearity makes the discontinuous PDE even more challenging. Here we present an iterative numerical method to solve the equation and discover the corresponding interface location to complete the PV inversion that leads to obtaining all other variables. (Received September 25, 2018)

90 ► Operations research, mathematical programming

1145-90-54 **Paul L. Goethals*** (paul.goethals@usma.edu) and **Natalie M. Scala** (nscala@towson.edu). *Modeling Threats to Maryland's Electoral Voting System*

In the last three years, the evolving cybersecurity threat has extended to the Nation's voting systems, affecting up to 21 states in the most recent U.S. presidential election. As a result, the voting system security problem has received a considerable amount of attention from practitioners, researchers, and the government. Most previous and ongoing studies, however, examine the cybersecurity problem from either a symmetric, static, or holistic perspective, offering 'best practices' and procedures for mitigating against known vulnerabilities. In contrast, this research considers both the external threat from an adversary and the internal threat posed by human error or subversive actors. Moreover, the threat is modeled over time, so that one may become more aware of how voting system risk changes with respect to one's cybersecurity posture. The study, which specifically investigated a county's election process in Maryland from September 2017 to the present, utilizes mathematical modeling techniques as a basis for further analysis and interpretation. (Received July 10, 2018)

1145-90-83 **Jesús A. De Loera*** (deloera@math.ucdavis.edu), Dept. of Mathematics, Univ. of California, Davis, CA 95618. *Algebraic, Geometric, and Topological Methods in Optimization.*

Optimization is the part of applied mathematics that seeks the best answer or optimal element, according to an objective function or optimization criterion, from among a domain of many possible solution values. This could mean the shortest path on a network, the optimal assignment of jobs in a company, or the best distribution of fire stations in a city. Optimization is at the core of techniques in machine learning, bioinformatics, management and operations planning, finances, and many other areas.

Mathematical optimization began to develop steadily only in the 1940's with contributions of mathematicians like George Dantzig, Ralph Gomory, John von Neumann, Harold Kuhn, Albert W. Tucker, and other pioneers. In my talk I wish to recount, through independent examples, how algebraic, geometric, and topological techniques have brought recent advances to the theory of optimization.

In my examples I will show how a rich mixture of algebraic geometry, convex and tropical geometry, and combinatorial topology appears in the analysis of algorithms for the linear optimization problem. My survey talk will be accessible to non-experts and students, who are encouraged to come and see how the dividing line between pure and applied mathematics can be erased. (Received July 24, 2018)

1145-90-152 **Elena Constantin***, 450 Schoolhouse Road, Johnstown, PA 15904. *Primal First-Order Necessary Efficiency Conditions for Locally Lipschitz Multiobjective Optimization Problems.*

In this talk some nonsmooth analogues of the Burachik-Rizvi regularity conditions are introduced for a nonsmooth multiobjective optimization problem with equality and inequality constraints and with an arbitrary set constraint. Primal first-order necessary conditions for efficiency and Geoffrion-proper efficiency are given for this problem. Illustrative examples are analyzed. (Received August 09, 2018)

1145-90-220 **D K Mohanty*** (dkmohanty.iitkgp@gmail.com), Department of Mathematics, Indian Institute of Kharagpur, Kharagpur, West Benga 721302, India, **R K Jana** (rkjana1@gmail.com), Indian Institute of Management Raipur, GEC Campus, Sejbahar, CG-492 015, 492015, India, and **M P Biswal** (mpbiswal@maths.iitkgp.ernet.in), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, Kharagpur, India. *Multi-Choice Stochastic Programming Problems Using Genetic Algorithm.* Preliminary report.

Genetic algorithm (GA) is a very important method used to solve difficult combinatorial optimization problems. Multi-choice programming (MCP) class of combinatorial optimization problems where the decision maker (DM) has to choose a value from a number of choices, and to nd a combination which optimizes an objective function subject to a given set of constraints. If some parameters present in the MCP problem follow some probabilistic distributions, then it is known as multi-choice stochastic programming (MCSP) problems. In this paper, a MCSP problem has been considered. First we apply chance constrained programming technique to nd a deterministic MCP problem. Generally, some transformation techniques are applied to transform the MCP problem to a mixed-integer programming (MIP) problem, then a standard mathematical programming is used to solve the transformed MIP problem which involves extra variables and extra constraints. But here we have proposed a GA to solve the MCP problem directly (without using any transformation technique). Finally, a numerical example is presented to illustrate the solution procedure. (Received August 21, 2018)

1145-90-294 **Cheng-Chang Lin*** (cclin@mail.ncku.edu.tw), 1 University Road, Department of Transportation Science, National Cheng Kung University, Tainan, 701, Taiwan. *The expected utility model on carrying capacity allocation for express carriers.*

The time-definite express freight delivery common carriers publish tariffs and deliver express freight shipments door-to-door with guaranteed delivery times. The carriers also bid on the time-indefinite cargo of key accounts to fill up otherwise unused carrying capacity. The carrying capacity allocation model is to determine prices for express freight and also to decide whether to bid on the cargo of key accounts so as to fill the available carrying capacity in a way that maximizes profit. We modeled this integral-constrained concave program in link formulation and demonstrated computationally using Taiwan's largest time-definite LTL freight carrier. (Received August 29, 2018)

1145-90-377 **Gabor Braun**, **Sebastian Pokutta*** (sebastian.pokutta@isye.gatech.edu), **Dan Tu** and **Stephen Wright**. *Blended Conditional Gradients.*

We present a blended conditional gradient algorithm for minimizing a smooth convex function over a polytope P, that combines gradient projection steps with conditional gradient steps, achieving linear convergence for strongly convex functions. The algorithm does not make use of away steps or pairwise steps, but retains all favorable properties of conditional gradient algorithms, most notably not requiring projections onto P and maintaining iterates as sparse convex combinations of extreme points. The algorithm decreases measures of optimality (primal and dual gaps) rapidly, both in the number of iterations and in wall-clock time, outperforming even the efficient lazified conditional gradient algorithms of Braun et al. [2017]. (Received September 04, 2018)

1145-90-499 **John Asplund*** (jasplund@daltonstate.edu), 650 College Dr., Dalton, GA 30720, and **Tom Gonzalez** (tgonzalez@daltonstate.edu), 650 College Drive, Ringgold, GA 30736. *Optimizing Geometric Requirements for Redistricting.*

A newly created school district needs to be divided into four regions to address the needs of the community. There are two rules that must always be followed: 1) each region must be made up of exactly one piece so that buses do not have to travel through another region to pick up their students and 2) each region must not have a hole so their sport teams can easily compete with more than one neighboring school. How do we choose the "best" way to divide this school district? Local search algorithms can be applied to search the space for this "best" redistricting, but checking to ensure the two above rules are satisfied can be computationally difficult. In this talk, we discuss how to efficiently ensure that when moving small parts from one district to another district while sampling the space of possible redistrictings, we continue to satisfy the above two rules using the geometry inherent in the problem. (Received September 07, 2018)

1145-90-789 **Rana Haber***, rana.haber@hotmail.com, and **Anand Rangarajan** and **Adrian M. Peter**. *Functional Data Classification by Discriminative Reconstruction.* Preliminary report.

Inspired by the representational aspect of functional data, we present a novel approach to time series classification. Our method combines the transformation of the data into a new space while simultaneously applying a support vector machine (SVM) classifier. SVM is one of the strongest 2-class classifiers and yet one of the simplest. The norm is to treat a functional curve as a D-dimensional vector and apply multivariate classifier to it. We propose learning a new representation of the data that allows it to leverage it's continuous properties while learning the best hyperplane that separates the two classes. Our methodology Classification by Discriminative Reconstruction (CDR) uses an appropriate bases for the data representation that is unique to each problem. We show and compare the results for two different bases, Wavelets and Radial Basis functions. Our experiments are run on all the 2-class datasets provided by the UCR Time Series Classification website. Our results show that our method CDR is as competitive or better than recent state-of-the-art methodologies. (Received September 14, 2018)

1145-90-821 **Cunlu Zhou***, University of Notre Dame, Department of Mathematics, 255 Hurley Hall, Notre Dame, IN 46556, and **Leonid Faybusovich**, University of Notre Dame, Department of Mathematics, 255 Hurley Hall, Notre Dame, IN 46556. *Long-Step Path-Following Algorithm for Nonlinear Symmetric Problems with Applications to Quantum Entropy Optimization.*

We developed a long-step path-following algorithm for a class of symmetric programming problems with nonlinear convex objective functions. The theoretical framework is developed for functions compatible in the sense of Nesterov and Nemirovski with $-\ln\det$ barrier function. Complexity estimates similar to the case of a linear-quadratic objective function are established, which gives an upper bound for the total number of Newton steps. The theoretical scheme is implemented for a class of spectral objective functions which includes the case of quantum (von Neumann) entropy objective function, important from the point of view of applications. We explicitly compare our numerical results with the only known competitor. (Received September 15, 2018)

1145-90-952 **Franklin Kenter** and **Daphne Skipper*** (skipper@usna.edu). *IP bounds on pebbling numbers of Cartesian-product graphs.*

A pebbling move takes two pebbles from a single vertex in a graph and places one pebble on an adjacent vertex. The pebbling number of a graph G is the smallest number π_G such that, given any vertex k of G and any assignment of π_G pebbles to the vertices of G, there exists a sequence of pebbling moves that places a pebble on k. Computing π_G is provably difficult. Graham's conjecture states that the pebbling number of the Cartesian-product of two graphs G and H, denoted $G \square H$, is no greater than $\pi_G \pi_H$.

This study combines the focus of developing a computationally tractable method for generating good bounds on $\pi_{G \square H}$, with the goal of providing evidence for (or disproving) Graham's conjecture. In particular, we present a novel integer-programming (IP) approach to bounding $\pi_{G \square H}$ that results in significantly smaller problem instances compared with existing IP approaches to graph pebbling. Our approach leads to an improvement on the best known bound for $\pi_{L \square L}$, where L is the Lemke graph. $L \square L$ is among the smallest known potential counterexamples to Graham's conjecture. (Received September 17, 2018)

1145-90-959 **Steffen Borgwardt*** (steffen.borgwardt@ucdenver.edu), University of Colorado Denver, Dep. of Mathematical and Statistical Sciences, 1201 Larimer Street, Suite 4000, Denver, CO 80204, and **Charles Viss**. *A Polyhedral Model for Enumeration and Optimization over the Set of Circuits.*

Circuits play a fundamental role in linear programming. For instance, circuits are used as step directions in various augmentation schemes for solving linear programs, or to leave degenerate vertices in a run of the simplex method. There are significant challenges when implementing these approaches: The set of circuits of a polyhedron may be of exponential size and it is highly sensitive to the representation of the polyhedron.

We devise a universal framework for enumerating the set of circuits, and optimizing over it, for a polyhedron given in any representation: we model a polyhedral set in which the circuits of the original polyhedron are encoded as vertices. Previous methods in the literature assume that a polyhedron is given in standard form; our framework is a direct generalization. We demonstrate its value through proving that a transformation to standard form may introduce exponentially many new circuits.

We then discuss further advantages of the new polyhedral model. It enables the direct enumeration of specific subsets of circuits, as well as optimization over the set of circuits, or a subset thereof. In particular, this leads to the efficient computation of a steepest-descent circuit direction or the construction of a conformal sum with additional properties. (Received September 17, 2018)

1145-90-1120 **Robert Hildebrand*** (rhil@vt.edu), **Matthias Koeppe** and **Yuan Zhou**. *Algorithms for understanding cut generating functions.*

Cut generating functions are central to the theory of integer programming and the cutting plane technique. Cut generating functions are used as a simple tool for generating cutting planes in a branch and cut framework of solving integer programs. We will discuss current progress on algorithms for understanding properties cut generating functions for pure integer programs for the one-row and two-row models. (Received September 19, 2018)

1145-90-1193 **Nan Chen*** (nchen@se.cuhk.edu.hk), 709A William Mong Engineering Building, The Chinese University of Hong Kong, Hong Kong, Peoples Rep of China, and **Xiang Ma** (xma@se.cuhk.edu.hk), The Chinese University of Hong Kong, Hong Kong, Peoples Rep of China. *Information Relaxation and the Duality-Based Dynamic Programming.*

We use the information relaxation technique to develop a value iteration method to solve stochastic dynamic programming problems. Each iteration generates a confidence interval estimate for the true value function so we can use the gap between the upper and lower bounds to assess the quality of the policy. We show that the resulted sequences of suboptimal policies converge to the optimal one within finite number of iterations. A regression-based Monte Carlo algorithm is introduced to overcome the curse of dimensionality in the implementation of this approach for high dimensional cases. The paper also discusses how to extend this approach to reinforcement learning. As numerical illustrations, we apply the algorithm in two financial applications such as optimal order execution and portfolio selection. (Received September 19, 2018)

1145-90-1416 **Stephen L. Hobbs*** (steve.hobbs@navy.mil), 6391 Caminito Del Pastel, San Diego, CA 92111. *A Mathematical Modeling Perspective on the US Navy, Humanitarian Aid, and International Relations.*

Modern US Navy engagements are carefully planned operations, with an attempt to optimize the desired outcome given resource and cost considerations. Given the cost of military conflicts between nations, perhaps we in the DoD should put more emphasis on optimizing long-term goals of world peace and economic growth, avoiding settling disputes by military means.

In this talk I will present a model to help optimize the US Navy's response to disaster relief, and discuss the added work required for implementing it. I may also discuss other models that address assistance to populations in situations where failure to assist might lead to a humanitarian crisis or armed conflict. In presenting these applications I will point out the large scope of mathematics that is required to create a significant capability in today's Navy. (Received September 21, 2018)

1145-90-1418 **Alberto Del Pia*** (delpia@wisc.edu), Wisconsin Institute for Discovery, 330 North Orchard Street, Madison, WI 53715. *Concave Integer Quadratic Programming with Totally Unimodular Matrices.*

We consider the problem of minimizing a separable concave quadratic function over the integral points in a polyhedron defined by a totally unimodular constraint matrix. This problem is NP-hard and it is equivalent to its continuous relaxation obtained by dropping the integrality constraint. The continuous problem admits a strongly polynomial-time approximation algorithm, provided that the number of variables that appear nonlinearly in the objective is fixed. In this paper we close the gap between the continuous and discrete version of the problem by giving an approximation algorithm for the discrete problem whose running time is strongly polynomial if the number of variables that appear nonlinearly in the objective is fixed. Our result in particular yields a strongly polynomial-time approximation algorithm for the integral minimum concave cost network flow problem with quadratic costs, provided that the number of nonlinear arc costs is fixed. (Received September 21, 2018)

1145-90-1732 **Quentin Louveaux*** (q.louveaux@uliege.be), Allée de la découverte 10, 4000 Liège, Belgium. *The disjunctive hull of facility location problems.* Preliminary report.

It is well known that describing explicitly the convex hull of an NP-hard problem is intractable. It is also hard to describe some superset approximations of it like the split or Chvatal closure. Here we investigate the opportunity of describing explicitly some good approximation of the integer hull for some structured problems. In particular, we focus on the disjunctive hull of the facility location problem. We show that it is possible to describe the disjunctive hull in the original space and to separate over it. (Received September 24, 2018)

1145-90-1816 **Francis J Vasko***, 230A Lytle Hall, Kutztown, PA 19530, and **Yun Lu**. *Binarizations of Continuous Metaheuristics to Solve the Set Covering Problem: Simpler is Better.* Preliminary report.

Recently, a number of metaheuristics originally designed for solving continuous nonlinear optimization problems have been adapted to solve the Set Covering Problem (SCP) which is a well-known discrete optimization problem. Many of these metaheuristics are bio-inspired and include Bee Colony, Black-Hole, Cat Swarm Optimization, Cuckoo Search, Electromagnetism-Like, Firefly Optimization, and Teaching-Learning Based Optimization (TLBO) algorithms. In this talk we will review how these metaheuristics are adapted or "binarized" to solve the SCP. Also, we will discuss how another metaheuristic, JAYA, introduced in 2016 for solving continuous nonlinear optimization problems can be easily adapted to solve the SCP. The performance of all these metaheuristics on the SCP will be evaluated based on how well they solve 65 SCPs from Beasley's OR library. The empirical results demonstrate that the simple, straightforward binarization approach used by Lu and Vasko on the TLBO metaheuristic gives the best results. (Received September 24, 2018)

1145-90-1844 **Yun Lu*** (lu@kutztown.edu), Kutztown, PA 19530, and **Francis Vasko** and **Charles Saternos**. *A Population-based Metaheuristic Approach for Solving the Multi-demand Multidimensional Knapsack Problem.* Preliminary report.

The Multi-Demand Multidimensional Knapsack Problem (MDMKP) is a combinatorial optimization problem with real-world applications that is extremely difficult to solve due to conflicting constraints. In this study, we adapt a population-based (a collection of solutions) metaheuristic to efficiently generate near-optimal solutions to the MDMKP. This metaheuristic, called Jaya (victory in Sanskrit) was introduced in 2016 by Rao to solve continuous nonlinear engineering design problems. Since the MDMKP is a binary optimization problem (variables are bit strings, not continuous variables), we made modifications to the Jaya metaheuristic in order to effectively solve the MDMKP. For test purposes, we use 810 large MDMKP instances available to researchers on the web. In this talk, we will report empirical results we obtained from solving these 810 MDMKP instances using our new Jaya-based metaheuristic approach. Our results will be compared to the optimal (if known) or best known results for these problems. (Received September 25, 2018)

1145-90-1850 **Stephanie Ann Allen*** (sallen7@math.umd.edu), 6817 Pineway, University Park, MD 20782. *Working in Reverse: Inverse Optimization Methods in Pyomo.* Preliminary report.

In a traditional constrained optimization framework, we aim to find the vector of decisions $\mathbf{x}^*$ such that an objective function $f(\mathbf{x})$ is minimized and such that $\mathbf{x}^* \in S$, with S defined by the intersection of a collection of constraints. However, it may be challenging to determine the appropriate parameter values for the objective function $f(\mathbf{x})$, making it valuable to use information about the solution to the model at a specific time point to estimate these unknown parameters. This process is known as inverse optimization. Although great progress has been made in this field over the last two decades, few software packages exist that implement methods associated with inverse optimization. Our research focuses on designing a model class for inverse optimization using the open source Python Optimization Modeling Objects (Pyomo) software package. We present preliminary results of this research, implementing methods presented by Ahuja & Orlin (2001) and Zhang et al. (2011) for linear and basic nonlinear cases, respectively. (Received September 24, 2018)

1145-90-1881 **Himanshu Ahuja** (himanshuahuja_bt2k15@dtu.ac.in) and **Alexander C Michels*** (michac22@wclive.westminster.edu). *Computational Fact-Checking through Relational Similarity based Path Mining.* Preliminary report.

The volume of information today is outpacing the capacity of experts to fact-check it, and in the Information Age the real-world consequences of misinformation are becoming increasingly dire. Recently, computational methods for tackling this problem have been proposed with many of them revolving around knowledge graphs. We present a novel computational fact-checking algorithm, RelPredPath, inspired by and improving on the techniques used in state-of-the-art fact-checking algorithms, PredPath and Knowledge Stream. Our solution views the problem of fact-checking as a link-prediction problem which relies on discriminitive path mining, but draws on relational similarity and node generality to redefine path length. This gives our solution the advantage of training on more specific paths consisting of edges whose predicates are more conceptually similar to the target predicate. RelPredPath shows performance at-par with other state-of-the-art fact-checking algorithms, but leads to a more robust and intuitive model for computational fact-checking. (Received September 24, 2018)

1145-90-2160 **Carla Michini*** (michini@wisc.edu), **Peter Ohmann**, **Ben Liblit** and **Jeff Linderoth**. *Solving the Customized Coverage Probing problem through Set Covering.* Preliminary report.

The Customized Coverage Probing problem is a NP-hard problem arising in software development and program debugging. A computer program is represented as a control-flow graph $G = (V, E)$ and each execution corresponds to a path from a designated entry point to an exit point.

Two executions are considered equivalent if they traverse the same nodes in $D \subseteq V$. Moreover, for $I \subseteq V$, we can instrument a node $u \in I$ to check whether u has been traversed during an execution. The Customized Coverage Probing problem asks for a minimum cost instrumentation that can determine whether any two paths are equivalent.

We exploit monotonicity to formulate this problem as a set covering problem. Our formulation has an exponential number of contraints, and we design a polynomial-time separation algorithm to generate violated inequalities.

Computational experiments show that our approach significantly reduces expected run-time probing costs and yields compilation-time overheads that are suitable for wider practical use. (Received September 24, 2018)

1145-90-2235 **Jamol Pender***, 228 Rhode Hall, Ithaca, NY 14853. *Queueing Theory in the Age of Technology.*

Many service systems provide real-time information to their customers via smartphones with the goal of reducing the customers' anxiety of the unknown. However, the information might be unreliable or not given in real-time. In this talk, we show how to prove fluid and diffusion limit theorems for a state dependent in nite server queueing model where customers choose which queue to join by a generalized customer choice model and where the information about the queue length is updated in discrete intervals. We compare our queueing model with periodic updates against queues that update constantly, but are delayed by a constant. We also show using data from Disneyland that giving customers information via smartphones may not be a smart decision. (Received September 25, 2018)

1145-90-2271 **Sanjeeb Dash*** (sanjeebd@us.ibm.com), IBM T. J. Watson Research Center, 1101 Kitchawan Rd, Yorktown Heights, NY 10520. *Cutting planes from extended formulations of mixed-integer programs.*

We discuss how to use extended formulations of the LP relaxation of a mixed-integer program to obtain stronger split cutting planes than those that can be obtained from the original LP relaxation. We analyze a few different approaches to building extended formulations, and the strength of split cuts in each case. In particular, we consider the Lovász-Schrijver and Sherali-Adams lift-and-project operator hierarchies and show how to define stronger hierarchies, and also discuss extended formulations of mixed-integer programs obtained by replacing integral variables by weighted sums of binary variables. We prove that certain binary extended formulations, studied earlier by Roy, by Bonami and Margot, and by Angulo and Van Vyve, are strongest possible with respect to adding split cuts in the extended space and projecting to the original space. Finally, we discuss the solution of some hard, quadratic, unconstrained optimization problems arising from Ising model problems defined on Chimera graphs, and how cutting planes from extended formulations can reduce solution times.

This talk is based partly on joint work with Merve Bodur, Oktay Gunluk, Robert Hildebrand, and Jim Luedtke. (Received September 25, 2018)

1145-90-2300 **Hamza Fawzi***, University of Cambridge, DAMTP, Cambridge, United Kingdom. *Lifts of convex sets.*

A central question in optimization is to maximize (or minimize) a linear function on a given convex set. Such a problem may be easy or hard depending on the geometry of the convex set. Motivated by this problem, this lecture considers the following question: given a convex set, is it possible to express it as the projection of a simpler convex set in a higher-dimensional space? Such a lift of the convex set allows us to reformulate the original optimization problem as an easier one over the higher-dimensional convex set. In order to make this question precise we need a way to measure the complexity of convex sets. We will focus in this lecture on two classes of lifts, namely polyhedral and spectrahedral lifts, where a natural notion of complexity can be defined. For spectrahedral lifts, we will see that the existence of lifts is characterized by the existence of SOS certificates for a certain class of nonnegative functions. We will give some examples of convex sets that admit small lifts, and others that do not, and will discuss applications in optimization. (Received September 25, 2018)

1145-90-2475 **Jeffrey A Braun*** (jbraun8@jhu.edu), 3404 Oakenshaw Pl, Baltimore, MD 21218, and **John C Wierman**. *Progress on the Symmetric Rendezvous Problem on the Line.* Preliminary report.

A famous open problem in the field of Rendezvous Search is to ascertain the rendezvous value of the symmetric rendezvous problem on the line wherein both agents begin 2 units apart. We provide a new, Bayesian framework to both create new strategies for the agents to follow and to provide a new interpretation of previously posited strategies. Additionally, we have developed a method that modifies any strategy, even those with potentially infinite expected meeting time, into a new strategy that is guaranteed to have a finite expected meeting time. This process, combined with using our Bayesian framework to create new strategies, yields an upper bound that is within 1% of the current best upper bound for the symmetric rendezvous value. (Received September 25, 2018)

1145-90-2491 **Nandini Rakala*** (nrakala2015@my.fit.edu), 150 W. University Blvd., Melbourne, FL 32901, and **Munevver Mine Subasi** and **Ersoy Subasi**. *Logical Analysis of Data using Multi-Objective Optimization.*

We propose a multi-objective machine-learning model for a classification technique known as Logical Analysis of Data (LAD). LAD is a multi-step procedure consisting of discretization, support set selection, pattern generation, classification, and cross-validation. The key ingredient of two-class LAD method is the identification of patterns, distinguishing between pairwise disjoint subgroups of observations in a data-set. In this paper, we present a multi-objective pre-classification process of feature selection involving two conflicting goals of minimizing the number of features and maximizing the prediction accuracy, in a Pareto-based dominance form. We compare the accuracy and run-times of different classification techniques such as Decision Trees, Naive-Bayes, Nearest Neighbor, and SVM, on various data-sets and show how the proposed algorithmic approach outperforms the rest. The proposed approach identifies the set of strong/weak Pareto-optimal LAD patterns to predict the slow and rapid progressions of Chronic Kidney Disease patients in the African-American Study of Kidney Disease. (Received September 25, 2018)

1145-90-2540 **Ted K Ralphs*** (ted@lehigh.edu). *Duality for Discrete Optimization: Theory and Applications.*

The duality theory for discrete optimization is a well-developed theory with many important applications. The theory generalizes a number of useful concepts from the duality theory of (continuous) linear optimization, which is much better-known within the optimization community. In this talk, we provide an overview of this theory and discuss its connection to the general theory of discrete optimization. We further describe applications in which duality theory provides key insights leading to practical algorithms. (Received September 25, 2018)

1145-90-2586 **Ahmad Ridley*** (adridle@tycho.ncsc.mil). *Mathematics in the Realm of Cyber Research.*

Our research goal is to demonstrate that an autonomous cyber defense (ACD) system can make an enterprise network, and its associated missions and services, more resilient to cyber-attack. An ACD system should leverage automation, artificial intelligence, and/or machine learning to autonomously reason and respond to cyber-attacks. There are several different mathematical concepts embedded in such an ACD with this cyber-reasoning and response capability. For example, game theory models can decide optimal cyber defender strategies, reinforcement learning algorithms can be used to automate and optimize cyber response actions, and statistical models can be used to determine the most important cyber features for efficient network monitoring. We will explore the applications of these types of mathematical techniques for cyber defense research. (Received September 25, 2018)

1145-90-2621 **Akshay Gupte*** (agupte@clemson.edu), Clemson University, Clemson, SC 29634. *New families of approximations for the integer hull of a compact set.*

For a nonempty compact set $X \subset \mathbb{R}^n$, we are interested in its integer hull X_I, which is the convex hull of $X \cap \mathbb{Z}^n$. Compactness of X means that X_I is a polytope. We propose a novel scheme for generating inner and outer approximations of X_I through the use of total orders over $\mathbb{Z}^n$. Each approximation is a polytope corresponding to a finite subset of total orders. We prove convergence guarantees of our approximations to X_I under some structural assumptions on X. We also show that for some total orders, the best possible approximations can be as bad as n-approx in the general case. The outer approximations (relaxations) in our scheme suggest a new approach for generating strong valid inequalities to X_I. A key part of our constructs is the computation of minimal and maximal (under a total order) points in $X \cap \mathbb{Z}^n$. We present some complexity results in this regard. (Received September 25, 2018)

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1145-91-88 **Igor Erovenko*** (igor@uncg.edu) and **Mark Broom**. *The evolution of cooperation in mobile populations with costly movement on evolving multiplayer networks.*

We create stochastic simulations of a finite evolving population of individuals on a network. Individuals move around the network following a Markov process and interact with each other via a public goods game. We investigate how the population size, movement cost, exploration time, and network structure affect the evolution of cooperation. This modeling framework allows to extend the analytic approach of Pattni, Broom, and Rychtar (2018) for complete graphs to arbitrary networks. (Received July 26, 2018)

1145-91-124 **Surajit Borkotokey*** (surajitbor@yahoo.com), Department of Mathematics, Dibrugarh University, Dibrugarh, Assam 786004, India, and **Dhrubajit Choudhury**, **Loyimee Gogoi** and **Rajnish Kumar**. *Group Interactions in TU games : The k-lateral value.*

In this paper, we propose the k-lateral value for TU cooperative games that accounts for simultaneous k-lateral interactions among players. The Shapley like values implicitly assume that players are independent in deciding to leave or join a coalition. However in many real life situations, players are likely to be influenced by their peers in making such decisions. Thus group interactions and group contributions are also important in determining players' shares in the total resource they generate. Following Shapley's rule of counting we first consider the marginal contributions of the players over all possible permutations of coalitions. Next we count the number of ways of forming groups of any size within each such coalition. The largest allowable size of a group within the coalitions is defined as the index of the group formation. All possible marginal contributions of the groups of a pre-defined index k are obtained. Our value then gives a player her share from each group of index k equally divided among the group members. The Shapley value is a particular value of the k-lateral value when $k = 1$. We give a characterization of the k-lateral value with a set of standard axioms. (Received August 05, 2018)

1145-91-225 **Jacob North Clark*** (jnc6w3@mail.missouri.edu) and **Stephen Montgomery-Smith** (stephen@missouri.edu). *Shapley-like values without symmetry.* Preliminary report.

Following the work of Lloyd Shapley on the Shapley value, and tangentially the work of Guillermo Owen, we offer an alternative non-probabilistic formulation of part of the work of Robert J. Weber in his 1978 paper "Probabilistic values for games." Specifically, we focus upon efficient but not symmetric allocations of value for cooperative games. We offer an alternative condition "reasonableness," and retain standard efficiency and linearity to replace the usual axioms. In the pursuit of the result, we discover properties of the linear maps that describe the allocations. This culminates in a special class of games for which any other map that is "reasonable, efficient" can be written as a convex combination of members of this special class of allocations, via an application of the Krein-Milman theorem. (Received August 22, 2018)

1145-91-483 **Trang T.H Bui*** (trang.bui@wayne.edu), Detroit, MI 48202, and **Xiang Cheng**, **Zhuo Jin** and **George Yin**. *Approximation of a class of non-zero-sum investment and reinsurance games for regime-switching jump-diffusion models.*

This work develops an approximation procedure for a class of non-zero-sum stochastic differential investment and reinsurance games between two insurance companies. Both proportional reinsurance and excess-of loss reinsurance policies are considered. We develop numerical algorithms to obtain the Nash equilibrium by adopting the Markov chain approximation methodology and applying the dynamical programming principle for the nonlinear integro-differential Hamilton-Jacobi-Isaacs (HJI) equations. Furthermore, we establish the convergence of the approximation sequences and the approximation to the value functions. Numerical examples are presented to illustrate the applicability of the algorithms. (Received September 07, 2018)

1145-91-566 **Yuanying Guan*** (guany@iun.edu), 3400 Broadway, Gary, IN 46408, and **Micah Pollak**. *Contagion in Heterogeneous Financial Networks.*

We extend the financial network contagion model of Gai P. and Kapadia S. to investigate the interaction of several types of heterogeneity found in real world banking systems. The first source of heterogeneity originates in the distribution of assets across banks in the financial system. The second source is in how individual banks then distribute these assets among their neighbors. We characterize how these two sources of heterogeneity interact to affect the probability and extent of financial contagions in three network structures. We find that greater heterogeneity has a stabilizing effect for networks that are sparsely connected and a destabilizing effect for networks that are highly interconnected. Finally, we consider multiple sequential shocks and find that when banks redistribute assets following an initial mild contagion it increases the stability, on average, of the system to subsequent shocks originating at weakened banks. (Received September 10, 2018)

1145-91-655 **Rachael Miller Neilan*** (millerneilanr@duq.edu), **Josef Di Pietrantonio** and **James Schreiber**. *Assessing the impact of motivation and ability on team-based productivity using an agent-based model.*

It is common for organizations to hire workers based on their knowledge, skills, and abilities. However, despite capable workers being hired, productivity may suffer if employees' motivational needs are not satisfied. We developed an agent-based model to simulate the completion of tasks by teams of workers with different motivational strengths and abilities. Each worker is described by an ability value (1 through 5) and a 3-parameter motive profile expressing the individual's needs for affiliation, achievement, and power. During each time step, workers contribute to their assigned task at rates based on ability, motive profile, and the incentive value of the task. At the end of 365 time steps, the model outputs the total number of completed tasks, which is the primary measurement of productivity. We use the model to investigate which worker populations result in highest measures of productivity. Additionally, we use the model to illustrate the benefit of identifying failing tasks in real-time and re-assigning new teams to these tasks. (Received September 12, 2018)

1145-91-742 **Srdjan Stojanovic*** (stojans@ucmail.uc.edu), Department of Mathematical Sciences, University of Cincinnati, Cincinnati, OH 45221-0025. *On hedging and pricing in general complete and incomplete markets.* Preliminary report.

The author's general theory of pricing and hedging for portfolios of financial contracts in general diffusive Markovian markets (see, e.g., S. Stojanovic, "Neutral and Indifference Portfolio Pricing, Hedging and Investing" Springer, New York, 2011) is reviewed, and then some new results and applications are presented. (Received September 13, 2018)

1145-91-746 **Nitya Mani***, nityam@stanford.edu, and **Rajiv Nelakanti**, **Simon Rubinstein-Salzedo** and **Alex Tholen**. *$\mathcal{P}$-Play in Candy Nim.*

Candy Nim is a variant of Nim in which both players aim to take the last candy in a game of Nim, with the added simultaneous secondary goal of taking as many candies as possible. We give bounds on the number of candies the first and second players obtain in 3-pile $\mathcal{P}$ positions as well as strategies that are provably optimal for some families of such games. We also show how to construct a game with N candies such that the loser takes the largest possible number of candies and bound the number of candies the winner can take in an arbitrary $\mathcal{P}$ position with N total candies. (Received September 13, 2018)

1145-91-756 **Scott Duke Kominers*** (kominers@fas.harvard.edu). *Respect for Improvements and Comparative Statics in Matching Markets.*

One of the oldest results in the theory of two-sided matching is the *entry comparative static*, which shows that under the Gale–Shapley deferred acceptance mechanism, adding a new agent to one side of the market makes all the agents on the other side better off. Here, we give a new proof of the entry comparative static, by way of a well-known property of deferred acceptance called *respect for improvements*. Our argument extends to yield comparative static results in more general settings, including the matching with contracts framework. (Received September 14, 2018)

1145-91-898 **Jan Rychtar*** (rychtar@uncg.edu), **Shan Sun** and **Michael Leshowitz**. *The signalling game between plants and pollinators.*

Plants can send floral signals to advertise their reward for pollinators. Based on the presence or absents of such signals, pollinators can determine whether to visit plants. Plants can send dishonest signals but foraging behaviors of pollinators can limit such cheating. We model the plant-pollinator interactions by the two-type Spence signalling game and investigate the conditions under which honest signalling can be established. In our model, plants either send costly signal or they do not. The cost of signal is dependent on the quality of plant. Pollinators can learn from the interactions with plants and can update their willingness to visit plants' flowers to maximize their foraging efficiency. We find three general conditions that are required for the evolutionary stability of honest signaling. Those conditions are satisfied if there is (a) a high frequency of high-yield signalling plants in the population, (b) the balance between cost and benefit of signalling, and (c) high cost of dishonest signalling. Our model also predicts that other factors contributing to the establishment of honest signaling are the low abundance of pollinators, and the positive density-dependent and positive frequency-dependent relationship between plants and pollinators. (Received September 17, 2018)

1145-91-1316 **Alexander Munson***, 329 East King St. (2nd Floor), Chambersburg, PA 17201. *Order in chaos - decentralized hedging, BTW sand piles, and directed self-organized criticality, an explanatory mathematical model for causally connected defaults in the derivative market.* Preliminary report.

We consider a quantitative mechanism that describes the rate of default in a finite, partially connected system of rational actors. The mechanism, supported by a simple but rarely used frequency distribution, displays both sudden nonlinear growth and decentralization of distributional probabilities. We examine the mechanism both in its probability density function and in its applications and implications in the derivative market. (Received September 20, 2018)

1145-91-1333 **Kelly A Rooker*** (kelly.rooker@jhuapl.edu). *Donald Trump vs. Kim Jong-Un: Can Game Theory Help Explain Their Nuclear Relationship?* Preliminary report.

In August 2018, the Johns Hopkins University Applied Physics Laboratory (JHU/APL) and the United States Department of State organized and hosted a workshop, meant to address the general question, "Is game theory useful to policymakers in the modern age?" In particular, this workshop focused on the current North Korean nuclear crisis. It brought together over 40 people, including officials from the U.S. Department of State, U.S. Department of Defense, and prominent game theorists and nuclear deterrence experts from across the country. First, I will show how the rhetoric of Donald Trump and Kim Jong-Un can be viewed as a 2-person game. Then, I will highlight previous work which has applied game theory to the North Korean nuclear crisis. Finally, I will conclude with insights gained from this workshop. Among other things, these insights will address collaboration between academics and policymakers, the potential utility of applying game theory to the North Korean nuclear crisis, where game theoretic methods can be most successful, and where game theory methods often fail. (Received September 21, 2018)

1145-91-1509 **Ben G Fitzpatrick*** (bfitzpatrick@lmu.edu), 1 LMU Drive, UH 2700, Los Angeles, CA 90045. *Optimization and Games for Environmental Federalism.*

Federalism in economics is the study of regulatory hierarchies, usually involving local, state, and federal governments. When a single resource or population ranges over multiple political entities, regulation becomes a multi-player decision problem. Determining the "best" policy can be difficult when decision makers have competing objectives.

We examine problems of federal versus local policymaking with a simple 2-patch model of a biological pest species that regulators seek to control. Regulators can invest effort in either harvesting the species infesting the patch they control or preventing the species from entering from the neighboring patch. Federal control will seek to minimize total cost of controlling the species across both domains, but independent local regulators may choose a number of possible options. We apply dynamic programming and Markov chain approximation techniques to examine different control and game approaches to this pest control problem. (Received September 22, 2018)

1145-91-1543 **Gopinath Panda*** (gopinath.panda@gmail.com), Pillar of Engineering Systems and Design, Singapore University of Technology and Design, Singapore. *Effect of information on the social efficiency of a service system in the presence of strategic customers.*

In this work, we study strategic behavior of customers in a single server Markovian queueing system with infinite buffer. Customers with respect to their acquired information are divided into two classes: informed and uninformed. The system manager reveals information about the number of customers present in the system and the state of the server to customers. Informed customers have full information about the system state and take decision whether to join or to balk the system upon arrival, whereas uninformed customers do not have system state information and decide to join the system with certain probability. Customers are charged a cost per unit time of their waiting in the system and receive a reward after service completion. Customers always try to increase their own benefit by making decisions at their arrival instant and the manager tries to maximize the social welfare by controlling the information level. We are interested to study the individual and social behavior of customers under equilibrium of this game. The effects of information level on customers' equilibrium and socially optimal balking strategies will be studied. Finally, several numerical results will be presented to exemplify the impact of queueing parameters on the customers' strategic behavior. (Received September 23, 2018)

1145-91-1624 **Maxim Bichuch** and **Ke Chen*** (kchen78@jhu.edu). *Systemic Risk: the Effect of Market Confidence.* Preliminary report.

In a crisis, when faced with insolvency, banks can issue shares/sell their treasury stock in the stock market and borrow money in order to raise funds. We propose a simple model to find the maximum amount of new funds the banks can raise in this way. To do this we incorporate market confidence of the bank together with market confidence of all the other banks into the overnight borrowing rate. Additionally, for a given cash shortfall, we find the optimal mix of borrowing and stock selling. We show the existence and uniqueness of Nash equilibrium strategy for all these problems. We then calibrate this model to market data and conduct an empirical study to access whether the current financial system is safer than it was before the last financial crisis. (Received September 24, 2018)

1145-91-1625 **Carey Caginalp*** (carey_caginalp@alumni.brown.edu). *A Dynamical Systems Approach to Cryptocurrency.*

Recently, assets known as cryptocurrencies have come to the fore of public interest. Despite the fact that they have no underlying value, they have seen a market capitalization that is an increasing fraction of the world economy. I model these assets from the perspective of asset flow equations developed by Caginalp and Balenovich, and investigate the key question of stability. I will illuminate the role of different factors such as types of investor sentiment and liquidity through several versions of the model. I will also describe how one introduces multiple timescales to more closely match real-life scenarios whereby market participants often react more quickly to certain pieces of information than others. (Received September 23, 2018)

1145-91-1743 **Xingru Chen***, 27 N. Main Street, 6188 Kemeny Hall, Hanover, NH 03755, and **Feng Fu**. *Temporal and topological patterns of reposting dynamics reveal online influence inflation in social media.*

We study structural and temporal features driven by online influence manipulation using a massive social media repost dataset collected from Weibo (a Chinese microblogging site similar to Twitter). Our analysis shows that the vast majority of shared information goes viral through very shallow diffusion chains, instead of spreading through long information cascades. We identify a handful of intentional boosters who have disproportionate influence and are responsible for influence inflation of the original Weibo post. Along with their sock puppets, these boosters orchestrate high volume reposting within short amount time, leading to pronounced spikes in repost counts. As the reposting network is dynamic and growing, with nodes and edges constantly added into the network, our data-driven stochastic modeling of reposting dynamics takes into account these topological and temporal pattern of reposting behavior in social media. (Received September 24, 2018)

1145-91-1803 **Maxim Bichuch*** (mbichuch@jhu.edu) and **Paolo Guasoni**. *The Learning Premium.*

We find equilibrium stock prices and interest rates in a representative-agent model where dividend growth is uncertain, but gradually revealed by dividends themselves, while asset prices reflect current information and the potential impact of future knowledge. In addition to the usual premium for risk, stock returns include a learning premium, which reflects the expected change in prices from new information. In the long run, the learning premium vanishes, as prices and interest rates converge to their counterparts in the standard setting with known dividend growth. If both relative risk aversion and elasticity of intertemporal substitution are above one, the model reproduces the increase in price-dividend ratios observed in the past century, and implies that – in the long run – price-dividend ratios may increase a further forty percent above current levels. (Received September 24, 2018)

1145-91-1929 **Alexandria Volkening*** (volkening.2@mbi.osu.edu), **Daniel Linder**, **Mason A Porter** and **Grzegorz Rempala**. *Forecasting U.S. elections with compartmental models.* Preliminary report.

Forecasting U.S. elections involves polling likely voters, making assumptions about voter turnout, and accounting for various features such as state demographics and voting history. While political elections in the U.S. are decided at the state level, errors in forecasting are correlated between states. With the goal of better understanding these correlations and shedding light on the election prediction process, we are modeling the evolution of political opinions in recent presidential, senate, and gubernatorial elections. Our compartmental modeling approach borrows ideas from the field of epidemiology, and we base our parameters for how states influence each other on public polling data from HuffPost and RealClearPolitics. Our work suggests a new method to elucidate and study how states are related and illustrates how accounting for uncertainty in different ways impacts election forecasts. (Received September 24, 2018)

1145-91-2000 **Samuel J Ferguson*** (ferguson@cims.nyu.edu), Courant Institute of Mathematical Sciences, 251 Mercer St, New York, NY 10012. *Obamacare Proofs Give More Healthcare: Ditching and Replacing the IRS Fixed-Point Iteration.*

Time magazine's film crew posted a video in April about a mathematician who got Obamacare for more Americans by proving a theorem. What's the story? Last winter, he took an Uber ride. His driver was eligible for Obamacare money, but tax software said he wasn't! How was this possible? IRS guidance asks self-employed Obamacare beneficiaries to calculate their Obamacare money as the limit of a sequence

$$s_1, s_2, s_3, \ldots$$

obtained via a fixed-point iteration. When the sequence diverges, beneficiaries accept at most

$$\liminf_{n\to\infty} s_n$$

as their Obamacare money, but this is too small, and often \$0; tax software and government calculators give this amount, or less. The IRS says *any* legal method may be used to find the right amount, though, so we introduce a new bisection procedure, and prove that it always gives the appropriate Obamacare subsidy. Some Americans now use this method to receive thousands of dollars of Obamacare money each, instead of using the IRS fixed-point iteration to receive nothing. The video on this adventure is at: http://time.com/money/5237795/irs-tax-problem-obamacare-subsidy/ (Received September 25, 2018)

1145-91-2088 **Andrew Lazowski***, 5151 Park Ave., Fairfield, CT 06825. *Combining plurality and alternative voting.*

We will review the voting procedures of plurality and alternative vote (AV). After describing the shortcomings of each we discuss a new voting procedure that combines the two. For three candidate elections we will explain how this procedure has its own shortcomings, however it has advantages over both plurality and AV alone which make it attractive. (Received September 24, 2018)

1145-91-2212 **Vince Nicolas Salas Campo*** (vincecampo1@gmail.com), University Dr., Mangilao, GU 96923, **John Lawrence Palacios** (johnlawrencepalacios@gmail.com), University Dr., Mangilao, GU 96923, **Hideo Nagahashi PhD.** (nagahashi_h@yahoo.com), University Dr., Mangilao, GU 96923, **Hyunju Oh Ph.D** (ohh@triton.uog.edu), University Dr, Mangilao, 96923, and **JaeYong Choi** (choij@triton.uog.edu), University Dr., Mangilao, GU 96923. *Dog Vaccination and Quarantine: A Mathematical Approach on Rabies.*

China, the world's second leading country in Rabies, is an area of interest when analyzing the lethal disease. Rabies, also known as Lyssavirus, is almost 100 percent lethal when fully incubated within the body, and attacks the immune system. By utilizing Game Theory the presentation offers a strategy for individual dog owners to take when considering the relative cost. The research defines a relationship on cost, for individuals to weigh the ratio between the cost of the disease, and the cost of the prevention. We analyze the sensitivity between the cost and the disease, and find that even a small change within the cost of the vaccine or quarantine will lead to a decrease in willingness to take these actions. The research finds that the vaccination is a more cost efficient method of combating the disease when comparing it to quarantine. When in the situation that both preventative actions are present, we find that vaccination is almost purely dominant since the relative cost of the vaccination is less than that of quarantine. (Received September 25, 2018)

1145-91-2244 **Xuan Xu** (xu-x16@mails.tsinghua.edu.cn), Room 112B, Zijing 12 Building, Tsinghua University, Haidian District, Beijing, 100084, and **Yifan Wu*** (201511130106@mail.bnu.edu.cn). *Credit Risk Valuation Based on Machine Learning.*

An ideal credit risk evaluation model will accurately reflect the actual financial status of enterprises, which can offer a reasonable reference for financial firms in decision-making. Traditional credit grading systems are usually using linear combinations of several indexes or Black-Scholes formula based on stochastic process, weighted by empirical constants, such as Z and Zeta Models or KMV model; there was no good explanation about why those indexes, distribution and constants were made. In this research, by nonparametric machine learning methods, we provide evaluation algorithms, which iterate successively until reach a stable state, thus explain their rationality. First, we do not assume any index to be superior, while using logistic regression, hybrid genetic algorithm, recurrent neural networks and support vector regression, we may find the best indexes and weights to provide a reliable approximation of the single index of current ratio, which has its own inevitable inaccuracy and is easy to make fraud; then use normal distribution function to convert the result into probability scale. We believe that our model will outperform current models. (Received September 25, 2018)

1145-91-2298 **Mathias S Kruttli** (mathias.s.kruttli@frb.gov), **Phillip J Monin*** (phillip.monin@ofr.treasury.gov) and **Sumudu W Watugala** (sumudu@cornell.edu). *Prime Broker Lending and Hedge Fund Exposures.* Preliminary report.

Events surrounding the collapse of Lehman Brothers illustrate the importance of managing prime broker counterparty risks for hedge funds. The central intermediary role played by prime brokers and hedge funds in financial markets also makes understanding their credit relationships a financial stability concern. We analyze the credit exposures between prime brokers and hedge funds using confidential regulatory lings from 2012 to 2017. The hedge fund-prime broker credit network exhibits a core-periphery structure. The average hedge fund diversifies its borrowing across three prime brokers. Liquidity shocks to a prime broker are passed through to connected hedge funds and result in reduced aggregate borrowing by these hedge funds. Large, well-connected and better-performing hedge funds and those that do less OTC trading are able to compensate for this loss by borrowing from other prime brokers. (Received September 25, 2018)

1145-91-2388 **Emmanuel M Estrada*** (emmanuel.m.estrada@gmail.com), 4912 Summit Way, Modesto, CA 95357. *Adaptive Zero Determinant Strategies in the Iterated Prisoner's Dilemma Tournament.* Preliminary report.

We have created an adaptive zero determinant strategy that changes its parameters using the outcome of the last round as input. We then ran this adaptive zero determinant strategy against a tournament of other zero determinant strategies. We observed that the adaptive strategy had a higher average score than the other zero determinant strategies when we ran the tournament for a large amount of rounds. (Received September 25, 2018)

1145-91-2478 **Carmen A Iasiello*** (ciasiell@masonlive.gmu.edu). *Uses of Agent Based Modeling for Social Science Hypothesis Development.*

When using agent based modeling (ABM), the model may act as either the theory being tested or the evidence. When the theory being examined is the computational model, there is a natural tension between attempts to falsify the theory in pursuit of proper science and bringing about practical application of the model as an evidentiary basis. In this session, I will present the benefits of using ABM in the hypothesis development phase, to improve the overall experimentation phase in a given social science experiment. I will argue for ABM as a uniquely useful tool in moving between the inductive and deductive processes, and present three brief examples of ABM use in hypothesis development in archeology, economics, and psychology. In archeology, I present how ABM allows for identification of socio-politically relevant hypotheses to explain the gap between the demise of the late Neolithic era and rise of the early state in East Asia. In economics, I demonstrate the use of ABM in examining the Hollywood labor system, and developing hypotheses for sufficiently explaining the phenomena of Hollywood racial minority underrepresentation. Finally, in psychology, I demonstrate the use of ABM in development of hypotheses of workplace incentive and disincentive frameworks. (Received September 25, 2018)

1145-91-2520 **Daewa Kim*** (daewakim@math.uh.edu), 3551 Cullen Blvd., Room 641, Philip Guthrie Hoffman Hall, Houston, TX 77204, and **Annalisa Quaini**. *A Kinetic Theory Approach to Pedestrian Motion.* Preliminary report.

We present a kinetic theory approach to model pedestrian dynamics. This approach models the dynamics caused by the interactions of pedestrians with other pedestrians as well as with the boundary of the domain. Four factors are taken into account: (1) the pedestrian's goal (e.g., to reach an exit), (2) the desire to avoid collisions with the

walls, (3) the tendency to look for less congested areas, and (4) the tendency to follow the stream unconsciously in a panic situation. Thanks to this approach, we simulate evacuation from a room under several different conditions. We analyze the role of the exit size and devise a strategy to handle obstacles within the domain. Moreover, we consider different numbers of pedestrians evacuating the room with two exits in order to compare with experimental data. In the end, we see the bidirectional motion in a straight periodic corridor to compare the numerical results with the experimental data. (Received September 25, 2018)

1145-91-2598 **Timmy Ma*** (timmy.ma@dartmouth.edu). *Object-Label-Order effect in a noisy learning environment.*

As we begin to understand more about symbolic learning, we are inclined to introduce layers of complexity to represent how our minds are able to process information and communicate to the world. We discuss how learners are able to differentiate and predict a label from objects or features and to predict features from a label. The differences between the two processes is known as the Object-Label-Order effect. We present a stochastic model to study the effects of the Object-Label-Order effect when noise elements are introduced into a learning environment. We report a novel experiment trial with human subjects and confirm with our model that there is a Object-Label-Order effect when introducing noise. We demonstrate the key differences between the two different type of learners from our model, showing that Object-Label learners exhibit a frequency boosting (regularization) property and are better equipped to process noise, whereas Label-Object learners lack this ability. We discuss the implications of our findings to the nature of language learning and its importance to symbolic learning.
(Received September 25, 2018)

1145-91-2647 **Amit Patel***, 100 Morrissey Blvd, McCormack Hall 3-425, Boston, MA 02125, and **Naoru Koizumi**, **Brian Wilson** and **Namesh Killemsetty**. *Agent-based Modeling as Policy support Tool for Emergent Social Systems: Case Studies in Informal Markets for Housing and Organs.*

We model emergent social systems using agent-based modeling in two distinct markets where informality is a norm rather than exception. First is the case of emergence of slums in cities of the global South and the second is the case of emergence of illicit trade networks for human organs. Both slums in cities and organ trade networks are known to be complex systems that emerge from human behavior of multiple types of agents. In both models, informal systems emerge as a result of human-human and human-environment interactions between relevant agents and the social and spatial environments within which they are embedded. The purpose of our models named Slumulation (in the case of slums) and OrganSIM (in the case of illicit organ trade networks) is to provide a laboratory to test several policy ideas in a simulated environment to study their impacts ex-ante. This research develops analytical frameworks to examine structural patterns and evolution of slums in cities and organ trafficking networks internationally. (Received September 25, 2018)

1145-91-2668 **Napoleon Martin*** (nmartin2@student.savannahstate.edu), 3219 College St., Department of Mathematics, Savannah, GA 31404, and **Hyounkyun Oh**. *A price-decision and order-making mechanism for a retail beverage store during sales dealer's promotion period.*

This research explores a price-decision and order-making mechanism for various sizes bottles of the same brand beverage during an intermediate sales dealer's promotion event. Considering the price elasticity on demand (PED) in liquor from other literature, and particular sale circumstances of the store, such as the effect of advertisement and high density of similar stores, a mathematical model is constructed on the tracked sales data. Then optimization techniques are employed to realize the maximum profits in two options: 1) Applying the dealer's promotion benefit to only one kind of product 2) Applying the benefit to all kinds of products. In each case the optimal selling price, profits, volume of order, as well as best time to place order again, are delivered, and hence the resultant information can increase a store operation efficiency. Although the mechanism is constructed focusing only on one store, the developed whole structure can be applied immediately to other stores as well.
(Received September 25, 2018)

92 ► *Biology and other natural sciences*

1145-92-21 **Suncica Canic*** (canics@berkeley.edu). *Development of Mathematical Methods for Next Generation Stent Design.*

Over the past 30 years, non-surgical, percutaneous coronary interventions with stent implantation transformed the practice of cardiology. Before the introduction of drug eluting stents (DES), bare metal stents (BMS) were

the only choice. DES have led to a significant reduction in in-stent restenosis rates, one of the major limitations of BMS. There is an on-going effort to continue to improve the current generation stents with thinner struts, lesion-dependent geometric designs for complicated lesions, better biocompatible polymer use for coating, biodegradable polymer, or polymer-free stents with porous-metal coating or nanoparticle-mediated drug delivery systems. In this talk we will review the stateof-the-art mathematical methods and models that are being developed to guide the next generation stent design. The methodology includes nonlinear movingboundary problems to study fluid-structure interaction between implanted stents, blood flow, and coronary artery elastodynamics, novel poroelastic, composite structural models to study drug diffusion and chemical reaction with vascular tissue, hyperbolic PDE models defined on graphs to study optimal geometric stent design, and Smoothed-Particle Hydrodynamics approaches to study nanoparticle-mediated drug delivery systems. (Received August 17, 2018)

1145-92-87 **David M. Chan** and **Candace M. Kent*** (cmkent@vcu.edu), 3510 Hanover Avenue, Richmond, VA 23221, and **Vlajko L. Kocic** and **Stevo Stevic**. *A Proposal for an Application of a Max-Type Difference Equation to Epilepsy.*

We propose, *for the sake of dialogue*, that the nonautonomous reciprocal max-type difference equation,

$$x_{n+1} = \max\left\{\frac{A_n^{(0)}}{x_n}, \frac{A_n^{(1)}}{x_{n-1}}, \dots \frac{A_n^{(k)}}{x_{n-k}}\right\}, \quad n = 0, 1, \dots,$$

where the parameters are positive periodic sequences and the initial conditions are positive, when $k = 1$ may serve as a *phenomenological model* of seizure activity as occurs in *mesial (or middle) temporal lobe epilepsy.* (Received July 26, 2018)

1145-92-121 **Marcella M Torres*** (torresmm@vcu.edu), **Angela Reynolds**, **Rebecca Segal** and **Shobha Ghosh**. *Parameter estimation and predictive modeling in a model of peritonitis focusing on the sequential immune cell response.*

Macrophages can be activated to a more inflammatory M1 phenotype or to an M2-like phenotype which promotes the resolution of inflammation. Problems with this phenotypic switch can result in a population imbalance that leads to chronic wounds or disease, and therapeutic interventions that target macrophages have been proposed and implemented in diseases that feature chronic inflammation such as diabetes mellitus and atherosclerosis. We have developed a model for the sequential influx of immune cells in the peritoneal cavity in response to a bacterial stimulus that includes macrophage polarization - the first of its kind to be fit to experimental data. With this model we are able to reproduce the expected timing of sequential influx of immune cells and mediators in a general inflammatory setting. Weighted least squares parameter estimates were obtained using trust region optimization in logarithmic parameter space. We then explored local structural and practical identifiability of the proposed model a posteriori, and obtained an identifiable subset of parameters that allows for simulation of proposed therapies. (Received August 03, 2018)

1145-92-163 **Rocio Marilyn Caja Rivera*** (rcajariv@nd.edu), 100 Galvin Life Science Center, Notre Dame, IN 46556. *Vector Feeding Preference in a Periodic Environment: Modeling The Andean Cutaneous Leishmaniasis in Peru.*

Vector-borne diseases, such as leishmaniasis, dengue, yellow fever transmitted by microparasites show periodic fluctuations in their transmission dynamic. The novelty in this research is about that the presence of vector feeding preference for infectious host causes a periodic environment. Parameters for the Andean cutaneous leishmaniasis in Peru are estimated. Numerical simulations illustrate that by increasing the vector feeding preference value in a periodic environment, the oscillations are accentuated and the endemic equilibrium average increases in sandfly and human populations. While increasing the vector feeding preference value, the amplitude increases for infectious human and sandfly populations. This periodic behavior shows a similar pattern with the Peruvian incidence data from 2000 to 2016 for Andean cutaneous leishmaniasis provided by the Ministry of Health of Peru. Using the Floquet theory, the time average method and the linear operator method provides for first time that $\mathcal{R}_0$ depends explicitly on the vector feeding preference for infectious host. Vector feeding preference is an important factor that should be considered by public health and veterinarian health for vector management control. (Received August 13, 2018)

1145-92-175 **Daniel B Cooney***, Program in Applied and Computational Math, Fine Hall, Washington Road, Floor 2, Princeton, NJ 08540. *The Replicator Dynamics for Multilevel Selection in Evolutionary Games.*

We consider a stochastic model for evolution of group-structured populations in which selection operates at two organization levels: individuals compete with individuals in their group, while groups compete with other groups. Payoff is obtained from the Prisoner's Dilemma or the Hawk-Dove game. In the limit of infinite population size, we derive a non-local PDE describing the probability distribution of groups in the population. We characterize the long-time behavior of our system, with an emphasis on understanding the most frequent group compositions at steady state.

When average payoff of groups is maximized by all-cooperator groups, steady state composition ranges from all-defector groups when individual-level selection dominates to all-cooperator groups when group-level selection dominates. When group payoff is maximized by a mix of cooperators and defectors, then the steady state features a fewer cooperators than required for the mix optimizing group payoff, even in the limit where group-level selection is infinitely stronger than individual-level selection. In such cases, the conflict between the two levels of selection cannot be decoupled, and cooperation cannot be sustained at all when between-group competition favors perfect coexistence of cooperators and defectors. (Received August 15, 2018)

1145-92-238 **Marissa Renardy*** (renardy@umich.edu), **Jill Gallaher**, **Diana White**, **Nessy Tania**, **Blerta Shtylla**, **Helen Moore**, **Karen Wood**, **Kamila Larripa** and **Urszula Ledzewicz**. *Modeling Tumor Immune Dynamics in Multiple Myeloma.*

We propose a mathematical model that describes the dynamics of multiple myeloma and three distinct populations of the innate and adaptive immune system: cytotoxic T cells, natural killer cells, and regulatory T cells. The model includes significant biologically- and therapeutically-relevant pathways for inhibitory and stimulatory interactions between these populations. We focus on five main aspects: 1) obtaining and justifying parameter ranges and point estimates; 2) determining which parameters the model is most sensitive to; 3) determining which of the sensitive parameters could be uniquely estimated given various types of data; 4) exploring the model and updated parameter estimates numerically; and 5) analytically exploring the equilibria and stability of a reduced model. Using multiple sensitivity analysis techniques, we found that the model is generally most sensitive to parameters directly associated with M protein levels. This analysis provides the foundation for a future ultimate application of the model: prediction of optimal combination regimens in patients with multiple myeloma. (Received August 23, 2018)

1145-92-312 **Huseyin Coskun*** (hcoskun@uga.edu), Department of Mathematics, University of Georgia, Athens, GA 30602. *Dynamic Ecological System Analysis.*

In this article, a new mathematical method for dynamic analysis of nonlinear compartmental systems is developed in the context of ecology. It is based on novel dynamic system and subsystem partitioning methodologies through which compartmental systems are completely decomposed to the utmost level, meaning that dynamic distribution and organization of all environmental and intercompartmental system flows and storages are determined individually and separately. The system flows and storages transmitted directly or indirectly between any two compartments or along a given flow path are analytically characterized, systematically classified, and mathematically formulated. The proposed methodology is a comprehensive approach in the sense that the proposed measures and major flow- and stock-related results of ecological mathematics are combined and integrated coherently in a novel and unifying mathematical framework and corresponding concepts and quantities are further extended from static to nonlinear dynamic settings. This unifying framework enables a holistic view and analysis of ecological systems. (Received August 30, 2018)

1145-92-347 **Suzanne Lenhart*** (slenhart@math.utk.edu), University of Tennessee, Department of Mathematics, Knoxville, TN 37996. *Assessing the Economic Tradeoffs Between Prevention and Suppression of Forest Fires.*

Optimal control theory is applied to a model of managing fire events incorporating the economic impacts. The number of large-scale, high-severity forest fires occurring is increasing, as is the cost to suppress these fires. We incorporate the stochasticity of the time of a forest fire into our model and explore the tradeoffs between prevention management spending and suppression spending. The problem is converted to a optimal control problem for ordinary differential equations by taking the expectation of the objective functional with respect to the random variable for a fire event. (Received September 03, 2018)

1145-92-348 **Suzanne Lenhart*** (slenhart@utk.edu), University of Tennessee, Department of Mathematics, Knoxville, TN 37996. *Optimal control of vaccination in a vector-borne reaction-diffusion model applied to Zika virus.* Preliminary report.

Optimal control theory of parabolic partial differential equations is used to choose vaccine distribution. A PDE system represents Zika virus disease spreading across a state in Brazil; the control depending on space and time is a vaccination rate. Data from reported cases in a state in Brazil in 2015 were used to estimate parameters. Simulation results will be shown. (Received September 03, 2018)

1145-92-405 **David Chan*** (dmchan@vcu.edu), 1015 Floyd Avenue, Richmond, VA 23284, and **Ben Ramage**, **Matthew Mills** and **John Atwood**. *The interaction of disturbances and conspecific inhibition and their effect on biodiversity in forests.* Preliminary report.

Two critical drivers of forest diversity are disturbance and conspecific inhibition. Disturbances are discrete events that kill or remove biomass such as hurricanes, fires, and timber harvest. Conspecific inhibition is defined as a reduction in performance when same species densities are high. While the importance of both of these phenomena has been recognized, they have rarely been considered simultaneously. There is evidence that suggests disturbance likely alters the strength of conspecific inhibition, and that complex interactions between disturbance and conspecific inhibition may drive diversity. Here we present simulation results of these interactions and show their effect on species diversity. (Received September 05, 2018)

1145-92-414 **Nicholas Randolph*** (nzrandol@ncsu.edu), 2110 Avent Ferry Rd, Unit 461, Raleigh, NC 27607, **E Benjamin Randall** (ebrandal@ncsu.edu), 3745 Yorktown Pl, Raleigh, NC 27609, and **Mette Olufsen**. *Global sensitivity analysis and model selection of a neurological control model.*

Mathematical model selection is an integral phase of the model development timeline, relying on numerous techniques and validation methods. Within this talk, I will discuss the implications of global sensitivity analysis and its role in model selection, highlighting two methods in particular - Sobol' indices and Morris Screening. The use of these methods will then be discussed in light of a neurological model based on the physiological response to the Valsalva maneuver. Specific selection criteria and an overview of the tests performed on this model will be outlined. Results will be interpreted through the lens of model selection, focusing on the necessity of (i) distinguishing between the aortic and carotid components and (ii) the discrete sympathetic delay. (Received September 05, 2018)

1145-92-466 **Yunshyong Chow** (chow@math.sinica.edu.tw), Taipei, Taiwan, **Sophia Jang*** (sophia.jang@ttu.edu), Lubbock, TX , and **Hua-Ming Wang** (hmking@mail.ahnu.edu.cn), Wuhu, 241000, Peoples Rep of China. *Cooperative hunting in a discrete predator-prey system.*

In this talk, we introduce a discrete-time predator-prey system with cooperative hunting in the predators, constructed from the classical Nicholson-Bailey host-parasitoid system with density dependent prey growth rate. A sufficient condition based on the model parameters for which both populations can coexist is derived, namely that the predator's maximal reproductive number exceeds one. We study existence of interior steady states and their stability. It is shown that the system behaves asymptotically similar to the model with no cooperative hunting if the degree of cooperation is small. Large cooperative hunting, however, may promote persistence of the predator, for which the predator would otherwise go extinct if there were no cooperation. (Received September 06, 2018)

1145-92-498 **Ibrahim Halil Aslan*** (iaslan@vols.utk.edu), 1516 GreenBrier Ridge Way, Knoxville, TN 37909. *Impulse model of Leptospirosis in Cattle.* Preliminary report.

As one of the most widespread zoonotic disease, Leptospirosis became endemic particularly in tropical and subtropical regions where the environment provides favorable conditions for propagation of the disease. It causes a large economic loss in the livestock industry. In this talk, we introduce an SVIR dynamical system of ordinary differential equations with impulse actions of vaccination at certain times in order to investigate whether the disease can be controlled with current vaccine schedules. Some analytical and numerical results will be presented. (Received September 07, 2018)

1145-92-516 **M. Ulmer** (mju9999@gmail.com), **Lori Ziegelmeier** (lziegel1@macalester.edu) and **Chad M. Topaz*** (cmt6@williams.edu). *Using topological data analysis to assess biological models.*

We use topological data analysis as a tool to analyze the fit of mathematical models to experimental data. This study is built on data obtained from experiments that motion tracked groups of aphids and from two random walk models that were proposed to describe the data [Nilsen et al., PLOS One, 2013]. One model incorporates social interactions between the insects, and the second model is a control model which excludes these interactions. We use computational persistent homology to calculate topological signatures of the experimental data and of the models. Statistical tests on the distances between these topological signatures suggest that the interactive model better describes the data, whereas traditional order parameters used to summarize the experiments give mixed results. (Received September 08, 2018)

1145-92-525 **Vanessa Rivera-Quinones*** (riveraq2@illinois.edu), 308 North Orchard Street Apt.15, Urbana, IL 61801-2563, and **Tara Stewart**, **Zoi Rapti** and **Carla Caceres**. *The Role of Recovery in Daphnia Epidemics.* Preliminary report.

Age of infection has been shown to influence host fecundity and mortality through parasite virulence. Specifically, in many systems, mortality increases, while fecundity decreases as the disease progresses. Furthermore, the ability of the infected host to recover may also depend on the age of infection. These changes, in turn, affect the between-host transmission. To investigate how these mechanisms affect disease transmission, we focus on the zooplankton host *Daphnia dentifera* commonly known as "water flea", which experiences epidemics by the virulent fungus *Metschnikowia bicuspidata*. Using a partial differential equation formulation, we explicitly model disease induced mortality and recovery as functions of the age of infection and investigate how epidemiologically relevant quantities such as disease prevalence and the basic reproductive number R_0 depend on them. (Received September 08, 2018)

1145-92-532 **Mondal Hasan Zahid*** (mdmondal.zahid@mavs.uta.edu) and **Christopher Kribs** (kribs@mathed.uta.edu). *Decoys and dilution: the impact of incompetent hosts on prevalence of Chagas disease.*

Biodiversity is commonly believed to reduce risk of vector-borne zoonoses. This study focuses on the effect of biodiversity, specifically on the effect of the decoy process (additional hosts distracting vectors from their focal host), on reducing infections of vector-borne diseases in humans. Here, we consider a specific case of Chagas disease and try to observe the impact of the proximity of chickens, which are incompetent hosts for the parasite but serve as a preferred food source for vectors. We consider three cases as the distance between the two host populations varies: short (when farmers bring chickens inside the home to protect them from predators), intermediate (close enough for vectors with one host to detect the presence of the other host type), and far (separate enclosed buildings such as a home and hen-house). Our analysis shows that the presence of chickens reduces parasite prevalence in humans only at an intermediate distance and under the condition that the vector birth rate associated with chickens falls below a threshold value, which is relative to the vector birth rate associated with humans and inversely proportional to the infection rate among humans. (Received September 23, 2018)

1145-92-576 **Scott Greenhalgh*** (sgreenhalgh@siena.edu), 515 Loudon Road, Loudonville, NY 12211, and **Veda Chandwani**. *Reducing severe malaria incidence with gut microbiota.*

Malaria is a major burden on the general health and economic wellbeing of Sub Saharan Africa. Sub Saharan Africa endures the highest malaria incidence in the world, with cases ranging from 130 to 266 million per year, and annual costs of at least 3.9 billion. A disproportionate amount of these incidences and costs are attributed to severe malaria in children. The reason for this is children generally have no prior immunity to malaria infection, and thus are far more likely to endure anemia, cerebral, and neurological side-effects. Consequently, interventions that reduce the occurrence of severe malaria are in desperate need. One potential intervention is gut microbiota. To elaborate, recent clinical studies have shown that gut microbiota have ability to mitigate the severity of malaria, which suggests the roll out of a dried yogurt (containing the microbiota) would dramatically reduce severe malaria incidence. However, the health benefit and cost-effectiveness of such an intervention at the population level has yet to be evaluated under the malaria transmission intensities occurring in Sub Saharan Africa. Here, we evaluate the roll out of such a gut microbiota intervention to gauge its benefit in reducing severe malaria incidence through the use of mathematical modeling. (Received September 10, 2018)

1145-92-584 **Najat Ziyadi*** (najat.ziyadi@morgan.edu), Morgan State University, 1700 East Cold Spring Lane, Baltimore, MD 21251, and **Abdul-Aziz Yakubu**. *A Discrete-Time Anthrax Model In Human and Herbivore Populations.*

In this talk, we will introduce a discrete-time anthrax disease model in human and herbivore populations, where the herbivore recruitment function is the classic Beverton-Holt model while that of humans is a constant recruitment function. We will use the next generation method to compute the basic reproduction numbers for the submodels consisting of only herbivores (R_0^A) and only humans (R_0^H). In addition, we will compute it for the full human-herbivore model (R_0^{AH}). When $R_0^A < 1$ or $R_0^H < 1$ or $R_0^A H < 1$, the number of anthrax infections decreases and the disease does not invade the corresponding population. Whereas, the number of anthrax infections increases and the disease invades the corresponding population when $R_0^A > 1$ or $R_0^H > 1$ or $R_0^{AH} > 1$. Our simulations will show that it is possible for the anthrax disease to invade a human-herbivore population where the disease does not invade either herbivores or humans in isolation. (Received September 10, 2018)

1145-92-604 **Allison Torsey*** (allison.torsey@gmail.com), **Amy Carpenter** and **Julia Arciero**. *Analyzing the Dynamics of an Inflammatory Response to a Bacterial Infection in Rats.*

Sepsis is a serious health condition defined by an overactive immune response that causes severe damage to healthy tissue, often resulting in death. Mathematical modeling has emerged as a useful tool to investigate key elements of the immune response and thus offers a useful method for studying sepsis. Here, a system of four ordinary differential equations is developed to simulate the dynamics of bacteria, the pro-inflammatory immune response, anti-inflammatory immune response, and tissue damage. The model is used to assess the conditions under which health, aseptic (inflammation-driven) death, or septic (bacteria-driven) death is predicted in both the presence and absence of an induced E. Coli bacterial infection in rats. Model parameters are fit to experimental data from rat sepsis studies. The model is used to predict the survivability range for an infection while varying the initial amount, growth rate, or virulence of the bacteria in the system. For highly virulent strains of bacteria, aseptic or septic death is predicted for very small levels of initial bacterial loads. Model predictions are also used to explain the experimentally observed variability in the mortality rates among rats. (Received September 11, 2018)

1145-92-616 **Jana Gevertz*** (gevertz@tcnj.edu). *Robust optimization of cancer immunotherapy.*

Mathematical models of biological systems are often validated by fitting the model to the average of an often small experimental dataset. Here we ask the question of whether predictions made from a model fit to the average of a dataset are actually applicable in samples that deviate from the average. We will explore this in the context of a mouse model of melanoma treated with two forms of immunotherapy. We have hierarchically developed a system of ordinary differential equations to describe the average of this experimental data, and optimized treatment subject to clinical constraints. Using a virtual population method, we explore the robustness of treatment response to the predicted optimal protocol; that is, we quantify the extent to which the optimal treatment protocol elicits the same qualitative response across virtual populations. We find that our predicted optimal is not robust and in fact is potentially a dangerous protocol for a fraction of the virtual populations. However, if we consider a different drug dose than used in the experiments, we are able to identify an optimal protocol that elicits a robust anti-tumor response across virtual populations. This is joint work with Eduardo Sontag (Northeastern University) and Michael Ochs (The College of New Jersey). (Received September 11, 2018)

1145-92-632 **Brian R Powers*** (brpowers@asu.edu), College of Integrative Sciences and Arts, Arizona State University, 7271 E Sonoran Arroyo Mall, Mesa, AZ 85212-6415, and **Xuetao Lu** and **Steven Saul**. *Avoiding Surprises: Understanding the Impact of the Deepwater Horizon Oil Spill on the Decisions of Fishers and the Management of Fisheries in the Gulf of Mexico using an Agent-Based Moel.* Preliminary report.

Fisher decision making can influence the effectiveness of management measures and dictates the spatial and temporal locations of fishery-dependent observations. In many stock assessments observations from fishers are used to infer the abundance of fish populations. The Deepwater Horizon oil spill disrupted the livelihoods of many fishers causing them to modify their operations (i.e. alter fishing locations, target species, gear used, etc.). This re-tasking had a direct effect on fishing catch and effort in 2010, and perhaps beyond, if modified behaviors were maintained in years subsequent to the spill. Not properly accounting for such changes in fisher behavior and operations can lead to stock assessments and management advise that are incorrect. This project builds on an existing spatially explicit, agent-based bioeconomic model that currently represents some commercial fishery species and the fleets on the West Florida Shelf in the Gulf of Mexico. This project extends the geographical scope of the current model to the entire Gulf of Mexico, to include additional fish species. Data provided by the National Marine Fisheries Service will be used to parameterize the expanded model. (Received September 11, 2018)

1145-92-659 **Leonid Hanin*** (hanin@isu.edu), Department o Mathematics and Statistics, Idaho State University, 921 S 8th Avenue, Stop 8085, Pocatello, ID 83209-8085. *Metastasis Suppression by the Primary Tumor: A Natural Law.*

We study metastatic cancer through an extremely general individual-patient mathematical model that is rooted in the contemporary understanding of the underlying biomedical processes yet is essentially free of specific biological assumptions of mechanistic nature. The model accounts for primary tumor growth and resection, shedding of metastases and their selection, dormancy and growth in a given site. Functional parameters descriptive of these processes are assumed to be essentially arbitrary. In spite of such generality, the model allows for computing the distribution of the sizes of detectable metastases in closed form. Under the assumption of exponential growth of metastases before and after primary tumor resection, we showed that, regardless of other model parameters and for every set of volumes of detected metastases, the likelihood-maximizing scenario is always the same: complete suppression of metastatic growth before primary tumor resection followed by an abrupt growth acceleration after surgery. This scenario is commonly observed in clinical practice and is supported by a wealth of studies conducted over the last 110 years. (Received September 12, 2018)

1145-92-693 **David A Hormuth II**, **Angela M. Jarrett**, **Ernesto A. B. F. Lima**, **Chengyue Wu**, **Ryan Woodall**, **Caleb Phillips** (thomas.yankeelov@utexas.edu) and **Thomas Yankeelov*** (thomas.yankeelov@utexas.edu), 1 University Station, C0800, Austin, TX 78712. *Linking multi-scale imaging with multi-scale modeling to predict the response of tumors to therapy.*

We will discuss our ongoing theoretical, pre-clinical, and clinical work employing serial measurements from time resolved microscopy and medical imaging to calibrate predictive, mathematical models of tumor growth and treatment response.

Our theoretical studies focus on developing mathematical representations that employ a combination of continuum mixture theory and the principal hallmarks of cancer. The immediate scientific goal is to provide a rigorous theory of tumor development, informed and validated by pre-clinical and clinical experimental data.

Regarding our in vitro, cell-scale experiments, we integrate pharmacokinetic and pharmacodynamic models with time-resolved fluorescence microscopy to quantify specific intracellular pathways contributing to therapeutic response to chemotherapy, and the effect of glucose concentration on tumor cell growth.

In the clinical setting, we use a system of mechanics-coupled, reaction-diffusion equations to predict the response of breast and brain cancers to therapy. Again, we use early, quantitative, MRI data to calibrate the model by predicting the observed response at the conclusion of therapy.

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1145-92-760 **Marissa Renardy*** (renardy@umich.edu) and **Denise Kirschner**. *Evaluating vaccination strategies for tuberculosis in endemic and non-endemic settings.* Preliminary report.

According to the World Health Organization, tuberculosis (TB) is the leading cause of death from infectious disease worldwide. While there is no effective vaccine against adult pulmonary TB, more than a dozen vaccine candidates are in the clinical trial pipeline. These include both pre-exposure vaccines to prevent initial infections and post-exposure vaccines to prevent reactivation of latent disease. Many epidemiological models have been used to study TB, but most have not included a continuous age structure and the possibility of both pre- and post-exposure vaccination. Incorporating age-dependent death rates, disease properties, and social contact data allows for more realistic modeling of disease spread. We propose a continuous age-structured model for the epidemiology of tuberculosis with pre- and post-exposure vaccination. We use uncertainty and sensitivity analysis to make predictions about the efficacy of different vaccination strategies in a non-endemic setting (United States) and an endemic setting (Cambodia). In particular, we determine optimal age groups to target for pre-exposure and post-exposure vaccination in both settings. (Received September 14, 2018)

1145-92-770 **E Benjamin Randall*** (ebrandal@ncsu.edu.), 3745 Yorktown Pl, Raleigh, NC 27609, and **Jesper Mehlsen** and **Mette Olufsen**. *A model-based analysis of autonomic nervous function in response to the Valsalva maneuver.*

The autonomic nervous system (ANS) involuntarily maintains homeostasis and responds to stimuli with 2 systems: parasympathetic (PNS) and sympathetic (SNS). Respiratory sinus arrhythmia (synchrony of heart rate (HR) and breathing) and the baroreflex (activation of baroreceptors due to sudden increases/decreases in blood pressure (BP)) are mechanisms that regulate HR, while the baroreflex also affects the vasculature. Autonomic dysfunction (AD) occurs when the ANS behaves abnormally. The Valsalva maneuver (VM) is forced expiration against a closed airway while maintaining an open glottis. This procedure activates both the PNS and SNS as intrathoracic pressure increases. The VM has 4 distinct phases and can help diagnose AD. Mathematical modeling of the cardiovascular system with ANS control can reveal neurological function, which is not easily measured in practice. We have noninvasively obtained data that we can analyze with the model. This talk focuses on the implementation of a patient-specific coupled model that predicts ANS responses due to the VM. Moreover, we establish an inverse problem, in which we use techniques to determine a subset of identifiable parameters estimated for patient-specificity. We use this analysis to visualize AD in abnormal patients versus healthy ones. (Received September 14, 2018)

1145-92-781 **Ruqiah A Muhammad*** (ruqiah-muhammad@uiowa.edu), Department of Mathematics, 14 MacLean Hall, Iowa City, IA 52242-1419, Iowa City, IA 52242. *Mathematical Model of Bone Regeneration in Bone Marrow-derived Mesenchymal Stem Cell Populations.* Preliminary report.

Millions of people fracture their bones every year. We focus on the bone regeneration process in vitro using multipotent bone marrow-derived mesenchymal stem cells (BMSCs) due to their ability to differentiate into bone cells. We have created a deterministic model that consist of a system of ordinary differential equations to capture the process of calcium formation, necessary for bone formation. This model is unique due to the use of chemically modified ribonucleic acid encoding a bone morphogenetic protein for the transfection of the BMSCs. It also incorporates gene expression levels of specific genetic markers. We will discuss our preliminary results. (Received September 14, 2018)

1145-92-840 **Leah M Mitchell*** (lmmitchell@wpi.edu) and **Andrea Arnold**. *Effects of observation function selection in nonlinear filtering for epidemic models.* Preliminary report.

Nonlinear filtering is an approach to solving the inverse problem of estimating unknown states and/or parameters of a system. The ensemble Kalman filter (EnKF) is one such algorithm that can be used for nonlinear, non-Gaussian systems within a Bayesian inference framework. One component of the EnKF is the observation model, which relates the discrete, noisy data back to the system model. The observation model can take different forms based on assumptions relating to the available data and relevant system parameters. The goal of this research is to explore the effects of selecting different observation models in the EnKF framework. In particular, four different observation models, of different forms and various levels of complexity, are examined through an application to epidemiology. Results discuss the effects of the observation model selection on the filter output. (Received September 16, 2018)

1145-92-841 **Xue-Zhi Li**, Department of Mathematics and Physics, Anyang Institute of Technology, Anyang, Henan 455500, Peoples Rep of China, **Junyuan Yang** (yangjunyuan00@126.com), Complex Systems Research Center, Shanxi University, Taiyuan, Shanxi 030006, Peoples Rep of China, and **Maia Martcheva*** (maia@ufl.edu), Department of Mathematics, University of Florida, Gainesville, FL. *A multi-patch SIS age-structured epidemic model with migration.* Preliminary report.

We consider a chronological age-structured SIS PDE model with n-patches and migration among the patches. The total population size is assumed constant. We show that the system always has a unique disease-free equilibrium. We define the basic reproduction number as the spectral radius of an appropriately defined operator. If the basic reproduction number is larger than one, then there is a unique endemic equilibrium. We show that if the reproduction number is less than one, the disease-free equilibrium is locally and globally stable. If the reproduction number is greater than one, the endemic equilibrium is locally and globally stable. (Received September 16, 2018)

1145-92-864 **Kamuela E Yong*** (kamuela.yong@hawaii.edu), 91-1001 Farrington Highway, Kapolei, HI 96707. *A mathematical model of the transmission and lifecycle of* Angiostrongylus cantonensis. Preliminary report.

Angiostrongylus cantonensis (AC) is a parasitic nematode with a complex lifecycle. Adult worms reproduce in the lungs and pulmonary artery of rats (Rattus sp.). Larvae exit rats through their feces which are consumed by gastropods such as snails. Gastropods become infected by consuming rat feces. Rats consume these snails and support the late-stage development of the larval worms in their brain. AC completes its lifecycle when worms leave the brain and mature in the cardiopulmonary region. Humans become infected by accidentally consuming infectious snails or produce contaminated by infectious snails. AC infection in humans causes rat lungworm disease (angiostrongyliasis) that may manifest with severe eosinophilic meningitis leading to chronic neurological abnormality. Although rat lungworm disease is an emerging public health problem, ecological drivers of AC transmission are poorly described. In this paper, we develop a mathematical model to represent the transmission of AC through its life cycle. Numerical simulations are conducted to determine the factors that have the most impact on the transmission of AC. The results have important implications for understanding AC transmission and informing mitigation strategies to suppress infection rates in human populations. (Received September 16, 2018)

1145-92-879 **Laura Ellwein Fix*** (lellwein@vcu.edu), 1015 Floyd Ave., Richmond, VA 23220. *Parameter identifiability of a respiratory mechanics model in an idealized preterm infant.*

The complexity of mathematical models describing respiratory mechanics has grown in recent years to integrate with cardiovascular models and incorporate nonlinear dynamics, but has rarely been studied in the context of patient-specific observable data. This study investigates parameter identification of a previously developed nonlinear respiratory mechanics model (Ellwein Fix et al, 2018) tuned to the physiology of 1 kg preterm infant, using local deterministic sensitivity analysis, subset selection, and gradient-based optimization. The model consists of 4 differential state equations with 34 parameters to predict airflow and dynamic pulmonary volumes and pressures generated under six simulation conditions. The relative sensitivity solutions were calculated with finite differences and a sensitivity ranking was created for each parameter and simulation. Subset selection found independent parameters that could be estimated for all six simulations. The combined analysis produced a subset of 6 independent sensitive parameters identifiable with observable data. Optimizations performed using pseudo-data with perturbed nominal parameters estimated parameters within 5% of nominal values on average, demonstrating the feasibility of studying patient-specific infant data with these methods. (Received September 16, 2018)

1145-92-904 **Margherita Maria Ferrari*** (mmferrari@usf.edu) and **Nataša Jonoska**. *Mathematical models for describing molecular self-assembly.* Preliminary report.

We present several mathematical models for describing molecular building blocks, called rigid tiles, that assemble in larger nanostructures. Rigid tiles can be seen as k-arm branch junction structures that join together by annealing to each other through the affinity of their arm-ends. Such a k-arm rigid tile is described with a set of k vectors joined at the origin that can be translated or rotated during the assembly. Besides the geometric shape of the building blocks, the models can take into account the geometry of the arm-ends joining together. We show distinctions between four models by characterizing types of structures that can be assembled from rigid tiles. (Received September 17, 2018)

1145-92-919 **Trachette L Jackson*** (tjacks@umich.edu), Department of Mathematics, University of Michigan, 530 Church St., Ann Arbor, MI 48109-1043. *Multiscale Modeling of Combined Traditional and Targeted Therapies Against Stem Cell Driven Cancers.* Preliminary report.

Targeting key regulators of the cancer stem cell phenotype to overcome their critical influence on tumor growth is a promising new strategy for cancer treatment. In this talk, a multi-scale mathematical model that operates at the intracellular, molecular, and tissue level is developed to investigate the impact of IL-6 signaling on crosstalk between cancer stem cells (CSCs) and vascular endothelial cells (ECs) during tumor growth. This EC-CSC model is used to study the therapeutic potential of Tocilizumab (TCZ), a competitive IL-6R inhibitor, on tumor growth and cancer stem cell fraction, alone and in combination with the traditional chemotherapeutic agent, Cisplatin. The approach is novel in that it includes full receptor occupancy dynamics between endothelial-cell produced IL-6, IL-6R, and TCZ. Validation is achieved by directly comparing model predictions to data generated by a series of in-vivo experiments. Simulations show excellent predictive agreement with the decrease in tumor volume, as well as a decrease in CSC fraction post therapy. This modeling framework can also be used to evaluate dosing strategies for IL-6 pathway modulation, as well as providing the basis for proposing combination treatments with IL-6 blockade and cytotoxic or other targeted therapies. (Received September 17, 2018)

1145-92-937 **Heyrim Cho*** (hcho1237@math.umd.edu), **Lisette de Pillis**, **Ya-Huei Kuo**, **Ami Radunskaya**, **Russell Rockne** and **Doron Levy**. *Modeling continuous levels of cell states in cancer development and drug resistance.*

Recent advances in single-cell sequencing data and high-dimensional data analysis techniques are bringing in new opportunities in modeling biological systems with continuous phenotypic structured models. In this talk, we first demonstrate that assuming continuous cell state may result in different dynamics when compared with the predictions of classical discrete models, particularly in anti-cancer drug resistance. We classify the cases when the continuum and discrete models yield different dynamical patterns in the emerging heterogeneity in response to chemotherapy, and study the maximal fitness resistance and effect of epimutations. In the second part, we develop a continuum cell state model using single-cell RNA sequencing data of hematopoietic stem cells. The trajectories of cell states in the differentiation space are abstracted as a graph, then modeled as directed and random movement on the graph with PDEs. We simulate normal and abnormal differentiation processes, that is, acute myeloid leukemia (AML) progression and predict the emergence of cells in novel intermediate states of differentiation consistent with immunophenotypic characterizations of a mouse model of AML. (Received September 17, 2018)

1145-92-943 **Ami Radunskaya*** (aer04747@pomona.edu), Math Dept. Pomona College, 610 N. College Ave., Claremont, CA 91711, and **Joshua Sack**. *How do immune cells kill cancer cells?*

The immune system is able to fight cancer by mustering and training an army of effector “killer” cells. There are several key steps to this process: recognition of the cancer cells, activating the effector cells, trafficking of the immune cells to the site of the tumor, and the killing itself. We have created a cell-based fixed-lattice model that simulates immune cell and tumor cell interaction involving MHC recognition, and two killing mechanisms. We are motivated by open questions about the mechanisms behind experimentally observed kill rates of tumor cells by different types of effector cells. These mechanisms play a big role in the effectiveness of many cancer immunotherapies. Results from model simulations, along with theories developed by ecologists, can help to illuminate which mechanisms are at work in different conditions. (Received September 17, 2018)

1145-92-967 **Alvaro A Ortiz Lugo*** (ortizlaa@mail.uc.edu), **BenJamin L Vaughan** (vaughabn@ucmail.uc.edu) and **Sadiqah Al Marzooq** (s_almarzooq@yu.edu.sa). *An Improved Mathematical Model of Pathogen Dynamics in Water Distribution Networks.*

A water distribution network aims to provide a safe water supply. Biological contamination of this system can occur by breach of pipes and other factors, impacting the water quality. Frequently, microorganisms form biofilms on the interior surface of pipes, which are aggregates of microorganisms that adhere to solid surfaces through self-secreted extracellular polymeric substances. The presence of biofilms can allow harmful bacteria to persist within the distribution network, possibly degrading water quality. In this talk, we analyze a mathematical model of the dynamics of non-native bacteria in the native drinking water biofilm within a large network of pipes, for different flow functions. We analyze the dynamics of models using linear stability analysis and other techniques. Realistic water distribution systems, have a large number of connections making computational calculations difficult, to address this we develop an efficient algorithm for predicting the long-time behavior of the pathogen population within the network and prove mathematically these predictions and the analytical results are validated using numerical simulations. The modeling framework brings together graph theory and ordinary differential equations, with impact in numerical methods and dynamical systems (Received September 17, 2018)

1145-92-1001 **Reinhard Laubenbacher*** (laubenbacher@uchc.edu), **Sherli Koshy Chenthittayil**, **Paola Vera-Licona**, **Michael Stevens** and **Andrew Poppe**. *The Dynamic Nature of Functional Brain Networks of Emotion Regulation.* Preliminary report.

Numerous psychiatric disorders, including Major Depressive Disorder and others are all thought to have underlying abnormalities in emotion regulation. Mostly, fMRI (functional MRI) scans of the patients either in resting state or while they are performing tasks are used to deduce network connectivity. The norm in the inference of neuroimaging network connectivity is to characterize a static representation of connectivity structure. However, such representations mask dynamic variation in the neural response as complex brain system interactions evolve over time. This talk will describe an approach to capturing some of the dynamic aspects of emotion regulation network connectivity, using probabilistic Boolean networks to infer dynamic signatures from a cohort of subjects. (Received September 18, 2018)

1145-92-1006 **Moussa Doumbia*** (mdoumbia@bison.howard.edu), Howard University, Department of Mathematics, Washington, DC 200590001, and **Abdul-Aziz Yakubu** (ayakubu@howard.edu), Howard University, Mathematics Department, Washington, DC 200590001. *Asymptomatic Malaria Infections in Pregnant Women of Ngbo in Ohaukwu local Government Area of Ebonyi State of Nigeria.* Preliminary report.

In this talk, we will use a deterministic parametrized mathematical model of malaria to capture the clinical data of Ogbodo et al. and Onyido et al., and then use the "fitted" model to study the impact of various control measures on malaria incidence among pregnant women of Ngbo in Ohaukwu Local Government Area of Ebonyi State in Nigeria. Our simulation results suggest control measures that will lead to the least episodes of the malaria disease infection among pregnant women, the most vulnerable group in the malaria hyper endemic region. (Received September 18, 2018)

1145-92-1034 **H. Reed Ogrosky*** (hrogrosky@vcu.edu), 1015 Floyd Ave., PO Box 842014, Richmond, VA 23284-2014, and **Roberto Camassa** and **Jeffrey Olander**. *A simplified model of air-driven film transport in human airways.*

Human airways are lined with a thin layer of mucus, a non-Newtonian fluid that traps harmful particles and transports them away from the lungs. This transport is typically driven by the beating of cilia; in the case that cilia do not function properly, other mechanisms such as coughing and breathing can play a more primary role in mucus clearance. In this talk, we study a mathematical model of a simplified version of this problem, namely the flow of a viscous fluid that lines the interior of a vertical tube with airflow in the center of the tube meant to mimic breathing or coughing. Physical experiments have shown that if such periodic airflow is biased, e.g. having relatively fast upwards flow for less than half the period and relatively slow downwards flow for the remainder of the period, it is possible for the airflow to transport the film upwards against gravity. A recently-derived single nonlinear partial differential equation model that describes the evolution of the film's free surface is presented, and linear stability analysis demonstrates improved agreement with experiments when compared with earlier versions of the model in the case of steady airflow. Model solutions found numerically will be shown to qualitatively match results of earlier film transport experiments. (Received September 18, 2018)

1145-92-1071 **Glenn S Young*** (gsy4@psu.edu) and **Andrew Belmonte**. *Explicit probability of fixation formula for mutual competitors in a stochastic population model under competitive trade-offs.* Preliminary report.

Competition is ubiquitous in nature, and mathematicians have a long history of studying general models for ecological competition, most notably the deterministic Lotka-Volterra competition model. However, deterministic modeling struggles to capture the effects of small fitness differences. In this talk, we consider the two-species stochastic Lotka-Volterra competition model, which allows for a more nuanced interpretation of the competitive advantage conferred by fitness differences. In particular, we study the probability that one species outcompetes the other, called the probability of fixation, by analyzing the associated backward Kolmogorov equation (BKE). By identifying and exploiting a natural slow timescale, we derive an approximation to the BKE that allows us to find a closed form expression for the probability of fixation, through which we can easily examine the effects of parameter changes. Finally, we use our result to study fitness tradeoffs within a competitive environment and show that certain tradeoff strategies are beneficial while the population exists at high frequencies, but harmful at low frequencies, and vice versa. As a specific biological example, we show that our results agree with the gut-invasion strategy of *Salmonella Typhimurium.* (Received September 18, 2018)

1145-92-1108 **Robert Gatenby*** (robert.gatenby@moffitt.org). *Mathematical Models to Guide Cancer Therapy.*

A number of successful systemic therapies are available for treatment of disseminated cancers but response to treatment is almost invariably transient due to emergence of resistant populations. Although cancers are highly dynamic systems, treatment is changed only when the tumor progresses. But, successful tumor adaptation begins immediately upon administration of the first dose. Applying evolutionary models to cancer therapy demonstrate the potential advantage of using more dynamic, strategic approaches that focus not just on the initial cytotoxic effects but also on evolved mechanisms resistance and the associated phenotypic costs. The goal of evolutionary therapy is to prevent or delay proliferation of resistant populations. Examples include adaptive therapy and double bind therapy. The former continuously alters therapy to maintain a stable tumor volume using a persistent population of therapy-sensitive cells to suppress proliferation of resistant phenotypes. The latter uses cytotoxic effects of an initial therapy to promote phenotypic adaptations that are then exploited using follow-on treatment. Ongoing clinical trials using treatment protocols based on mathematical models of evolutionary principles will be presented. (Received September 19, 2018)

1145-92-1126 **Jesse Kreger*** (kregerj@uci.edu), **Natalia L. Komarova** and **Dominik Wodarz**. *Mathematical models of cancer evolution through Moran processes with migration.*

In this talk, we investigate mathematical models regarding the evolutionary dynamics of cancer cells. These models are based on the Moran process, which is a simple birth-death stochastic process used in biology to describe constant populations with competing healthy and mutant cell types. We consider models with variations on the basic Moran process. These variations include migration and exchange between many connected regions, which represent different locations and tissues in the body. In the context of multiple related models, we implement analytical methods and stochastic simulations in order to assess the probability of cancerous mutant fixation as well as the mean conditional time until such fixation occurs. These results can improve understanding of cancer-specific evolutionary dynamics and can help predict the progression of cancer through the body. (Received September 19, 2018)

1145-92-1129 **Jim Cushing*** (cushing@math.arizona.edu), Department of Mathematics, 617 N Santa Rita, University of Arizona, Tucson, AZ 85721, and **Shandelle Henson**. *Evolutionary adaptation of cannibalism in fluctuating environments.* Preliminary report.

Recent observations of breeding and feeding behaviors in colonies of glaucous-winged gulls show distinctive changes during periodically occurring El Niño events. Of particular notice is the significant increase in egg cannibalism during these events. Cannibalism is an example of a behavior that has both negative and positive effects on fitness of individuals in the population. Dynamic models show that under certain circumstances cannibalism can promote population survival in a (constant) degraded environment. Moreover, evolutionary versions of the models show that cannibalism can be an evolutionarily stable strategy. In this talk I consider periodically and stochastically forced versions of these evolutionary models and their predictions about population survival and the evolutionary selection in favor of or against cannibalism. Of the many scenarios that these models predict, one interesting case is when evolution selects in favor of cannibalism in a periodically fluctuating environment, but against it in a constant or a stochastic environment. (Received September 19, 2018)

1145-92-1132 **Jim Cushing*** (cushing@math.arizona.edu), Department of Mathematics, 617 N Santa Rita, University of Arizona, Tucson, AZ 85721. *Darwinian difference equation models and the evolution of semelparity versus iteroparity.* Preliminary report.

A classic question in life history strategies of biological populations concerns reproductive timing and output and, specifically, the choice between semelparity (one reproductive event only in an individual's life, e.g. annual plants) and iteroparity (multiple reproductive events, e.g. perennial plants). Under what circumstances will evolution favor one of these strategies over the other? While early investigations suggested semelparity should be favored by evolution, subsequent studies have shown there is no simple answer to this question and that many factors can be in play, including density dependence, variable environmental conditions, and many others. In this talk I formulate evolutionary versions of some standard difference equation population models and discuss their implications with regard to this question, focusing on the role of density dependence of reproduction and survival. The analysis involves equilibrium bifurcations and stability and on multiple attractor scenarios. Conditions are obtained under which semelparous equilibria and iteroparous equilibria are stable and conditions under which either type of stable equilibrium might or might not be an evolutionarily stable strategy. (Received September 19, 2018)

1145-92-1147 **Katherine Morrison*** (katherine.morrison@unco.edu), 501 20th St CB 122, Greeley, CO 80639. *Predicting neural network dynamics from graph structure.*

Neural networks often exhibit complex patterns of activity that are shaped by the intrinsic structure of the network. For example, spontaneous sequences of neural activity have been observed in cortex and hippocampus, and patterned motor activity arises in central pattern generators for locomotion. In this talk, we will focus on a simplified neural network model known as Combinatorial Threshold-Linear Networks (CTLNs) in order to understand how the pattern of neural connectivity, as encoded by a directed graph, shapes the emergent nonlinear dynamics of the corresponding network. We will see that important aspects of these dynamics are controlled by the stable and unstable fixed points of the network, and show how these fixed points can be determined via graph-based rules. (Received September 19, 2018)

1145-92-1151 **Cassandra L Williams*** (williamc18@hawkmail.newpaltz.edu), 6 Hollyberry Drive, Hopewell Junction, NY 12533, and **Anca Radulescu** and **Annalisa Scimemi**. *Revising estimates of glutamate transporter density in astrocytes: a geometric computation.*

Glutamate is the main excitatory neurotransmitter released in the brain. Its removal from the extracellular space is important to terminate synaptic transmission between neurons, and prevent build-up of neurotoxicity. The removal process is intermediated by non-neuronal cells called astrocytes. These take in the excess extracellular glutamate via prism-shaped cross-membrane transporters densely expressed in the wall of the cell membrane. To understand their impact on neurotransmission efficiency, one needs to estimate the density of transporters for an average astrocyte. All existing computations are based on simplifying assumptions of spherical shape for a typical astrocyte. However, the actual, 3-dimensional fractal geometry of an astrocyte may drastically reduce this number, since cross-membrane transporters cannot collide. We use a geometric modeling argument, based on the known crystal structure of the transporter, to study how the structural complexity of astrocytic processes influences the surface density of transporters. We then use Monte Carlo reaction-diffusion simulations to determine whether these theoretical estimates challenge our knowledge of how glutamate transporters shape efficiency of synaptic transmission. (Received September 19, 2018)

1145-92-1153 **Fnu Eric Ngang Che*** (ericngangche@yahoo.com), Howard University, Department of Mathematics, Washington, DC 200590001, and **Abdul-Aziz Yakubu** (ayakubu@howard.edu), Mathematics Department, Howard University, Washington, DC 200590001. *Risk Structured Model of Cholera Infections In Cameroon.* Preliminary report.

In this talk, we will introduce a high and low risk structured model of cholera infections in the population of Cameroon. The model has two cholera infection pathways, direct (human-to-human) and indirect (contaminated water-to-human) transmissions. We will use our model's demographic equation to "fit" the population of Cameroon, and then use the fitted cholera model to capture cholera cases in Cameroon from 1990 to 2017. Furthermore, we will explore optimal control strategies that will minimize the number of cholera infections in Cameroon and the cost of controls over time. (Received September 19, 2018)

1145-92-1154 **Yan Wang*** (ywang36@email.wm.edu), 1449A N Mount Vernon Avenue, Apt A, williamsburg, VA 23185, and **Junping Shi**. *Persistence and Extinction of Population in Reaction-Diffusion-Advection Model with Strong Allee Effect Growth.*

A reaction-diffusion-advection equation with strong Allee effect growth rate is proposed to model a single species stream population in a unidirectional flow. Here random undirected movement of individuals in the environment is described by passive diffusion, and an advective term is used to describe the directed movement in a river caused by the flow. Under biologically reasonable boundary conditions, the existence of multiple positive steady states are shown when both the diffusion coefficient and the advection rate are small, which lead to different asymptotic behavior for different initial conditions. On the other hand, when the advection rate is large, the population becomes extinct regardless of initial condition under most boundary conditions. It is shown that the population persistence or extinction depends on Allee threshold, advection rate, diffusion coefficient and initial conditions, and there is also rich transient dynamical behavior before the eventual population persistence or extinction. (Received September 19, 2018)

1145-92-1176 **Sebastian Schreiber*** (sschreiber@ucdavis.edu), Department of Evolution and Ecology, University of California, Davis, CA 95616. *Genetic diversity as a rescue mechanism in stochastic environments.*

Environmental stochasticity corresponds to fluctuations in environmental conditions resulting in fluctuations in the fitness of individuals. As these fluctuations reduce the geometric mean of fitness, environmental stochasticity can result in populations going extinct. In this talk, I illustrate how genetic diversity within populations can rescue populations from this extinction. Specifically, I introduce a system of stochastic difference equations representing the dynamics of a diploid population with k alleles at a single locus. An analysis of these equations yields conditions for when (i) all alleles stochastically coexist (i.e. exhibit a statistical tendency for the allelic frequencies to remain away from zero) and (ii) the population stochastically persists or goes asymptotically extinct for all initial conditions. In the special case of alleles with identically distributed additive contributions to fitness, (i) and (ii) characterized in terms of the number of alleles and the mean, variance, and covariance of their additive contributions to fitness. This characterization reveals when there is a critical number of alleles required for population persistence (i.e. rescue via genetic diversity). (Received September 19, 2018)

1145-92-1212 **Abdul-Aziz Yakubu*** (ayakubu@howard.edu), Howard University, Department of Mathematics, 2441 6th Street NW, Washington, DC 200590001, and **Pauline van den Driessche**. *Analysis of Age-Structured Discrete-Time Model of Infectious Salmon Anemia.* Preliminary report.

In many epidemiological models, the disease-free state is a stable periodic cycle, rather than a stable static state (non-cyclic). When these cycles are intrinsic to the model and are not generated from periodic perturbations, van den Driessche and Yakubu developed an extension of the next generation matrix method (ENGM) for calculating the basic reproduction number. We will use the ENGM approach to two different discrete-time models with cyclic demographic dynamics, an SIR model and an infectious salmon anemia model. (Received September 20, 2018)

1145-92-1273 **William F. Fagan*** (bfagan@umd.edu), **Tyler Hoffman**, **Daisy Dahiya**, **Robert Stephen Cantrell** and **Chris Cosner**. *How switching between movement modes improves foraging success in fragmented landscapes: exploring the benefits of context-dependent diffusion and advection.*

Animals use different dispersal modes at different times and scales. For example, animals may use relatively large scale non-oriented (e.g., diffusive) movements to search for resources but use smaller scale, directed movements to exploit them. Incorporating such context-dependence in models represents a substantial increase in mathematical complexity, but creates an opportunity to more fully integrate real biology. Using a partial integro-differential equation framework, we consider the spatial dynamics of a population of foragers with two subunits. In one subunit, foragers move via diffusion (random search) whereas in the other, foragers move via advection (gradient-following search). Foragers switch back and forth between the subunits as functions of their spatial context. We consider a one dimensional binary landscape of resource patches and non-habitat and assume that different movement modes predominate inside patches versus outside. We find that actively switching between dispersal modes offers a substantial increase in the spatial overlap between foragers and their resources relative to a dispersal model in which foragers merely blend advection and diffusion modes at all times. (Received September 20, 2018)

1145-92-1312 **Ayush Prasad*** (aprasad8@jhu.edu), **Nigar Karimli** and **Richard Schugart**. *Constructing an Optimal Design Method in a Mathematical Model for the Interactions of Matrix Metalloproteinases and Their Inhibitors in a Wound.*

Because the medical treatment of diabetic foot ulcers remains a challenge for clinicians, a quantitative approach using patient data and mathematical modeling can help researchers understand the physiology of the wounds. In this work, we estimate parameter values using individual patient data curve-fitted to a modified version of a mathematical model that describes the interactions among matrix metalloproteinases, their inhibitors, extracellular matrix, and fibroblasts at a wound site (Krishna et al., 2015). The model and parameter values were then analyzed using global and local sensitivity analyses, which were used to describe how sensitive each parameter value of the model was to changes in the system. However, these model parameters can be estimated more efficiently and accurately by implementing an optimal design method that calculates optimal observation times for collecting clinical data. We introduce an SE-optimal design (standard error optimal design) by using a Fisher Information Matrix (FIM) to determine the time evolution of sensitivity values. The goal of this work is to quantify and understand the differences between patients to predict future responses and individualize treatment for each patient. (Received September 20, 2018)

1145-92-1317 **Joseph P Rusinko**, **Jennifer Vandenbussche*** (jennifer.vandenbussche@kennesaw.edu) and **Qingyi Lu**. *Improving Statistical Binning Techniques for Species Tree Reconstruction.*

This talk presents the results of an analysis of the mechanism by which the use of statistical binning in species tree reconstruction, introduced by Mirarab et al., results in estimated species trees more closely aligned with true species trees. We also present evidence that the use of Transfer bootstrap values (introduced by Lemoine et al.) in conjunction with a topological constraint, rather than traditional Felsenstein bootstrap values, can lead to more accurate binning decisions. Unlike the original statistical binning approach, the recommended decision criteria does not depend on the level of incomplete lineage sorting. (Received September 20, 2018)

1145-92-1322 **Tracy L. Stepien*** (stepien@math.arizona.edu), Department of Mathematics, University of Arizona, Tucson, AZ , and **Timothy W. Secomb** (secomb@u.arizona.edu), Department of Physiology, University of Arizona, Tucson, AZ. *Spreading Mechanics and Differentiation of Astrocytes During Retinal Development.*

Retinal vasculature is essential for adequate oxygen supply to the inner layers of the retina, the light sensitive tissue in the eye. In embryonic development, formation of the retinal vasculature via angiogenesis is critically dependent on prior establishment of a mesh of astrocytes, which are a type of brain glial cell. Astrocytes emerge from the optic nerve head and then migrate over the retinal surface as a proliferating cell population in a radially symmetric manner. Astrocytes begin as stem cells, termed astrocyte precursor cells (APCs), then transition to immature perinatal astrocytes (IPAs), which eventually transition to mature astrocytes. We develop a partial differential equation model describing the migration of astrocytes where APCs and IPAs are represented as two subpopulations. Numerical simulations are compared to experimental data to assist in elucidating the mechanisms responsible for the distribution of astrocytes. (Received September 21, 2018)

1145-92-1339 **Victor James Barranca***, 500 College Avenue, Swarthmore, PA 19081, and **Douglas Zhou**. *The Role of Sparsity in Inverse Problems for Networks with Nonlinear Dynamics.*

Sparsity is a fundamental characteristic of numerous biological, social, and technological networks. Network connectivity frequently demonstrates sparsity on multiple spatial scales and network inputs may also possess sparse representations in appropriate domains. In this work, we address the role of sparsity in solving inverse problems in networks with nonlinear and time-evolving dynamics. In the context of pulse-coupled integrate-and-fire networks, we demonstrate that nonlinear network dynamics imparts a compressive coding of both network connectivity and inputs provided they possess a sparse structure. Driving the network with a small ensemble of random inputs, we derive a mean-field set of underdetermined linear systems relating the network inputs to the corresponding activity of the nodes via the feed-forward connectivity matrix. In reconstructing the network connections, we utilize compressive sensing theory, which facilitates the recovery of sparse solutions to such underdetermined linear systems. This framework underlines the central role of sparsity in information transmission through network dynamics, providing new insight into the structure-function relationship for high-dimensional networks with nonlinear dynamics. (Received September 21, 2018)

1145-92-1355 **Sungwoo Ahn*** (ahns15@ecu.edu), Department of Mathematics, East Carolina University, 124 Austin Building, East Fifth Street, Greenville, NC 27858, and **Choongseok Park**, **Katie N Clements** and **Fadi A A Issa**. *Social status-dependent regulation of endocannabinoids and modulation of spinal motor circuits: Empirical and computational analysis.* Preliminary report.

Understanding how social factors influence nervous system function is of great importance. Studies have shown that social status influences the behavior and physiological processes of many social animals. However, the neural mechanisms underlying the capacity of the nervous system to adapt to social changes remain poorly understood. Using zebrafish as a model system, we explored the cellular mechanisms of how social status affects the neuromodulatory system and its regulation of spinal motor circuits (escape and swimming). Based on the empirical results, we built a neurocomputational model by using a system of differential equations. Our integrative approach of empirical and computational analysis will improve our understanding of fundamental principles of neuromodulatory mechanisms that shape nervous system function and motor behavior. (Received September 21, 2018)

1145-92-1356 **Amy Veprauskas*** (aveprauskas@louisiana.edu) and **Tingting Tang**. *Understanding species persistence under reoccurring and interacting disturbances.* Preliminary report.

We develop a mathematical framework for examining the impact of multiple types of (independent) disturbances on a population. We assume that the occurrence and duration of these disturbances are independent of each other, but how these disturbances collectively impact the population is not. In particular, we allow for the combined effect of the disturbances to be greater or less than their additive effects, corresponding to synergistic or antagonistic interactions, respectively. This model uses a discrete-time Markov chain to describe the environment, with the impact of the environment on the population incorporated into the vital rates of a structured matrix model. We use this model to examine how persistence of a single or interacting species is impacted by multiple, interacting disturbances. (Received September 21, 2018)

1145-92-1369 **Camille Hankel** and **Judith R. Miller*** (judith.miller@georgetown.edu). *Invasion by competing types in a heterogeneous environment.* Preliminary report.

We model competition between two subtypes of an asexually reproducing species in a discrete environment where two habitat types alternate periodically. Each habitat type favors a different species subtype. We study the long-term behavior of the modeled populations, showing that in some cases it differs qualitatively from what is known to occur in a continuous environment. For example, in the discrete environment, competition can "pin" the range of a subtype that would have expanded without bound in the absence of its competitor. Furthermore, increasing the growth rate of each type in its less favorable habitat at times leads to worse outcomes for a focal type (e. g. extinction rather than pinning). (Received September 21, 2018)

1145-92-1387 **Bernardo A Hernandez Adame*** (bernardo.a.hernandez.adame@gmail.com), 70 Pacific St. #484A, Cambridge, MA 02132, and **Erin Stafford**, **Amanda McAdams** and **Jonathan Galvan Bermudez**. *Cellular-Scale Modeling of Oncogenic Proteins.*

Mutations in the RAS family of proteins have been implicated in roughly 25% of all human tumors and up to 90% in certain types of cancerous tumors, such as pancreatic cancer, as mutations can lead to overactive signaling in cells preventing cell death and leading to tumor growth. In order to better understand the dynamics of RAS protein interactions with the cell membrane and RAF proteins, we constructed a combination of an atomistic and a continuum scale mathematical model. The various interactions are incorporated into the model through a "free energy" functional, which describes the available work in this thermodynamic system. Furthermore, using dynamic density functional theory, we derive the evolution equations describing the changes in the membrane's lipid concentrations, the membrane's height, and the proteins' positions . A sensitivity analysis is then conducted on the parameters of the interactions due to the uncertainty in these values, as well as providing various simulations of the membrane evolution under the mutated proteins. (Received September 21, 2018)

1145-92-1400 **Preeti Dubey*** (pdubey1@luc.edu), 37 Rockford Avenue, Unit 21, Forest Park, IL 60130. *Mathematical modeling of hepatitis delta virus (HDV) dynamics during prenylation inhibitor lonafarnib (LNF) treatment.* Preliminary report.

Hepatitis delta virus (HDV) is a satellite virus that propagates in individuals infected with hepatitis B virus. It is the most severe form of chronic viral hepatitis infection in humans, infecting about 15-20 million persons worldwide. Therapy with interferon alpha is unsatisfactory. The prenylation inhibitor lonafarnib (LNF) has proven anti-HDV activity in early phase clinical trials. In LOWR HDV-3 clinical trial 12 patients were randomized into 3 groups: LNF 50/75/100mg + ritonavir (RTV) 100mg once daily for 24 weeks. We identified four

different viral kinetic patterns in each dosing group: (i) a triphasic decline consisting of a first phase with rapid virus load decline, followed by a "shoulder phase" in which virus load decays slowly or remains constant, and a third phase of renewed viral decay, (ii) a flat partial response (FPR), consisting of a first phase with rapid virus load decline followed by a lower set point of viral load, (iii) a rebound, in which FPR or triphasic kinetic patterns were observed followed by a rebound in viral load (due to varying effectiveness of drug) and (iv) non-response. I will present developed mathematical model that provides insights into HDV-host dynamics and LNF+RTV efficacy. (Received September 21, 2018)

1145-92-1435 **Ram C Neupane*** (ram.neupane@tamut.edu), 7101 University Avenue, SCIT 104G, Texarkana, TX 75503, and **James Powell** (jim.powell@usu.edu), 3900 Old Main Hill , Animal Science(ANSC), Logan, UT 84322. *Modeling Pinyon-Juniper Dispersal in Real Landscapes.*

Tree distribution models are commonly used to understand the structure of forest communities in space. These models take geographic variables as input and are therefore helpful for long-term decision support and climate adaptation planning. Normally the process of seed germination and seedling survival are resolved probabilistically with explanatory variables such as soil type, elevation and weather inputs using landscape and regional presence-absence data. How seeds are distributed in these models, however, is far more problematic since it is difficult to accurately parameterize dispersal models using large-scale presence-absence data, particularly for actively dispersed tree species. The challenge is that variables conditioning vertebrate seed dispersal are not represented in large scale distribution models, and in fact vary on scales around ten to hundred meters that are much smaller than the smallest pixel size for the distribution model of more than a kilometer. The homogenized seed dispersal kernel offers a tool to make use of this scale separation. In this paper we develop scenarios for seed dispersal on landscape scales, linking small-scale variables with dispersal probabilities on large scales and we reflect the species, pinyon and juniper, dispersal in real landscapes. (Received September 21, 2018)

1145-92-1461 **Kaia R. Lindberg*** (klindberg923@g.rwu.edu) and **Edward T. Dougherty** (edougherty@rwu.edu). *Investigating Cellular-Level Effects of Neurostimulation Therapies with a Partial Differential Equation Based Mathematical Model.* Preliminary report.

Neurostimulation therapies have demonstrated success in mitigating symptoms of neurodegenerative diseases, but despite these promising clinical results, the cellular-level impacts of these treatments remain elusive. We have implemented a novel mathematical model that integrates the Poisson-Nernst-Planck system of PDEs and Hodgkin-Huxley based ODEs to model the effects of this neurotherapy on transmembrane voltage, ion channel gating, and ionic mobility. The governing system of equations is solved in part using the finite element method, on a biologically inspired discretized domain. Our results suggest two possible mechanisms by which neurostimulation operates to achieve therapeutic success. First, neurostimulation polarizes the cell membrane, elevating resting membrane potential in regions to facilitate action potential firing. Second, a neurostimulation-induced calcium influx alters cytosolic calcium concentrations, which is essential for proper neurotransmitter secretion and its dyshomeostatis is a known associate of neurodegenerative diseases. We also compare the effects of two different types of neurostimulation (transcranial electrical stimulation and deep brain stimulation) showcasing cellular-level differences resulting from these distinct forms of electrical therapy. (Received September 22, 2018)

1145-92-1468 **Nathan A Poppelreiter*** (nathan.poppelreiter@huskers.unl.edu). *Dynamic Observers for Unknown Populations.*

The concept of a dynamic observer is revisited in the context of population modeling. We describe their potential use for reconstructing population distributions for density-independent populations and a certain class of density-dependent populations, via dynamic measurements of the population. In the density-independent case, we show that these observers reconstruct the population faster than the state decays, and, in the density-dependent case, we show that this may or may not happen, although we give a guaranteed rate of convergence for the observer error to zero which is strictly less than a guaranteed rate of convergence of the population to a globally stable equilibrium. In both the density-dependent and -independent cases, we show, in several ecologically reasonable circumstances, that there is a natural, optimal construction of these observers. (Received September 22, 2018)

1145-92-1473 **Elizabeth M. Gilchrist*** (egilchrist140@g.rwu.edu), **Abigail T. Small** and **Edward T. Dougherty**. *A Computational Approach for Constructing an Intracellular Signaling Pathway Mathematical Model with Application to Parkinson's Disease.* Preliminary report.

Parkinson's disease (PD) is the second most common neurodegenerative disorder. Despite this, there is no cure and the exact cellular level pathogenesis remains elusive. In an attempt to gain new insights, we created a mathematical model of the intracellular signaling pathway of a dopaminergic neuron cell with application to

PD. A comprehensive literature search was conducted to construct a signaling wiring diagram, which was used to generate a system of ordinary differential equations using the law of mass action and the Michaelis-Menten equation. Many of the kinetics are presently unknown, so a novel computationally-based reverse engineering method was used to identify them; this approach uses the expected system behavior and the Metropolis Algorithm to numerically determine appropriate values. Suitable rates were ranked based on performance in a phenotype-based computational assessment, and then robustly screened using a k-means clustering assessment, sensitivity analyses, and an eigen-analysis. The result is a mathematical model that efficiently emulates the signaling network of a dopaminergic neuron model. We also showcase the ability of the model to emulate the intracellular processes of both a healthy dopaminergic neuron and one that presents with PD. (Received September 22, 2018)

1145-92-1507 **Kelly Anne Reagan*** (reaganka2@mymail.vcu.edu), **David Chan** and **Gonzalo Bearman**. *Impact of Chlorhexidine Gluconate Bathing on Hospital Acquired Infections.* Preliminary report.

Recent clinical research supports the use of Chlorhexidine gluconate (CHG) washcloths over bathing with soap and water to reduce hospital acquired infections (HAIs) (Vernon et al., 2006). A probabilistic model was created to examine CHG bathing compliance to describe HAI dynamics. Assuming a constant population size and constant discharge rate, the model incorporates the daily probabilities that a patient may be discharged, may acquire a hospital acquired infection (HAI) and may get CHG bathed. In this talk we explore the dynamics of this model. (Received September 22, 2018)

1145-92-1518 **Kendall Clark**, **Mayleen Cortez*** (mayleen.cortez136@myci.csuci.edu), **Cristian Hernandez** and **Beth Thomas**. *Combating tuberculosis: using time-dependent sensitivity analysis to develop strategies for treatment and prevention.* Preliminary report.

Although many organizations throughout the world have worked tirelessly to control tuberculosis (TB) epidemics, no country has yet been able to eradicate the disease completely. In this talk, we present two compartmental models representing the spread of a TB epidemic throughout a population. The first is a general TB model; the second is an adaptation for regions in which HIV is prevalent, accounting for the effects of TB/HIV co-infection. Using active subspaces, we conduct time-dependent sensitivity analysis on both models to explore the significance of certain parameters with respect to the spread of TB. We use the results of this sensitivity analysis to determine the most effective strategies for treatment and prevention throughout the epidemic. (Received September 22, 2018)

1145-92-1519 **Emek Kose** and **Allison L Lewis*** (lewisall@lafayette.edu), 210 Pardee Hall, Lafayette College, 730 High St., Easton, PA 18042, and **Elizabeth Zollinger**. *Investigating the effects of cancerous stem cells on tumor growth.* Preliminary report.

The stem cell hypothesis states that cancerous stem cells are the reason that tumors grow and persist, and proposes targeting treatments towards the cancerous stem cells instead of, or in addition to, the standard tumor cells. Building upon previous models, we develop a compartmental ODE model that includes the cancer stem cell, tumor cell, activated T-cell, regulatory T-cell, and TGF-β populations to investigate how they interact within the tumor. We apply a standard chemotherapy treatment protocol and show that even after treatment, the cancer stem cells are often strong enough to overcome the initial deterioration of the tumor from the effects of chemotherapy, aiding in the later resurgence of the tumor cell population. (Received September 22, 2018)

1145-92-1524 **Istvan Lauko**, **Gabriella Pinter** and **Rachel Elizabeth TeWinkel*** (tewinke2@uwm.edu), Department of Mathematical Sciences, PO Box 413, Milwaukee, WI 53201-0413. *Exploration of a Monkeypox Model.*

We build off of a monkeypox model with both human and animal populations where the infection is transferred within these populations and from animals to humans. There has been an increase in the incidence of monkeypox in human populations in recent years – partially due to the eradication of smallpox. The smallpox vaccine provides some protection against monkeypox, but since the eradication of smallpox, there is decreased presence of those vaccinated against it in human populations. Hence, we model infectivity in the human population as a function of time instead of being constant. We also investigate what changes when the birth and migration rates are functions of time instead of constants. We will present simulation results showing possible outcomes and will discuss what considerations may help minimize the impact of monkeypox. (Received September 22, 2018)

1145-92-1568 **Ting Hao Hsu** (thhsu296@gmail.com), **Tyler Meadows** (tm09ts@gmail.com), **Lin Wang** (lwang2@unb.ca) and **Gail S.K. Wolkowicz*** (wolkowic@mcmaster.ca), Hamilton, Ontario L8S 4K1, Canada. *Growth on Two Limiting Essential Resources in a Self-Cycling Fermentor.*

In this talk a system of impulsive differential equations with state-dependent impulses to model the growth of a single population on two limiting essential resources in a self-cycling fermentor is considered. Potential applications include water purification and biological waste remediation. The self-cycling fermentation process is a semi-batch process and the model is an example of a hybrid system. In this case, a well-stirred tank is partially drained, and subsequently refilled using fresh medium when the concentration of both resources (assumed to be pollutants) falls below some acceptable threshold. We consider the process successful if the threshold for emptying/refilling the reactor can be reached indefinitely without the time between successive emptying/refillings becoming unbounded and without interference by the operator. We derive necessary and sufficient conditions for the successful operation of the process that are shown to be initial condition dependent. We show that the fraction of the medium drained from the tank at each impulse plays a crucial role with respect to maximizing the output of the process. (Received September 23, 2018)

1145-92-1586 **Sebastian Schreiber*** (sschreiber@ucdavis.edu), Department of Evolution and Ecology, University of California, Davis, CA 95616. *Evolutionary games in spatially and temporally variable environments.*

Evolutionary game theory provides a framework for studying frequency-dependent population dynamics. Remarkably, the three basic games (the Prisoner's Dilemma, the Hawk-Dove game, and the Rock-Paper-Scissor game) have provided fundamental insights about the evolution of cooperation, animal contests, and Red Queen dynamics. An important, yet often under-appreciated, consideration in these games are the effects of spatial and temporal environmental heterogeneity on the maintenance of coexisting strategies. To model these effects, I will introduce a class of discrete-time, stochastic replicator equations that account for discrete space and stochastic fluctuations in payoffs for the interacting strategies. For these equations, I will describe theorems for stochastic persistence (i.e. the statistical tendency to stay away from low frequencies of any strategy) and asymptotic extinction of one or more strategies. These theorems will be used to characterize persistence and extinction for the hawk-dove and rock-paper scissor games. These characterizations will provide new biological insights about how dispersal rates, spatial and temporal variability, and autocorrelations in this variability influence the evolutionary maintenance or loss of biological diversity. (Received September 23, 2018)

1145-92-1598 **Katharine Gurski*** (kgurski@howard.edu), Howard University, Department of Mathematics, 2400 Sixth St, NW, Washington, DC 20059. *Sexually Transmitted Diseases and Longterm Relationships: Pair vs Non-pair formation models.*

Over the years, population models of sexually transmitted infections have included several approaches to modeling concurrency, i.e. overlapping sexual partnerships, and its effect of disease spread. In 2017, Kretzschmar and Heijne published a primer on pair formation models that considered monogamous pairs of different durations. They acknowledged that the difficulties of pair formation models are the inability to capture concurrency except through brief casual sexual partnerships and the rapidly increasing number of differential equations needed when adding heterogeneity to the population. In this talk we compare results from non-exclusive pair formation models to results from a non-pair model that instead incorporates the added infection from non-monogamous longterm partners to the rate of infection. Our model allows for multiple longterm partnerships, which adds the advantage of network models, the means to include serially monogamous and concurrent relationships, within the traditional strengths of a population model for computational speed and understanding of how each parameter affects the disease spread in an analytic reproduction number. The model can be further diversified by including populations divided by sexual behavior, age, and/or race/ethnicity. (Received September 23, 2018)

1145-92-1604 **Azmy Ackleh**, **Hal Caswell**, **Ross Chiquet** and **Tingting Tang*** (ttang@nd.edu), Notre Dame, Notre Dame, IN 46556, and **Amy Veprauskas**. *Sensitivity analysis of the recovery time for a population under the impact of an environmental disturbance.*

Wildlife populations are often affected by natural or artificial disasters which reduce their vital rates leading to drastic fluctuations in population dynamics. We use a stage-structured matrix model to study the recovery process of a population given an environmental disturbance. We focus on the time it takes the population to recover to its pre-event level and develop general formulas to calculate the sensitivity and elasticity of the recovery time to changes in the initial population, vital rates, and event severity. Our results suggest that the recovery time is independent of the initial population size but it is sensitive to the initial structure. Moreover, the recovery time is more sensitive to reductions in vital rates than to the duration of the impact of the event.

We explore an application of the model to the sperm whale population in Gulf of Mexico following a disturbance such as the Deepwater Horizon oil spill. (Received September 23, 2018)

1145-92-1615 **Timothy D Comar*** (tcomar@ben.edu), Dept of Mathematics, Benedictine University, 5700 College RD, Lisle, IL 60532. *Analysis of an Agent-Based Model for Integrated Pest Management with Periodic Control Strategies.*

We consider an agent-based model (ABM) for integrated pest management (IPM). The model incorporates stage structure for the pest and predator species. The control strategies of augmentation of the predator species and pesticide application and the pest births occur periodically at possibly different frequencies. Moreover, the amount of augmentation depends on the ratio of the population densities of the pests and predators. We determine conditions under which pest eradication occurs and under which both species persist. We further investigate how varying the frequencies of the control strategies affects the amounts pesticide and augmentation needed to obtain pest eradication or persistence.

To provide further insight to the dynamics of the ABM, we compare the model to analogous impulsive differential equation and difference equation models that exhibit similar behavior, for which we prove conditions for the global asymptotic stability of the pest eradication solution and the permanence of the systems. (Received September 23, 2018)

1145-92-1632 **William E Fitzgibbon**, **Jeff J Morgan**, **Glenn F Webb** and **Yixiang Wu*** (yixiang.wu@vanderbilt.edu). *Spatial Models of Vector-Host Epidemics with Directed Movement of Vectors Over Long Distances.*

We investigate a time-dependent spatial vector-host epidemic model with non-coincident domains for the vector and host populations. The host population resides in small non-overlapping sub-regions, while the vector population resides throughout a much larger region. The dynamics of the populations are modeled by a reaction-diffusion-advection compartmental system of partial differential equations. The disease is transmitted through vector and host populations in criss-cross fashion. We establish global well-posedness and uniform a prior bounds as well as the long-term behavior. The model is applied to simulate the outbreak of bluetongue disease in sheep transmitted by midges infected with bluetongue virus. We show that the long-range directed movement of the midge population, due to wind-aided movement, enhances the transmission of the disease to sheep in distant sites. (Received September 23, 2018)

1145-92-1646 **Mykhaylo M. Malakhov*** (mykhaylo@andrews.edu), **Ishan Phadke** (iphadke473@gmail.com), **Junyan Duan**, **Jordan Pellett**, **Katriona Shea** and **Julie C. Blackwood**. *Federalism in Epidemic Modeling: Multi-objective Management of Interconnected Populations.* Preliminary report.

Public health policy is inextricably linked with the allocation of regulatory authority between different levels of government. While infectious disease dynamics are in general well-understood, few modeling studies have considered spatially heterogeneous populations that fall under multiple administrative jurisdictions and hence under levels of government with potentially differing objectives. We pose and numerically analyze a two-patch $SIRS$-type model that explicitly incorporates migration and allows managers to choose between quarantine, vaccination, border closure, medication, and a travel ban on infected individuals while aiming to minimize either the number of patients or the number of deaths. In particular, we consider three classes of manager: a central government that acts equitably, local governments that act selfishly, and a non-governmental organization that seeks to maximize the overall good. We establish general guidelines for optimal governance and demonstrate several anomalous cases of interest. (Received September 23, 2018)

1145-92-1679 **Junping Shi***, Department of Mathematics, College of William and Mary, Williamsburg, VA 23187, and **Chuncheng Wang**, **Hao Wang** and **Qingyan Shi**. *Modeling animal movement with memory with partial differential equations with time-delay.*

Animal populations often self-organize into territorial structure from movements and interactions of individual animals. Memory is one of cognitive processes that may affect the movement and navigation of the animals. We will introduce our recent work using partial differential equations with time-delay to model and simulate the memory-based movement. We will show the bifurcation and pattern formation for such models. (Received September 23, 2018)

1145-92-1688 **Jue Wang***, Union College, 807 Union St., Schenectady, NY 12308. *Automatic Detection of Breast Masses and Location of the Prostate.*

A fast Enclosure Transform is developed to localize complex objects of interest from ultrasound images. This approach explores spatial constraints on regional features from a sparse image feature representation. Unrelated, broken ridge features surrounding an object are organized collaboratively, giving rise to the enclosureness of the object. Three enclosure likelihood measures are constructed, consisting of the enclosure force, potential energy, and encloser count. In the transform domain, the local maxima manifest the locations of interest objects, for which only the intrinsic dimension is known a priori. I will demonstrate two medical applications in detecting (1) suspicious breast masses in screening breast ultrasound, and (2) the location of the prostate in trans-abdominal ultrasound for verification of patient positioning in radiotherapy treatment of prostate cancer. (Received September 23, 2018)

1145-92-1730 **Anna Konstorum*** (konstorum@uchc.edu), **Anthony T. Vella**, **Adam J. Adler** and **Reinhard C. Laubenbacher**. *An intracellular model of synergistic CD8 T cell costimulation by 4-1BB (CD134) and OX40 (CD137).*

Combined agonist stimulation of the CD8 T cell costimulatory receptors OX40 (CD137) and 4-1BB (CD134) has been shown to generate supereffector T cells that survive longer and produce a greater quantity of cytokines that mediate tumor cell killing in vivo compared to T cells stimulated with an agonist of either costimulatory receptor individually. In order to understand the mechanisms for this synergy, we have created a multistate discrete logic-based mathematical model for the activation of the CD8 T cell intracellular signaling network by mono- or dual-costimulation (DCo). We show that synergy occurs from downstream interacting pathways that are activated upon activation of both receptors, and in silico simulation of the model supports published experimental results. We propose that the model can be used to identify critical molecular targets of synergy in the context of cancer immunotherapy. (Received September 24, 2018)

1145-92-1747 **Feng Fu***, 27 N. Main Street, 6188 Kemeny Hall, Hanover, NH 03755. *Mathematical models of adoptive cell transfer approach for cancer immunotherapy.* Preliminary report.

Recent continued breakthroughs in antibody research and advances in T-cell engineering techniques have begun to unleash the curative potential of cancer immunotherapy. Here our model takes into account two means of immunotherapy. First, administration of monoclonal antibodies with high specificity, which will result in an increase in the ability of immune cells to detect and eliminate cancer cells – its killing rate or efficacy. Second, adoptive immune cell transfer, characterized by the infusion of in-vitro engineered and personalized immune cells into patients. These two novel treatment methods can be combined to take advantage of the bistability phenomenon in cancer, and may be applied in concert as combination immunotherapy. We provide a quantitative mathematical framework to provide practical guidance for clinical assessment of immunotherapy. (Received September 24, 2018)

1145-92-1752 **Kelley France*** (kwarren3@uco.edu), **Brittany Bannish** and **Sean Laverty**. *Got Milk? Modeling a Dairy Allergy: Oral Immunotherapy and the Immune Response.*

The Centers for Disease Control & Prevention reports that the prevalence of food allergies in children increased by 50 percent between 1997 and 2011, and continues to rise. There is no cure and treatment and diagnostic protocols are limited. Understanding the dynamics of one treatment strategy, Oral Immunotherapy, is crucial to uncovering the potential for a cure. We build a differential equations model to study the interaction of a dairy allergen with helper T-cells and dendritic cells. Specifically, we are interested in how consistent exposure to an allergen can switch the production of Th2 helper T-cells (responsible for anaphylaxis) into production of Th1 helper T-cells (which do not produce an allergic reaction). Taking into account Th2 cells, Th1 cells, naive helper T-cells, Il-4 and Il-2 cytokines, and dendritic cells, we model the immune response to allergen exposure. We present our model and results, identifying conditions under which the Th1 cells outnumber Th2 cells, thereby changing the body's reaction to an allergen. We conclude by discussing the dynamics for various parameters. (Received September 24, 2018)

1145-92-1761 **Rebecca A Segal***, Dept of Mathematics, PO Box 842014, Richmond, VA 23284, and **Marcella Torres**, **Jing Wang**, **Paul J Yannie**, **Shobha Ghosh** and **Angela M Reynolds**. *Development of a mathematical model for the role of inflammation in atherosclerosis.* Preliminary report.

Atherosclerotic cardiovascular disease is a leading cause of morbidity and mortality despite significant advances in lipid management. Complex cellular interactions occur within the artery wall requiring the infiltration/egress of immune cells and lipoproteins within a changing inflammatory milieu and lead to the progression of an atherosclerotic plaque. We developed an ODE model for the influx of immune cells in the peritoneal cavity in response to a bacterial stimulus. Switching of macrophage phenotype from initial pro-inflammatory or M1 phenotype to anti-inflammatory or resolving M2 phenotype is described. The model parameters were calibrated using experimental data. This model is expanded to describe plaque formation arising from inflammatory

events. A two-compartment model includes local and systemic dynamics. The local compartment accounts for inflammation at the site the atherosclerotic plaque and progression to foam cells. In the systemic compartment, cells can be activated by LPS to take up lipoprotein derived cholesterol and become foam cells. We use the model to look at the connection between systemic and local measures of M1, M2, N, and pro-and anti-inflammatories. (Received September 24, 2018)

1145-92-1762 **Suzanne Robertson*** (srobertson7@vcu.edu). *Modeling and control of enzootic West Nile virus transmission: The role of the avian nesting curve.*

West Nile virus (WNV) is a major public health concern in the United States. While seasonal WNV outbreaks have been widely observed to be associated with the end of the avian nesting season, the ecological mechanisms responsible for this synchronicity are poorly understood. Newly hatched birds, or nestlings, have less feather coverage and fewer defense mechanisms than older birds, rendering them more vulnerable to mosquitoes. The rate at which new nestlings are produced is determined by the nestling recruitment curve, which can vary with avian species as well as climate. We use a mathematical model incorporating avian (host) stage-structure and within-species heterogeneity in the form of stage-specific mosquito (vector) biting rates to investigate the connection between properties of the avian nesting curve and enzootic WNV transmission. We determine the extent to which temporal fluctuations in host stage and vector abundance throughout the season, along with the differential exposure of these stages to mosquito bites, affects the timing and magnitude of WNV activity, as well as implications for public health interventions. Specifically, we explore the viability of nestling vaccination as a control for WNV. (Received September 24, 2018)

1145-92-1780 **Sarah Minucci**, **Rebecca Heise**, **Michael Valentine**, **Franck Kamga Gninzeko** (areynolds2@vcu.edu) and **Angela Reynolds*** (areynolds2@vcu.edu). *The modeling of Ventilator-Induced Lung Injury focusing on age-dependent stretched-induced inflammation at the cellular level: an Agent Based Model and ODE model.*

The elderly are the largest population requiring mechanical ventilation, and age is a predictive factor for the severity of ventilator-induced lung injury (VILI). VILI affects 800K patients/year with 53% of patients being 65 or older. Harmful mechanical stretch of the alveolar epithelium is a recognized mechanism of VILI, yet little is known about how mechanical stretch leads to inflammation and how this response changes with age. Therefore, we modeled age-dependent cellular level dynamics of this inflammatory response and alveolar type II (AT2) cells using both an agent based model and an ODE model. The ODE model was developed by expanding previous models for inflammation to include different immune cell types, neutrophils and various macrophage phenotypes and AT2 cells. Both models rely on experimental results for calibration. This talk focuses on this progression of models and how aging effects the initial conditions and resulting dynamics in these models. (Received September 24, 2018)

1145-92-1781 **Lucia Carichino*** (lcarichino@wpi.edu) and **Sarah D Olson**. *Emergent Three-Dimensional Sperm Motility Coupled to Calcium Dynamics.*

Sperm are navigating in a complex three-dimensional fluid environment in order to reach and to penetrate the egg. Changes in calcium concentration along the sperm flagellum regulate flagellar bend amplitude and beat asymmetry, enabling the sperm to achieve egg fertilization. However, the exact mechanisms of how calcium regulates the flagellar beat form are yet under investigation. We propose a fluid-structure interaction model that couples the three-dimensional motion of the flagellum in a Newtonian viscous fluid with the calcium dynamics in the flagellum. The flagellum is modeled as an elastic rod with preferred curvature and twist, using the Kirchhoff rod model. The calcium dynamics are represented as a one-dimensional reaction-diffusion model on the moving flagellum. The sperm motility and calcium dynamics are coupled assuming that the sperm flagellum preferred curvature depends on the local spatiotemporal evolving calcium concentration. The model is used to investigate the calcium coupling effect on the three-dimensional emergent waveforms and trajectories, compared to the two-dimensional case. Model results are in agreement with experiments, and show that three-dimensional trajectories can be characterized as hypotrochoid curves. (Received September 24, 2018)

1145-92-1786 **Stephen Gourley**, **Feng-bin Wang** and **Yanyu Xiao*** (yanyu.xiao@uc.edu). *A Model for machine tool vibration.*

We develop a delay differential equation that arises in the modeling of vibration (chatter)that can occur when machining a rotating workpiece using a lathe, in the case when the cutis made longitudinally. We explore conditions of eliminating chatter by spindle speed variation(SSV). (Received September 24, 2018)

1145-92-1819 **Andrew J. Bernoff**, **Michael Culshaw-Maurer**, **Rebecca Everett**, **Maryann E. Hohn**, **Christopher Strictland** and **Jasper Weinburd*** (weinburd@umn.edu).
Collective waves from individual behavior in foraging locusts.

Locusts gather by the millions to feed on crops, destroying fields of agricultural produce. As juveniles, wingless locusts march together and form a wave of advancing insects. We examine this collective propagation through two models: an agent-based model and a set of partial differential equations. The agent-based model is directly linked to individual behavior, via observations from the biological literature, while the PDE model yields insight into the collective behavior of the aggregate group. In this talk, we introduce both models and use them to determine the speed of the locust wave and the amount of food it leaves behind. (Received September 24, 2018)

1145-92-1836 **Taylor Meredith*** (taylor.meredith@nyu.edu), Courant Institute, 251 Mercer Street, New York, NY 10012, and **Calina Copos** and **Jennifer Crodelle**. *A Model of the Neuromuscular Junction and its Application to Myasthenia Gravis.*

The neuromuscular junction is an important biological structure where signals from a motor neuron are transmitted to muscle fibers and ultimately lead to a coordinated muscle contraction. Myasthenia gravis (MG) is an autoimmune disease characterized by muscle weakness. MG is caused by the blockage of a signifiant portion of ion channels, thus reducing the transmission of electrical activity to the muscle fiber. Treatment for MG extends the activation time of the working ion channels, resulting in a return of muscle strength. We develop a mathematical model to describe the dynamics of the ion channels and their effect on the electrical activity of muscle fibers. This model is then coupled to an existing framework for calcium dynamics of muscle contraction and force generation in the muscle. We demonstrate that our model reproduces experimentally-observed force generation under healthy, diseased, and treated conditions. The effectiveness of the treatment for MG is investigated using our model for varying degrees of the disease. (Received September 24, 2018)

1145-92-1842 **Christine Heitsch*** (heitsch@math.gatech.edu). *Spaces of RNA branching configurations.*

Understanding the folding of RNA sequences into three-dimensional structures is one of the fundamental challenges in molecular biology. For example, the branching of an RNA secondary structure is an important molecular characteristic yet difficult to predict correctly, especially for sequences on the scale of viral genomes like Influenza, Hepatitis C, and HIV. However, as we will show, results from enumerative, probabilistic, and geometric combinatorics characterize different types of branching landscapes. These theorems yield insights into RNA structure formation, and suggest new directions in viral capsid assembly. (Received September 24, 2018)

1145-92-1853 **Elena S Dimitrova***, edimit@clemson.edu. *Network modeling through multistate canalization.*

Boolean canalization, a type of hierarchical clustering of the inputs of a Boolean function, has been studied in the context of network modeling where each layer of canalization adds a degree of stability in the dynamics of the network. Multicellular populations give rise to emergent features such as patterns based upon the collective communication between neighboring and distant cells. This talk will present a recently introduced generalization of canalization to multistate functions and discuss the role of canalization in the study and control of multicellular populations. (Received September 24, 2018)

1145-92-1867 **Naveen K. Vaidya*** (nvaidya@sdsu.edu). *Role of the immune status of infected individuals on the transmission dynamics of HIV: From within-host to between-hosts models.*

Previous studies have suggested that HIV transmission highly depends on the immune status, particularly antibody levels, of the virus-source partners, indicating that the within-host immune status of infected individuals may have important role on the between-hosts transmission dynamics of HIV epidemics. In this talk, I will present mathematical models to estimate the effect of source partner's antibody-level status on the per-contact probability of HIV transmission. Using estimated probability in the between-hosts models, I will discuss how the source-host's disease status affects the HIV transmission dynamics in a community.

This is a joint work with 2018 REU (Research Experiences for Undergraduates) students Aidan Backus, Angelica Bloomquist, Carlos Villanueva-Chavez, J Montgomery Maxwell, Elyssa Sliheet, and Yuanming Tang. (Received September 24, 2018)

1145-92-1914 **Alexandria Volkening*** (volkening.2@mbi.osu.edu), MBI, 3rd Floor Jennings Hall, 1735 Neil Ave., Columbus, OH 43210. *Modeling and analysis of agent-based dynamics: an overview.*

Agent-based dynamics appear across the natural and social world; applications include swarming and flocking, pedestrian crowd movement, traffic flow, and the self-organization of cells during early development of organisms. Though disparate in application, many of these emergent patterns and collective dynamics share similar features (e.g. long-range communication, noise, fluctuations in population size, and multiple types of agents) and face some of the same modeling and analysis challenges. In this talk, we will use the concrete example of pigment cell interactions during zebrafish pattern formation to illustrate various ways of modeling agent behavior, including cellular automaton, agent-based, and continuum (PDE) models. We will discuss the benefits and drawbacks of these different approaches and highlight new ways to analyze collective behavior using TDA. This talk will be a general overview to how agent-based dynamics are described and analyzed mathematically and provide an introduction to the rest of the session. (Received September 24, 2018)

1145-92-1919 **Sarah B Minucci*** (minuccisb@vcu.edu), **Rebecca L Heise**, **Michael S Valentine**, **Franck J Kamga Gninzeko** and **Angela M Reynolds**. *Understanding the Role of Macrophages in Lung Inflammation Through Mathematical Modeling.*

Mechanical ventilation is used to provide support to the lungs for patients with severe breathing issues, but as the air is pushed into the alveolar space it can trigger an immune response which leads to ventilator-induced lung injury (VILI). We develop a compartmental ordinary differential equations (ODEs) model of the immune response to VILI. This model is also the first to account for various states of the epithelial cells (healthy, damaged, and dead). We use dynamical system approaches and sampling of parameter space to analyze the VILI immune response and illustrate multiple outcomes corresponding to health and severe damage. (Received September 24, 2018)

1145-92-1924 **Sergiy Koshkin** and **Isaiah G. Meyers*** (isaiah.meyers@utexas.edu), 1300 Crossing Place, APT 3631A, Austin, TX 78741, Austin, TX 78741. *A Harmonic Oscillator Analogy to Mathematical Biology Systems.* Preliminary report.

We give a novel presentation of a number of models in virus dynamics, epidemiology and plant biology as damped versions of the Lotka-Volterra predator-prey model. The analogy with the classical harmonic oscillators is drawn based on the use of Lyapunov functions, which allows for rich characterizations of these models. We consider applications to a model of virus dynamics, and a simplified model of plant growth. In the former, Lyapunov functions allow us to prove stability and provide a general method for bounding trajectories of the system. In the latter case, we are able to characterize the final length of the plant by using trapping regions produced by a family of Lyapunov functions. (Received September 24, 2018)

1145-92-1928 **Carina Curto*** (ccurto@psu.edu), ccurto@psu.edu. *Graph rules for inhibitory network dynamics.*

Many networks in the nervous system possess an abundance of inhibition, which serves to shape and stabilize neural dynamics. The neurons in such networks exhibit intricate patterns of connectivity, whose structure controls the allowed patterns of neural activity. In this work, we examine inhibitory threshold-linear networks whose dynamics are dictated by an underlying directed graph. We develop a set of parameter-independent graph rules that enable us to predict features of the dynamics from properties of the graph. These rules provide a direct link between the structure and function of these networks, and provides new insights into how connectivity may shape dynamics in real neural circuits. Our results can be found in https://arxiv.org/abs/1804.00794. (Received September 24, 2018)

1145-92-1970 **Sofya Zaytseva***, szaytseva@email.wm.edu, and **Leah B. Shaw**, **Junping Shi**, **Romuald N. Lipcius** and **Matthew L. Kirwan**. *Model of pattern formation in marsh ecosystems with nonlocal interactions.*

Spatial self-organization, a common feature of multi-species communities, can provide important insights into ecosystem structure and resilience. We present a mathematical model to describe self-organization of an eroding marsh shoreline based on three-way interactions between sediment volume and two ecosystem engineers – smooth cordgrass and ribbed mussels. The proposed model is a system of reaction-diffusion equations with nonlocal interaction terms accounting for scale-dependent grass-sediment and mussel-mussel interactions and modeled using Mexican hat kernel functions. We find that the emergence of spatial patterns depends on the scale and strength of the scale-dependent feedbacks modulated by the shape of the Mexican hat kernel functions. Further, changes in wavelength and variance of the observed spatial patterns can give insight into marsh recession.

Overall, the model suggests that self-organization of the marsh edge increases the system's productivity, allows it to withstand harsh erosion, and delays degradation that otherwise would occur in the absence of strong nonlocal species interactions, demonstrating the potential value of self-organization for marsh ecosystem management and restoration. (Received September 24, 2018)

1145-92-2002 **Abigail T. Small*** (asmall873@g.rwu.edu) and **Edward T. Dougherty** (edougherty@rwu.edu). *A Mathematical Approach for assessing tDCS efficacy for Post-Traumatic Stress Disorder.* Preliminary report.

Post-Traumatic Stress Disorder (PTSD) is a neurological condition caused by distressing or traumatic events. It has been recently found that symptoms of PTSD can be combated using forms of neurostimulation, in particular, transcranial direct current stimulation (tDCS). While it is known that the electrical energy delivered by this treatment to targeted portions of the brain is effective in treating PTSD, the optimal positioning of tDCS electrodes and treatment parameters for achieving the greatest treatment efficacy for an individualized patient is unknown. We have implemented a partial differential equation based mathematical model of tDCS with application to PTDS, and have generated numerous numerical simulations using the finite element method, all using distinct electrode montages, treatment parameters known to mitigate PTSD symptoms, and a three-dimensional MRI-derived cranial cavity with biologically-based tissue conductivities. The model provides a prediction not only of voltage and electrical current density within the head cavity, but also of the sensitivity of the brain tissue to fire an action potential during treatments. We present our current results and findings that begin to shed light on optimal tDCS settings for treating Post-Traumatic Stress Disorder. (Received September 24, 2018)

1145-92-2005 **James Greene*** (j.c.greene@rutgers.edu), Hill 216, 110 Frelinghuysen Road, Piscataway, NJ 08854, and **Eduardo Sontag**, **Jana Gevertz** and **Cynthia Sanchez-Tapia**. *The Impact of Induced Drug Resistance in Cancer Chemotherapy.*

Resistance to chemotherapy is a major impediment to successful cancer treatment that has been extensively studied over the past three decades. Classically, resistance is thought to arise primarily through random genetic mutations, after which mutated cells expand via Darwinian selection. However, recent experimental evidence suggests this evolution to resistance need not occur randomly, but instead may be induced by the application of the drug. Indeed, phenotype switching via epigenetic alterations is just recently beginning to be understood. In this work, we present a mathematical model to that describes both random and induced resistance. We discuss issues related to both structural and practical identifiability of model parameters. A time-optimal control problem is formulated and analyzed utilizing differential-geometric techniques. Specifically, the control structure is precisely characterized, and therapy outcome is analyzed for different levels of resistance induction through a combination of analytic and numerical results. Further extensions to combination therapies are also considered, and questions of combination vs. sequential therapy are studied. (Received September 24, 2018)

1145-92-2044 **Heather Z Brooks*** (hbrooks@math.ucla.edu), **Nina H Fefferman**, **Maryann E Hohn**, **Candice R Price**, **Ami E Radunskaya**, **Suzanne S Sindi**, **Nakeya D Williams** and **Shelby N Wilson**. *Parasites and the Evolution of Sociality: How Social Complexity and Grooming Efficiency Affect the Selective Pressures on Group Organization.*

Individuals who live in close, collaborative social groups are susceptible to infectious diseases such as pathogens and parasites. Ectoparasites are a particularly interesting case because social grooming (allogrooming) reduces the parasite load of one individual while potentially exposing both the groomer and groomee to additional transmission. Using an agent-based model that shows parasite spread based on individual behavior in a dynamic network, we model the interactions between social organization and allogrooming efficiency to consider whether or not certain physiological or energetic expenditures may have been required to allow the evolution/existence of increasingly complex social systems. Conversely, we explore whether social complexity may have been an adaptation to alleviate burdens of allogrooming under parasitic threat. We also consider the role of social position for individuals (where status is often correlated with frequency of allogrooming) and contextualize the fitness consequences for individuals in both high and low ranking positions as they feed back to determine the fitness of the whole population. (Received September 24, 2018)

1145-92-2047 **Leif Zinn-Bjorkman*** (zinn@math.ucla.edu) and **Frederick R Adler**. *Modeling factors that regulate cell cooperativity in the zebrafish posterior lateral line primordium.*

Collective cell migration is an integral part of organismal development. We consider migration of the zebrafish primordium during development of the posterior lateral line, a sensory system that detects water movement patterns. Experiments have shown that the chemokine ligand CXCL12a and its receptors CXCR4b and CXCR7b

are key players for driving migration of the primordium, while FGF signaling helps maintain cohesion. In this work, we formulate a mathematical model of a laser ablated primordium separated into two smaller cell collectives: a leading collective that responds to local CXCL12a levels and a trailing collective that migrates up a local FGF gradient. Our model replicates recent experimental results, while also predicting a "runaway" behavior when FGF gradient response is inhibited. We also use our model to estimate diffusion coefficients of CXCL12a and FGF in the lateral line. (Received September 24, 2018)

1145-92-2050 **Chunhua Shan*** (chunhua.shan@utoledo.edu), **Guihong Fan** and **Huaiping Zhu**. *Transmission dynamics and oscillations in a model of West Nile virus.*

West Nile virus is a typical vector-borne disease transmitted to humans and animals by Culex mosquitoes. For the virus, avian birds serve as amplification hosts, yet vector mosquitoes play a critical role in the disease transmission. To investigate the role of mosquitoes in transmission dynamics of West Nile virus, we formulate a system of delay differential equations with a standard incidence rate to model the interaction between mosquitoes and birds. Our analysis shows that the mosquito population can force the system to oscillate, while incidental interaction between mosquitoes and birds would not cause oscillations. This result indicates that the population of mosquitoes is the fundamental driving factor for the oscillation in disease transmission when the impact of temperature is taken into consideration. (Received September 24, 2018)

1145-92-2074 **Gaurav Mendiratta*** (gmendiratta@salk.edu), CA. *Modeling cell-cell interaction based pattern generation by Notch pathway.* Preliminary report.

Notch pathway plays a crucial role in cell fate decisions in developmental processes in all animals. Members of Notch pathway have been shown to be commonly dis-regulated in a large number of cancers. The mechanism of interaction of notch and it's ligands is primitive and at least in some cases follows simple rules of cis-inhibition and trans-activation. We define a model of interacting nearest neighbors representing the cell-cell interaction mediated by notch pathway. We use this model to explore the implications to pattern formation and response to perturbations. We computationally simulate the model to study the effects of different modifications of the signaling pathway which are used in biological systems to achieve different, sometimes opposing phenotypes. (Received September 24, 2018)

1145-92-2107 **Carolyn M Eady*** (ceady@math.fsu.edu), Florida State University, Department of Mathematics, 1017 Academic Way, Tallahassee, FL 32306. *Discrete Conformal Invariants on Triangle Meshes of Brain Data.*

The human brain is highly folded, making visualization difficult. We employ discrete conformal methods to map three-dimensional cortical surface data in the form of triangulated meshes. Using the quasi-conformal method of circle packing, we map the cortical surface to a desired constant curvature surface. We calculate discrete conformal invariants, such as harmonic measure. To calculate harmonic measure, we simulate random walks on a triangulated mesh and measure the probability that a walk exits through each boundary edge, as well as investigate the distribution of the number of times it takes each walk to reach the boundary. By calculating such invariants across data sets, we can compare and contrast between healthy and diseased brains to determine macro-scale abnormalities.

We also discuss methods for comparing two cortical surfaces using a distortion metric. This uses a composition of conformal mappings, under which a distortion energy function must be minimized. Previously this work has been applied to closed surfaces; we give a proof of concept for extending it to open surfaces. (Received September 24, 2018)

1145-92-2130 **Eleni Panagiotou*** (eleni-panagiotou@utc.edu) and **Kevin W Plaxco**. *A topological study of protein folding kinetics.*

Focusing on a small set of proteins that i) fold in a concerted, "all-or-none" fashion and ii) do not contain knots or slipknots, we show that the Gauss linking integral, the torsion and the number of sequence-distant contacts provide information regarding the folding rate. Our results suggest that the global topology/geometry of the proteins shifts from right-handed to left-handed with decreasing folding rate, and that this requires more sequence-distant contacts. (Received September 24, 2018)

1145-92-2239 **James A Powell*** (jim.powell@usu.edu), Logan, UT. *One spot, two spot, red spot grew spots: How differential dispersal, phenology and the Allee effect predict pattern formation in mountain pine beetle impact.*

The mountain pine beetle (MPB), is an aggressive insect which attacks pine trees. Pines have significant physical/chemical defenses, requiring the beetles to attack en masse to successfully colonize. Beetle larvae consume the phloem, killing the host and requiring dispersal to find new hosts. Temperatures nonlinearly control development and emergence, creating a thermal niche depending on synchronized timing and dispersal. Warming has broadened this niche across western North America, causing recent tree mortality over 60 million hectares. Observed patterns run the gamut from apparently random, persistent spots to aggregating spots and growing patches to complete mortality in susceptible age classes. A mechanistic model based on differential beetle motility between forested and unforested habitats (ecological diffusion), temperature control of MPB and the Allee effect recovers most variability at landscape scales but misses spots appearing at low emergence levels. Landscape resistance to movement (minimal travel time) can be calculated using host-dependent motility, and we argue that spots should follow a power-law distribution in travel time from previous infestations. The power-law hypothesis is tested against data from MPB outbreaks in Idaho, Colorado and Washington state. (Received September 25, 2018)

1145-92-2247 **Eric Marland*** (marlandes@appstate.edu), 121 Bodenheimer Drive, Boone, NC 28608, and **Gregg Marland**. *Timing of Carbon Release from Harvested Wood Products: Implications for Climate Policy.*

The role of harvested wood products has always taken a back seat in conversations about managing climate change. Harvests are sometimes seen as a necessary evil that helps manage natural disturbances and placate the lumber industry. This talk presents a careful look at both the role that harvested wood currently plays in sequestering carbon and the potential role that it could play. (Received September 25, 2018)

1145-92-2255 **Caleb L Adams*** (cadams5@radford.edu), Radford University, PO Box 6942, Radford, VA 24142. *Dynamics of Liver Glycogen in a Glucose-Regulatory Model.* Preliminary report.

The body's blood glucose concentration is tightly controlled by counter-regulatory hormones insulin and glucagon. In order to maintain a basal state, the body stores glucose in the liver when glucose is in excess, typically from a meal, and utilizes this storage when glucose is scarce, often during prolong fasts. Presented in this talk is an extension of a glucose-insulin-glucagon model which incorporates the storage and utilization of liver glycogen. Discusses will be dynamics of the model at each phase of development. (Received September 25, 2018)

1145-92-2295 **Nakeya D Williams*** (nakeya.williams@usma.edu), Cornwall, NY 12518. *Cardiovascular dynamics during orthostatic stress assessed via pulsatile and non-pulsatile models.* Preliminary report.

This study develops non-pulsatile and pulsatile models for prediction of blood flow and pressure during orthostatic stress. The head-up tilt (HUT) test is used to diagnose potential pathologies due to orthostatic stress within the autonomic control system, which acts to keep the cardiovascular system at homeostasis. Mathematical modeling is utilized to predict changes in cardiac contractility, vascular resistance, and arterial compliance, quantities that cannot be measured, but are useful to assess the system's state. These quantities are predicted as time-varying parameters modeled using piecewise linear splines. Having models with various levels of complexity formulated with a common set of parameters, allows us to combine long-term non-pulsatile simulations with pulsatile simulations on a shorter time-scale. Results show that if volume data is available for all vascular compartments three parameters can be identified, cardiovascular resistance, vascular compliance, and ventricular contractility, whereas if model predictions are made against arterial pressure and cardiac output data alone, only two parameters can be estimated either resistance and contractility or resistance and compliance. (Received September 25, 2018)

1145-92-2333 **Lauren Marazzi**, Center for Quantitative Medicine, 263 Farmington Avenue, Farmington, CT 06030, and **Paola Vera-Licona*** (veralicona@uchc.edu), Center for Quantitative Medicine, Farmington, CT 06030. *Reversion of the attractor landscapes of an intracellular regulatory network for triple-negative breast cancer.* Preliminary report.

In this talk we will present a system biology pipeline to study the reversion of triple negative breast cancer. The core of the pipeline is the construction of a Boolean model of a core intracellular signaling network of triple negative breast cancer. The model integrates key regulatory molecules and their interactions from survey of literature and experimental data. To evaluate attractors associated to cancerous states, readout nodes include features of hallmarks of cancer. We will discuss a systematic procedure to identify molecular targets that, when perturbed in the model, can modify the attractor landscape with respect to readout cancer hallmarks. Finally we will discuss prioritization and validations of identified targets. (Received September 25, 2018)

1145-92-2342 **Punit Gandhi*** (gandhi.138@mbi.osu), Mathematical Biosciences Institute, Ohio State University, 374 Jennings Hall, 1735 Neil Ave, Columbus, OH 43210, and **Sara Bonetti**, **Sarah Iams**, **Amilcare Porporato** and **Mary Silber**. *Water transport in models of dryland vegetation patterns.* Preliminary report.

Many dryland ecosystems exhibit bands of vegetation growth alternating with bare soil on very gently sloped terrain. The vegetation bands are typically tens of meters thick with spacing on the order of a hundred meters, and form a regular striped pattern that can occupy tens of square kilometers on the landscape. Such patterns have been qualitatively reproduced by reaction-advection-diffusion systems that model various interactions between the plants and their water-limited environment. I will discuss aspects of the surface/subsurface water dynamics. Capturing these hydrological processes on appropriate timescales may allow us to better utilize observational data as we work to identify the dominant mechanisms underlying the formation of dryland vegetation patterns and understand how environmental factors influence pattern characteristics. (Received September 25, 2018)

1145-92-2404 **Joe John Klobusicky*** (klobuj@rpi.edu), 110 8th St., Troy, NY 12180, and **Peter Kramer** and **John Fricks**. *Averaging for molecular motors with switching behavior.*

We present a stochastic model for the evolution of molecular motors along a microtubule. The model allows for attachment and detachment of motors at rates which depend on motor positions. This results in a system of stochastic differential equations with an underlying Cox process which determines switching. In this talk, we will show a separation of scales for motor variables, which allows us to take homogenization limits to describe effective behavior of the expected position of the motor system. We also include several experiments comparing theoretical results with simulations. (Received September 25, 2018)

1145-92-2432 **Joseph Benson*** (jbenson4@macalester.edu), **Andrew Bernoff**, **Mariya Bessonov**, **Simone Cassani**, **Danielle Ciesielski**, **Daniel Cooney**, **Veronica Ciocanel** and **Alexandria Volkening**. *A social force agent based model for pedestrian dynamics.* Preliminary report.

Pedestrian crowds display rich and complex walking behaviors. They separate into lanes when walking in opposite directions, form zipper-like lanes when crossing at an angle, and display stop-and-go waves in high density situations. We investigate a social force agent-based model that can reproduce the aforementioned scenarios. This talk will describe the details of the model, as well as ongoing work to study pedestrian dynamics in large classroom settings. This study may have applications to efficient classroom entrance and evacuation for large university lecture halls. (Received September 25, 2018)

1145-92-2445 **E E Goldwyn***, goldwyn@up.edu. *Data Driven Models of Pathogen Competition in Gypsy Moth Populations.* Preliminary report.

The North American gypsy moth is a non-native pest which causes widespread economic damage and forest defoliation. Gypsy moth populations undergoes episodic outbreaks that are driven by interactions with a viral and a fungal pathogen. While viral transmission is strongly density dependent, fungal transmission is weather dependent. Using maximum likelihood techniques and an MCMC routine, we fit parameters from a predictive SIR-type disease transmission model of the within season dynamics of the gypsy moth to field data collected from natural populations. (Received September 25, 2018)

1145-92-2467 **Hildur Knutsdottir***, hildur@jhu.edu, and **Eirikur Palsson** and **Leah Edelstein-Keshet**. *Force-based modeling framework of individual cells used to study collective cell migration in development and cancer.*

Cell migration is driven by biophysical and biochemical cues that act in unison and across multiple spatial and temporal scales. The research presented here focuses on cell-cell interactions and how individual cell behavior influences collective cell migration. The framework that I use is a hybrid discrete cell model, HyDiCell3D. Cells are represented as deformable ellipsoids that interact through both mechanical (i.e. cell-cell adhesion) and chemical (i.e. chemotaxis) signals. Internal biochemistry of each cell is captured by ordinary differential equations describing the evolution of a particular factor (i.e. protein or gene) and it is linked to the cell's mechanical properties. Cell motion is calculated from the net force acting on the cell. These forces are, 1) active forces, both random and chemotactic, 2) adhesive forces associated with cell-cell and cell-substrate contact and 3) exclusion forces that prevent cells from overlapping. The HyDiCell3D is fast, simulating thousands of cells in minutes on a laptop, fully 3D and has the flexibility to design simulations to capture different biological experiments. I will present examples of the use of HyDiCell3D to study breast cancer metastasis as well as a process that occurs in early development of sensory organs in zebrafish. (Received September 25, 2018)

1145-92-2482 **Lester Caudill*** (lcaudill@richmond.edu) and **Barry Lawson** (blawson@richmond.edu). *Not Just Either/Or: Discrete and Continuous Models Play Nicely Together in a Model of Hospital Infection.*

Differential equations (DE) have a long and storied history in biomedical modeling, and remain a sensible choice in many instances. Likewise, agent-based modeling (ABM) is the tool of choice in a growing number of biomathematical applications. While these two modeling approaches vary wildly in their strengths and implementations, there exist situations in which both can play a significant and interactive role within a single project. We will report on one such enterprise, designed to investigate the effectiveness of proposed efforts to control the spread of antibiotic resistance in hospitals. Emphasis will be on the roles of ABM and DE, the leveraging of their relative strengths, and efforts to mesh the two disparate methods into a single, working entity. (Received September 25, 2018)

1145-92-2488 **Gangaram S Ladde*** (gladde@usf.edu), Department of Mathematics and Statistics, University of South Florida, Tampa, FL 33620-5700. *Interconnected Nonlinear Survival State Hybrid Dynamic Models.* Preliminary report.

In this work, a large-scale interconnected nonlinear stochastic hybrid dynamic model for survival state process is developed. Employing energy function and differential inequalities methods, comparison theorems are developed. These comparison theorems are applied to investigate various types invariant sets and their qualitative properties, in a systematic way. (Received September 25, 2018)

1145-92-2489 **Mariel Vazquez***, Department of Mathematics, UC Davis, One Shields Ave., Davis, CA 95616. *Modifying DNA topology through packing and enzymatic reactions.*

Flexible circular chains appear often in nature, from microscopic DNA plasmids to macroscopic loops in solar corona. Such chains entrap rich geometrical and topological complexity which can give insight into the processes underlying their formation or modification. While knotted and interlinked DNA molecules are believed to be undesired in the cellular environment, they have been shown to occur as by-products of enzymatic reactions and of DNA packing. Reconnection processes involving one or two cleavages are used to simplify the topology of DNA. Examples include the action of type II topoisomerases and DNA recombination. We use techniques from knot theory and low-dimensional topology, aided by discrete methods and computational tools to study DNA packing, and the action of enzymes that change the topology of DNA. We are particularly interested in processes of unknotting and unlinking by local reconnection, and in the packing of DNA in bacteriophage capsids. In this talk I will give and overview of some of this research. (Received September 25, 2018)

1145-92-2503 **Adrienna Bingham*** (anbingham@email.wm.edu), **Elsa Rousseau**, **Leah Shaw**, **Simone Bianco** and **Raul Andino**. *Multiscale Competition Between Defective Interfering Particles and Wild Type Poliovirus.*

Defective interfering particles (DIPs) are a mutation of a wild type (WT) virus that lack essential elements needed for viral reproduction. In order to successfully reproduce, they steal these elements from the WT, acting as cheaters and limiting WT production. With shorter genomes, DIPS are able to reproduce more quickly, giving them an advantage over the WT. DIPs have been engineered to steal capsids from WT poliovirus. Poliovirus, still endemic in some countries, is a model RNA virus, so results can yield insights into other RNA viruses. We have created a two-patch organ model to simulate the competition between DIPs and WT poliovirus, allowing free virus particles to travel from one organ to another. By changing parameter values, initial conditions, and virion migration rates, we can simulate different scenarios of DIP and WT competition. Using parameter values found in the literature and from individual experiments, DIPs will lower the WT population size. Additionally, we have created a one-patch interferon immune response model to capture the competition of DIPs and WT poliovirus in a single organ with the added complication of reduced susceptible cells. (Received September 25, 2018)

1145-92-2625 **Anna Mummert*** (mummerta@marshall.edu), **Roger Estep** (estep102@marshall.edu), **Robert Hughes** (robhghes@gmail.com) and **Jessica Shiltz** (jessica.l.shiltz@wv.gov). *Two Waves of Pandemic Influenza: An Agent-based Exploration.* Preliminary report.

In the United States, the past four pandemic influenza outbreaks have shown two waves of infection – one in the summer and one in the winter. This contrasts with seasonal influenza which has only one wave during the winter. The exact mechanisms leading to one wave or two are not know. In this talk I will describe an agent-based Susceptible-Exposed-Infectious-Recovered disease model for a closed population. The model is parameterized using values for seasonal influenza spread in the United States. Remarkably, though rarely, the seasonal influenza model can show two waves of infection, matching that of a pandemic influenza outbreak. The agent-based model is modified using several intervention strategies, such as vaccination and quarantine. The each modified model is explored for conditions leading to two waves of infection. (Received September 25, 2018)

1145-92-2631 **Christopher E Miles***, 215 Mercer Street, New York, NY 10012, and **Sean D Lawley**. *How receptor diffusion and cell rotations increase association rates with extracellular reactants.* Preliminary report.

Signaling involving extracellular ligands that undergo diffusion and bind to surface receptors is a critical for cells to function. For this reason, the rate at which receptors receive signals has been of great theoretical interest for over 40 years. However, this previous work has largely neglected orientation effects: both the cells rotating and the receptors diffusing laterally along the surface. We'll propose a stochastic PDE model including both of these effects, and using a matched asymptotic analysis, derive an analytical expression for the mean arrival rate of ligands to the receptor. To compare to Monte Carlo simulations, we also propose a single particle interpretation of the solution to the stochastic PDE. Ultimately, we find that these rotational effects can greatly increase the association rates in certain biological contexts. (Received September 25, 2018)

1145-92-2741 **Richard Schugart*** (richard.schugart@wku.edu). *Using a Mathematical Model with Individual Patient Data to Quantify Differences Between Patients with Diabetic Foot Ulcers.* Preliminary report.

In this work, we quantify differences in healing responses between type-II diabetic patients with foot ulcers. This work builds off of our previous publication (Krishna et al., B Math Biol, 2015), where we formulate a mathematical model to describe healing responses using averaged time-course data from another study (Muller et al., Diabet Med, 2008). In Mullers work, they collect data from 16 patients with type-II diabetes. In addition to recording wound areas, Muller also measures levels of matrix metalloproteinases and their inhibitors at Weeks 0, 1, 2, 4, 8, and 12, collected from wound fluid. The patients are divided into two groups categorized as good healers and poor healers dependent upon the healing response at the four-week point. In our previous work, we use the average data to calibrate our mathematical model and quantify differences between the two groups. In our current work, we have calibrated our mathematical model for each individual patient and have quantified differences between these patients. In this presentation, we will discuss how our model has identified differences across patients using a variety of techniques. (Received September 25, 2018)

1145-92-2761 **Lindsey Fox*** (lfox7@vols.utk.edu), Ayres Hall 208, 1403 Circle Drive, Knoxville, TN 37996. *A Model to Explore the Origin of Heart Rate Variability.*

Heart rate variability (HRV) is the variation in the time interval between heartbeats. Correlation between loss of HRV and a body undergoing a state of stress (exercise, disease, etc.) has been well documented in clinical practice and experimental studies. However, this correlation has not been fully linked to underlying physiological mechanisms. Previous work hypothesizes that current cardiovascular models need to incorporate a respiratory component to capture the variability seen in heart rate data. This work attempts to model heart rate as a function of blood pressure and respiration, and incorporates neuroendocrine control of these mechanisms by the parasympathetic and sympathetic branches of the nervous system, to explain the source of HRV in a resting, healthy state. (Received September 25, 2018)

1145-92-2817 **Tin Phan*** (tin.t.phan@asu.edu), **Yang Kuang**, **Maria Emelianenko**, **Daniel M Anderson**, **Fatah Kashanchi**, **Catherine Demarino**, **Michelle L Pleet**, **Daniel O Pinto** and **Maria Cowen**. *Differences in Transcriptional Dynamics Between T-cells and Macrophages as Determined by a Three-State Mathematical Model.*

The treatment of HIV-1 with the use of combination antiretroviral therapy greatly reduced viral loads. Yet, viral transcription persists despite treatment. We created and validated a three-state mathematical model to explore the states of the HIV-1 LTR and generation of viral products. This model is novel in its integration of long and short HIV-1 RNA products and can be used to successfully model different cell types in a variety of physiological conditions.

We demonstrated that the overall patterns of change in LTR states are similar in T-cells and macrophages. However, both cell types exhibit unique LTR dynamics in terms of timing, relative proportion of LTR states, and differences in LTR state variability. These variations result in differences in the magnitude of viral products generated in infected T-cells and macrophages. The model can provide a reasonable match for the experimental data without any computational fitting techniques.

Through incorporation of transcription inhibitor into the model, we showed how to implement the model to assess drug efficacy among cell types. Furthermore, the model provides a platform to study various transcriptional dynamics. (Received September 25, 2018)

1145-92-2825 **Devin Akman*** (akman2@illinois.edu), **Carlos Bustamante**, **Jordy Cevallos**, **Cui-Hua Wang**, **Jordan Bates**, **Viswanathan Arunachalam**, **Leon M. Arriola** and **Baojun Song**. *Modeling an Anthrax Plume: Prioritizing the Delivery of Antibiotics After an Anthrax Bioterrorism Event.*

Anthrax is a potentially fatal pathogen and could be used as a biological weapon with devastating consequences. In the case of a hypothetical anthrax attack on Maricopa County, the current governmental response plan is inadequate. The standard plume model predicts an unrealistically high number of infections because it assumes that anthrax spores are uniformly distributed over a large area and that all who breathe the spores get infected. It is impossible to deliver the requisite number of antibiotics under that model before the infections progress to an untreatable stage. We develop a fine-grained plume model with GIS data. The model is based on the scalar transport equation and in-host modeling and assumes a drone attack. We obtain the diffusion and advection coefficients of the plume of anthrax spores and use the resultant concentrations along with census data to build a susceptibility model. This model predicts which areas will be the hardest hit and, therefore, what quantity of antibiotics should be delivered based on population density. Wind conditions play a significant role in shaping the plume. We conclude that state and local governments should modify their simplistic Gaussian plume models in order to better serve the people in harm's way. (Received September 25, 2018)

1145-92-2828 **Zhisheng Shuai*** (shuai@ucf.edu), Department of Mathematics, University of Central Florida, Orlando, FL 32816. *Target Reproduction Numbers: A General Framework for Threshold Parameters in Population Dynamics.* Preliminary report.

A general framework for threshold parameters in population dynamics is developed using the concept of target reproduction numbers. This framework identifies reproduction numbers and other threshold parameters in the literature in terms of their roles in population control. The framework is applied to the analysis of several common control strategies in ecology and epidemiology, which provides new biological insights. (Received September 25, 2018)

1145-92-2900 **Dan Hrozencik*** (dhro@att.net), 9501 S. King Dr., HWH 332, Chicago, IL 66028, and **Olcay Akman**. *On The Implementation of Artificial Neural Networks For Estimation Of Gene Regulatory Network Propensities.*

This paper presents a innovative method for optimizing the state transition variability of gene regulatory networks (GRNs) due stochastic variation of propensity probabilities caused by internal noise at the molecular level. Using neural network modeling the state transition variability was measured to be within reasonable bounds. Results show promising agreement with theoretical predictions and significant improvement over previous efforts by Akman et al. The work presented here has profound implications for future studies of stochastic GRN modeling. (Received September 25, 2018)

1145-92-2954 **Laura F Strube*** (lfstrube@vt.edu) and **Frederick R Adler** (adler@math.utah.edu). *A Mathematical Model of Translation Regulation by the Integrated Stress Response: the ISR as an Analog-Digital Mechanism Tuned by eIF2B.*

The integrated stress response (ISR) is a conserved pathway that is activated in response to a range of intracellular stress conditions. At its core, this mechanism diverts two central factors from the translation cycle and in doing so attenuates canonical protein translation. Paradoxically this diversion also upregulates expression of stress response genes via a non-canonical translation mechanism. The key players of this system are the translation factor eIF2, its recycler eIF2B, an eIF2 kinase, and the transcription factor ATF4. We describe a non-linear ODE model of ISR-induced translation regulation incorporating probabilistically-derived reaction rates to describe translation as a function of stress level. We show that this model exhibits a range of responses tuned by eIF2B. At one extreme, low eIF2B produces a digital response with small amounts of stress causing a dramatic drop in canonical translation and increase in the expression of ATF4. At the other, high eIF2B produces an analog response in which translation rates change gradually with stress. Intermediate eIF2B concentrations produce a hysteretic hybrid of these two behaviors. This model shows that variation in eIF2B concentration across cell tissues provides a means of tuning the sensitivity of the ISR to stress. (Received September 25, 2018)

1145-92-2985 **Casian Pantea*** (cpantea@math.wvu.edu) and **Murad Banaji**. *Inheritance of bistability in mass action reaction networks.*

This talk focuses on the question of bistability, or existence of multiple (stable) positive equilibria, a dynamical property that underlies important cellular processes, and a recurring theme in recent work on reaction networks. Namely, we consider the question: "when can we conclude that a network admits multiple stable positive equilibria based on analysis of its subnetworks?" We identify a number of operations on reaction networks that

preserve bistability as we build up the network, and we illustrate the power of this approach on the much-studied Huang-Ferrell MAPK cascade. Work in this direction falls within the theory of "motifs", an important theme in systems biology. (Received September 26, 2018)

1145-92-3023 **Jared O Barber***, Department of Mathematical Sciences, 402 N Blackford St, LD 270E, Indianapolis, IN 46202, and **Luoding Zhu**. *A mathematical model of breast cancer cell motion through a microfluidic device.* Preliminary report.

Deaths due to breast cancer are primarily due to metastasis to other parts of the body. Decreasing the frequency of the events that form the metastatic cascade has been the subject of many studies that aim to mitigate the effects of breast cancer on the 3.5 million Americans affected by the disease. Experiments suggest that mechanotransduction, a process by which mechanical forces initiate cellular processes, may play an important role in the metastatic cascade. Because of these insights, we have developed a mechanical model of breast cancer cell translocation for use in microfluidic devices as well as in vivo settings. The initial model is two-dimensional and consists of several interconnected viscoelastic elements that are submersed in a surrounding Stokes flow. We have used the model to consider flow through tapered and square microfluidic channels. With further calibration, we believe the model can be used to assess the effectiveness of various diagnostic microfluidic devices including suggesting ways to improve device design. We also believe that further model development will enable consideration of metastatic potential in in vivo settings. (Received September 26, 2018)

1145-92-3027 **Sara Amato*** (sara.amato@assumption.edu), **Lauren Moore**, **Kaitlin Ragosta**, **Shelby Stowe**, **Sarah Gaichas**, **Burt Tilley** and **Andrea Arnold**. *Modeling the Spatio-Temporal Dynamics of Interacting Fish Species in the Northeast Continental Shelf.*

Knowledge of the population dynamics of marine species is vital to understanding ocean sustainability. This project aims to develop and analyze spatio-temporal single-species and multi-species models for studying fish population dynamics in the Northeast Continental Shelf, specifically Atlantic cod and Atlantic herring. We formulate partial differential equation models and integrodifference models that take into account species interactions between Atlantic cod and Atlantic herring. We determine a method to compare our single-species and multi-species models, to provide information to the Northeast Fisheries Science Center on whether either species would benefit from being assessed with a multi-species model. All models consider species' behavior, including seasonal migrations. We employ statistical approaches such as nonlinear filtering to estimate model parameters and quantify uncertainty in model predictions, comparing the results to synthetic data. (Received September 26, 2018)

93 ► Systems theory; control

1145-93-356 **Roby Poteau*** (rpoteau2010@my.fit.edu) and **Ugur Abdulla** (abdulla@fit.edu). *Identification of Parameters in Systems Biology.*

We consider the inverse problem for the identification of the finite dimensional set of parameters for systems of nonlinear ordinary differential equations (ODEs) arising in systems biology. A numerical method which combines Bellman's quasilinearization with sensitivity analysis and Tikhonov's regularization is implemented. We apply the method to various biological models such as the classical Lotka-Volterra system, bistable switch model in genetic regulatory networks, gene regulation and repressilator models from synthetic biology. The numerical results and application to real data demonstrate the quadratic convergence. (Received September 03, 2018)

1145-93-717 **Addison W Bohannon*** (addison.w.bohannon.civ@mail.mil). *Adaptive Individualized Technology to Facilitate Teamwork in Human-Agent Military Teams.* Preliminary report.

Military operations require the teamwork of Soldiers to plan and execute collective action in a dynamic and adversarial environment. As military teams expand to include increasingly autonomous and intelligent robots, drones, and sensors, how will these human-agent teams coordinate to execute complex missions? In human teams, teamwork processes such as communication, mutually supporting goals, and shared mental models underlie effective team performance. The Army believes that adaptive interventions at the individual level can facilitate teamwork in human-agent teams. This talk will outline that approach and its scientific questions: What are the relevant teamwork processes in human-agent teams? What dynamics govern these processes? How do we observe a latent teamwork process? Finally, how do we then influence that process through individually adapted technologies? We will discuss a preliminary effort to predict latent team processes such as effective communication from the structured interactions of a military staff during a training exercise. From the pairwise interactions of team members encoded as a weighted adjacency matrix, we use matrix recovery techniques to identify communication patterns that track external evaluations of teamwork. (Received September 24, 2018)

1145-93-1516 **Cara J. Sulyok***, csulyok@vols.utk.edu. *Modeling the Immune Response of Celiac Disease.* Preliminary report.

Celiac disease is a hereditary autoimmune disease that affects approximately 1 in 133 Americans. It is caused by a reaction to the protein gluten found in wheat, rye, and barley. After ingesting gluten, a patient with celiac disease may experience a range of unpleasant symptoms while small intestinal villi, essential to nutrient absorption, are destroyed in an immune process mediated by T cells. The only known treatment for this disease is a lifelong gluten-free diet and there is currently no drug treatment. A gluten-free diet will not address the damage in all cases; this is referred to as refractory celiac disease.

This preliminary work provides a mathematical framework to better understand the biological and immunological mechanisms in celiac disease. The model will be able to analyze various theories behind the progression of this disease by capturing the dynamics of a healthy subject, a patient with celiac disease, and a patient with refractory celiac disease. By doing so, we can evaluate and suggest potential therapies to mitigate the effects of celiac disease. (Received September 22, 2018)

1145-93-2031 **Laura Munteanu*** (laura.munteanu@oneonta.edu), State University of New York at Oneonta. *Nonlinear Control Systems as Collections of Vector Fields.* Preliminary report.

A classical control system can be seen as an ordinary differential equation containing a parameter. This parameter, called control, can be varied so as to induce diverse trajectories of the given system through its solutions. More precisely, from a fixed point or state, we could reach an entire set of other states by varying the control. Many physical processes can be modeled by non-linear rather than linear control systems. In this presentation, we will outline a few examples illustrating the possible structure of the so-called reachable sets for certain linear as well as non-linear control systems, and we will look at how non-linear control systems can be viewed as collections of vector fields on finite dimensional differentiable manifolds. (Received September 25, 2018)

1145-93-2207 **Scott Hansen*** (shansen@iastate.edu), Department of Mathematics, Iowa State University, Ames, IA 50011. *Controllability of a Cochlea with Localized Control on the Basilar Membrane.*

A model for the cochlea within the inner ear which consists of a one-dimensional basilar membrane modeled by an elastic beam or wave equation and an adjacent body of fluid, modeled as a linear potential fluid is considered. Exact controllability of the system is shown to hold with locally distributed control applied to an arbitrary open interval of the basilar membrane. As a step toward modeling a cochlear implant, we also consider the control problem with a piezoelectric patch over a portion of the basilar membrane. Some preliminary controllability results for this system will be described. The proof of controllability is based on mini-max eigenvalue estimates and application fo Ingham's inequality. (Received September 25, 2018)

1145-93-2689 **Dylan R Poulsen*** (dpoulsen2@washcoll.edu), 300 Washington Ave, Chestertown, MD 21620. *Consensus of Multi-Agent Systems: A Time Scales Approach.* Preliminary report.

We are motivated by the consensus problem for multi-agent systems, wherein agents try to reach global agreement about the value of a certain quantity by communicating only locally. If the line of communication between two agents is unreliable, then the time set on which the agents can communicate forms a so-called pulse time scale with varying and random gap sizes and interval lengths. Solving the consensus problem on time scales can be related to the asymptotic stabilization problem on time scales. Therefore, we discuss the stability theory for linear systems on such stochastic pulse time scales, where the length of communication uptime and downtime are random variables. (Received September 25, 2018)

1145-93-2769 **Matthew Rose*** (mrose891@g.rwu.edu) and **Hasala Gallolu Kankanamalage** (hgallolu@rwu.edu). *Characterizations of string stability of interconnected automobile systems.*

String stability plays an important role in modeling self-driving automobile systems and automated smart traffic flow systems. This plays an important role specially in designing Adaptive Cruise Control (ACC) systems and Cooperative Adaptive Cruise Control (CACC) systems. In this work we present a few variants of string stability conditions and we analyze these variants. We provide characterizations for certain types of string stability. We analyze theoretical significance of these stability notions together with numerical validations. (Received September 25, 2018)

1145-93-2931 **Hasala Gallolu Kankanamalage*** (hgallolu@rwu.edu). *Lyapunov descriptions of string stability for systems with delays.*

String stability plays a central role in analysis of interconnected systems. This special stability property is especially important analysis and design of Adaptive Control Systems and intelligent interconnected systems. There are Lyapunov descriptions available for string stability in the literature of interconnected systems. However, systems associated time delays need special consideration. In this work, we consider Lyapunov characterizations of variants of string stability for systems associated with time delays. Main contribution includes theoretical framework of Lyapunov descriptions accompanied by potential practical implementations. (Received September 26, 2018)

94 ► Information and communication, circuits

1145-94-79 **Mohamad Moussa***, moussa7@math.arizona.edu, and **Marek Rychlik**, rychlik@email.arizona.edu. *Beyond RAID 6 — an Efficient Systematic Code Protecting Against Multiple Errors, Erasures, and Silent Data Corruption.*

RAID systems combine multiple storage devices to be accessed in parallel and thus give a greater throughput than a single device. RAID employs the techniques of mirroring, stripping, or parity to make the array of devices more reliable. RAID systems experience two types of errors which are known as erasures "Z" (errors whose locations are known by the system, such as failure of storage devices), and random errors "E" (errors whose locations are unknown and should be determined by the system). Random errors arise from a variety of factors such as software or hardware malfunction.

An error correcting code is capable of recovering from any combination of Z and E provided that $Z + 2E \leq d - 1$, where d is the minimum distance of the code. RAID 6 is able to recover from any combination provided that $Z + 2E \leq 2$. Hence, when in degraded (i.e., when $Z \geq 1$), RAID 6 loses its ability for detecting and correcting random errors (i.e., $E = 0$), leading to a data loss known as silent data corruption.

We developed a replacement for RAID 6, based on a new linear, systematic code, which detects and corrects any combination of E and Z provided that $Z+2E \leq 4$. The computational complexity of our RAID is comparable to that of RAID 6. (Received July 24, 2018)

1145-94-553 **Ankur Mallick***, 4720 Forbes Avenue, CIC 4th floor, Pittsburgh, PA 15213, and **Malhar Chaudhari** and **Gauri D Joshi**, 4720 Forbes Avenue, CIC 4105, Pittsburgh, PA 15213. *Fast and Efficient Distributed Matrix-Vector Multiplication Using Rateless Fountain Codes.*

Large-scale machine learning and data mining applications require computer systems to perform massive computations that need to be parallelized across multiple nodes, for example, massive matrix-vector and matrix-matrix multiplication. The presence of straggling nodes – computing nodes that unpredictably slowdown or fail – is a major bottleneck in such distributed computations. We propose a *rateless fountain coding* strategy to alleviate the problem of stragglers in distributed matrix-vector multiplication. Our algorithm generates linear combinations of the m rows of the matrix and assigns them to different worker nodes, which then perform row-vector products with the encoded rows. The original matrix-vector product can be decoded as soon as slightly more than m row-vector products are collectively completed by the nodes. This strategy enables fast nodes to steal work from slow nodes, without requiring the knowledge of node speeds. Compared to recently proposed fixed-rate erasure coding strategies which ignore partial work done by straggling nodes, rateless coding achieves significantly lower overall delay, as well as small computational overhead. (Received September 09, 2018)

1145-94-610 **Umberto Martinez-Penas*** (umberto@math.aau.dk) and **Frank R. Kschischang** (frank@ece.utoronto.ca). *Sum-Rank Codes and Linearized Reed-Solomon Codes.*

The sum-rank metric naturally extends both the Hamming and rank metrics in coding theory. In this talk, we will present some of their applications and general properties. We will also present linearized Reed-Solomon codes, which constitute the first general family of maximum sum-rank distance (MSRD) linear codes whose field sizes are subexponential in the code length. Moreover, these codes are tightly connected to skew Reed-Solomon codes, and are natural hybrids between generalized Reed-Solomon codes and Gabidulin codes. (Received September 11, 2018)

1145-94-1096 **Daniele Bartoli** and **Ariane Masuda*** (amasuda@citytech.cuny.edu), New York City College of Technology, Department of Mathematics, 300 Jay St., Brooklyn, NY 11201, and **Maria Montanucci** and **Luciane Quoos**. *Pure gaps on curves with many rational places.*
We consider the algebraic curve defined by $y^m = f(x)$ where $m \geq 2$ and $f(x)$ is a rational function over $\mathbb{F}_q$. We extend the concept of pure gap to **c**-gap and obtain a criterion to decide when an s-tuple is a **c**-gap at s rational places on the curve. As an application, we obtain many families of pure gaps at two rational places on curves with many rational places. We present the parameters of codes constructed using our families of pure gaps. (Received September 18, 2018)

1145-94-1098 **Kevin M. Byrnes*** (dr.kevin.byrnes@gmail.com). *Circuit Codes With Long Bit Runs.*
A circuit code of spread k is a simple cycle C in the graph of the d-dimensional hypercube $I(d)$ with the property that for any vertices $x, y \in C$, $d_{I(d)}(x, y) \geq \min\{d_C(x, y), k\}$. One application of circuit codes is as error-correcting codes, so it is of interest to find the maximum length of a circuit code in dimension d with spread k, $K(d, k)$. However, finding closed form expressions for $K(d, k)$ for classes of (d, k) combinations is extremely rare. In this work we build upon previous results of Singleton, Douglas, Deimer, and others to derive a new upper bound on $K(d, k)$ for a class of symmetric circuit codes with long bit runs (sequences of distinct transitions). We also present a construction that we conjecture (after extensive numerical testing) achieves this upper bound, suggesting a new closed form expression for $K(d, k)$ on this class of codes. (Received September 18, 2018)

1145-94-1163 **Emma Lennen*** (elennen@ucsb.edu), **Wade Bloomquist**, **Jose Zavala**, **Gulnoza Bobokalonova** and **Rebecca Embar**. *Combinatorial Properties of Diagonal Distance.*
This talk will be devoted to the study of diagonal distance on graphs. Quantum codes can be represented by graphs with vertices labeled by an element of $(\mathbb{Z}/2\mathbb{Z})$. When transmitting this information, two kinds of errors can occur. A vertex could either flip its value, or flip the value of the vertices adjacent to it. The definition of diagonal distance arose through the study of these graph codes by Luna, Reid, De Sanctis, and Gheorghi and is defined as the minimal number of errors that reverts a labeling back to itself.
We construct graphs with arbitrarily high diagonal distance, utilizing combinatorial relationships between the neighborhoods of vertices. We explore relationships between diagonal distance and other properties of graphs. For instance, we have proven that diagonal distance is invariant under local complement, i.e. taking the complement of the neighborhood subgraph of a vertex. In addition, we studied the effect of the Cartesian graph product on diagonal distance. Understanding the construction of underlying graphs with certain diagonal distance will provide insight on how to construct better quantum error correcting codes. (Received September 19, 2018)

1145-94-1228 **Elie Alhajjar*** (eliealhajjar@gmail.com). *A Case Study of the Noordin Terrorist Network.*
In this talk we provide a new methodology to study dark networks. Our main idea is to transform a set of unweighted graphs into one weighted graph that encompasses the contributions of each actor. The goal is to identify the key players in the network based upon the metrics used. Our toy example is the Noordin terrorist network, whose data was published in 2006. We represent this network as a graph with 139 nodes connected through relations stemming from several attributes and we assign weights to the edges via a collapsing function. We then use this model to analyze the central components of the network. (Received September 20, 2018)

1145-94-1253 **Anna Melikyan*** (anna34@ksu.edu). *Random Spanning Trees on Homogeneous Graphs.* Preliminary report.
The decision problem to determine whether there exist two completely independent spanning trees in a graph G is NP-hard. In this context, we desire to generate spanning trees that collide as little as possible.This can be done by selecting trees with probability μ so as to minimize the expected overlap of two independent identically distributed spanning trees. We partition the graph into homogeneous components where μ-random spanning trees use every edge fairly. We provide further analysis of an optimal μ for homogeneous graphs. (Received September 20, 2018)

1145-94-1297 **Weiqi Li**, **Zhiying Wang*** (zhiying@uci.edu) and **Hamid Jafarkhani**. *Repairing Reed-Solomon Codes.*
Reed-Solomon (RS) codes are widely used in distributed storage systems. In this talk, we study the repair bandwidth and sub-packetization size of RS codes. The repair bandwidth is defined as the amount of transmitted information from the surviving storage nodes to a failed node. The RS code can be viewed as a polynomial over a finite field $GF(q^\ell)$ evaluated at a set of points, where ℓ is called the sub-packetization size. Smaller bandwidth reduces the network traffic in distributed storage, and smaller ℓ facilitates the implementation of RS codes with

lower complexity. In this work, we present code constructions and repair schemes that accommodate different sizes of the evaluation points. These schemes provide a flexible tradeoff between the sub-packetization size and the repair bandwidth. In addition, we generalize our schemes to manage multiple failures. (Received September 20, 2018)

1145-94-1336 **Samuel Baker*** (shbaker812@gmail.com) and **Franklin H. J. Kenter** (kenter@usna.edu). *Inverse Problems of Mixed Random Graph Models.* Preliminary report.

This study focuses on the relationship between random graphs and real world networks. By combining known random graphs, such as the Geometric and Erdős-Réyni models into new random graph models, we are looking to find the optimal way to represent real world networks. We look to solve the inverse problem: given a real world network, we attempt to find the parameters that could generate that graph. (Received September 21, 2018)

1145-94-1629 **Sudhir R Ghorpade*** (srg@math.iitb.ac.in), Department of Mathematics, Indian Institute of Technology Bombay, Powai, Mumbai, 400076, India. *Generalized Hamming weights of projective Reed-Muller codes.*

Projective Reed-Muller codes are linear codes corresponding to evaluations of homogeneous polynomials of a fixed degree d in $m+1$ variables with coefficients in a finite field $\mathbb{F}_q$, and these codes can be viewed as a projective analogue of (generalized) Reed-Muller codes. The problem of determination of the generalized Hamming weights of these codes is open in general, and is equivalent to the determination of the maximum number of common solutions that a fixed number of linearly independent homogeneous polynomials of degree d in $m+1$ variables with coefficients in $\mathbb{F}_q$ can have in the corresponding projective space over $\mathbb{F}_q$. A conjecture of Tsfasman and Boguslavsky about these generalized Hamming weights has recently been shown to be true in several cases, but false in general. A new conjecture has been proposed and it has been shown to be valid in many, but not all, cases. We will give an expository account of these developments. These are mainly based on joint works with Mrinmoy Datta as well as with Peter Beelen and Mrinmoy Datta. (Received September 23, 2018)

1145-94-1893 **Allison Beemer***, allison.beemer@asu.edu, and **Joerg Kliewer** and **Oliver Kosut**. *Coding to thwart adversarial interference.*

Error-correcting codes seek to address the problem of transmitting information efficiently and reliably across noisy communication channels. The arbitrarily varying channel (AVC) models the situation in which there is an active, malicious adversary interfering with transmission. Such a model has important applications in, for example, wireless communications. While fundamental limits of this channel have been explored extensively, practical coding schemes are less prolific. In this talk, we outline a coding strategy designed for reliable communication over the AVC. (Received September 24, 2018)

1145-94-2054 **Katie Haymaker*** (kathryn.haymaker@villanova.edu), **Allison Beemer** and **Christine A Kelley**. *Absorbing sets of LDPC codes from finite incidence structures.*

An absorbing set is a graph substructure that can impact iterative decoding algorithms for codes on graphs. We examine the presence of absorbing sets, fully absorbing sets, and elementary absorbing sets in low-density parity-check codes arising from certain classes of finite geometric structures. In particular, we prove the parameters of the smallest absorbing sets for finite geometry codes using a tree-based argument. Moreover, we obtain the parameters of the smallest absorbing sets for a special class of codes whose graphs are d-left-regular with girth g. (Received September 24, 2018)

1145-94-2120 **Austin P. Allen*** (apallen@andrew.cmu.edu) and **Keller L. Blackwell** (kellerb@mail.usf.edu). *Distinguisher-attack resistance and decoding of twisted Hermitian codes.*

The McEliece public-key cryptosystem is a code-based scheme that is thought to achieve post-quantum security through the NP-hardness of decoding a random linear code; however, its reliance on binary Goppa codes forces impractical key sizes and relatively low data rates. Implementation of the McEliece PKC with more structured codes can improve feasibility, but care must be taken to avoid incurring vulnerabilities under cryptanalysis. For instance, while Reed-Solomon codes are highly structured, they have a small dimensional Schur square that makes them unsuitable for the McEliece PKC. Recently, twisted Reed-Solomon codes were introduced to increase the dimension of the Schur square. In this talk, we introduce a new variant of Hermitian codes, called twisted Hermitian codes. We identify a subfamily of these new codes that achieve large Schur square dimension and show their resistance to distinguisher attacks. Furthermore, we demonstrate a decoding algorithm for twisted Hermitian codes. This is joint work with Olivia Fiol, Rutuja Kshirsagar, Bethany Matsick, and Zoe Nelson, supervised by Gretchen Matthews. (Received September 25, 2018)

1145-94-2122 **Alexander Barg*** (abarg@umd.edu) and **Zitan Chen**. *Constructions of codes for some models of distributed storage.*

The problem that we consider is motivated by distributed storage applications. The data is encoded with an (n,k,l) MDS array code over some finite field F, and the coordinates of the codeword are placed on different storage nodes. When a node fails, the code is used to correct an erasure under the constraint that as little data as possible is transmitted from the other nodes in order to complete the correction. We consider a model when the n nodes are grouped in subsets of size u such that the communication within each subset does not contribute toward the repair cost, and the only communication that matters is the one between the subsets (this corresponds to the so-called rack-aware model of storage). We present algebraic constructions of MDS codes of length n such that $u|n$ that correct one erasure using the minimum possible amount of communication and have some other properties commonly considered in this type of problems. Our constructions exist for all admissible code parameters n,k and require the field size $|F|\geq n^2/u$ and $l\approx((n-k)/u)^{n/u}$. (Received September 24, 2018)

1145-94-2147 **Sarah E. Anderson*** (ande1298@stthomas.edu), **Ann Johnston**, **Gauri Joshi**, **Gretchen L. Matthews**, **Carolyn Mayer** and **Emina Soljanin**. *Service Rate Region of Coded Storage Systems.*

In this talk, we consider coded storage systems in which K files are stored over N nodes. Each node is either systematic or coded. A node is systematic for a particular file in the sense that access to that node gives access to that file. Alternatively, a node may be coded, meaning that node gives access to a particular file only when combined with other nodes (which may be coded or systematic). Requests for file f_i arrive at rate λ_i. We analyze the service rate region of a coded system; that is, the set of arrival requests that can be supported by a coded system. (Received September 24, 2018)

1145-94-2230 **Gretchen Matthews*** (gmatthews@vt.edu). *Algebraic geometry codes in the McEliece cryptosystem.*

There is renewed interest in the McEliece cryptosystem, which was developed in the late 1970s, due to its potential resilience in the presence of quantum algorithms. The McEliece cryptosystem utilizes error-correcting codes to keep private information secure, and its effectiveness depends on the properties of the underlying codes. In this talk, we consider the use of algebraic geometric (AG) codes and demonstrate modifications of traditional AG codes that yield superior performance. (Received September 25, 2018)

1145-94-2262 **Rutuja Kshirsagar*** (rutujak@vt.edu), 461L McBryde Hall, Department of Mathematics, Virginia Tech, Blacksburg, VA 24061. *Expander codes and local properties.* Preliminary report.

Expander codes are formed using a double cover H of an expander graph $G=(V,E)$ of degree d and inner codes of length d over a finite field $\mathbb{F}$. The properties of the expander code depend on those of the underlying expander graph as well as the inner code. It has been shown by Hemenway et al. that when the inner code has a good rate, distance, and a smooth reconstruction algorithm in a noiseless setting, a corresponding expander code also has a good distance and is locally correctable (in a noisy setting). In this discussion, locally correctable means any codeword symbol can be recovered from a random sample of a small number of coordinates of a received word with high probability. A related but weaker notion is that of local recoverability where a codeword coordinate may be recovered by a specified set of coordinates (assumed to be error free) as opposed to a random sample. In this talk, we explore properties of expander codes that depend on their construction and properties of their inner codes. For example, we consider the effect of replacing the inner code with a locally recoverable code. (Received September 25, 2018)

1145-94-2282 **Elisa Gorla**, **Relinde Jurrius**, **Hiram H. López*** (hhlopezv@gmail.com) and **Alberto Ravagnani**. *Rank-Metric codes and q-Polymatroids.*

On this talk we will introduce the concepts of Rank-Metric codes and q-Polymatroids. Then we will associate a pair of q-Polymatroids to a rank-metric code and show that several invariants and structural properties of the code are captured by the associated combinatorial object. (Received September 25, 2018)

1145-94-2444 **Rachel Grotheer***, 1021 Dulaney Valley Road, Baltimore, MD 21204, and **Natalie Durgin**, **Chenxi Huang**, **Shuang Li**, **Anna Ma**, **Deanna Needell** and **Jing Qin**. *Application of Stochastic Algorithms for Multiple Measurement Vectors to the Hyperspectral Diffuse Optical Tomography Problem.* Preliminary report.

The multiple measurement vector (MMV) problem has generated a growing interest in signal processing. In the MMV setting, multiple signals, with a commonality such as joint support, are to be recovered using more than one measurement vector. We develop stochastic algorithms both to recover the joint support and reconstruct the signals in the MMV setting. We then apply these algorithms to the reconstruction problem in hyperspectral diffuse optical tomography (hyDOT), a type of medical imaging used primarily for soft tissue imaging. In this application, we consider a signal to be the level of light absorption at each location in the tissue imaged for a particular wavelength, and the non-zero entries of those signals the absorption coefficient values in cancerous cells. We find that the stochastic algorithms are effective in reconstructing and recovering the support of the signals, and in a much shorter time than a conventional gradient descent algorithm. (Received September 25, 2018)

1145-94-2671 **Russell G. Impagliazzo*** (rusell@cs.ucsd.edu), 4175-158 Porte de Merano, San Diego, CA 92122. *Connections between learning, pseudo-randomness, and regularity.* Preliminary report.

Boosting is a technique from machine learning theory with many applications. In this talk, we will sketch how to use boosting arguments to provide a unified framework that can be used to derive consequences to additive combinatorics, graph theory, computational complexity, cryptography, and even back to machine learning. By using this common framework, these results are easy to generalize, and by using different boosting algorithms, variations suitable for a given domain can be obtained. We will describe this general framework, and then show how it implies a variety of generic regularity lemmas that imply the Frieze-Kannan Weak Regularity Lemma, Szemeredi Regularity Lemma for graphs, and versions of the same for sparse graphs. These both reproduce known results, and in some cases, give quantitative improvements. We will then sketch other applications of generic regularity to additive combinatorics, computational complexity, cryptography, and machine learning. (Received September 25, 2018)

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1145-97-95 **Kimberly Spayd*** (kspayd@gettysburg.edu). *Using Real Data to Study the Heat Equation.*

The heat (diffusion) equation is one of the fundamental topics discussed in any introductory Partial Differential Equations course. As a basis for student motivation, understanding and application of the mathematical model, student groups experimented with the physical phenomenon: heating a long, thin, metal rod with prescribed boundary conditions. The experiments occurred during the second class meeting of the semester, before any rigorous mathematical development. Temperature data collected from the experiments were used later in the semester for a project which included both analytical and numerical components. The experimental set-up and execution will be discussed, along with the perceived impact on student learning. (Received July 28, 2018)

1145-97-378 **W. Y. Chan*** (wychan@tamut.edu), Department of Mathematics, Texas A&M University - Texarkana, 7101 University Drive, Texarkana, TX 75503. *Teaching Differential Equations and Their Applications Using Projects, Online Resource, and More.* Preliminary report.

Differential equations is one of the required courses for some STEM majors. This course covers techniques for solving differential equations and their applications on various disciplines. To keep the balance of reaching both, homework problems and projects are assigned to help students understand principles and methods, and envision applications. In this talk, we share the assigned projects, online resources, and other activities in coordinating this class. (Received September 04, 2018)

1145-97-705 **Keneth Allen Horwitz***, 215 D Cullimore Hall, New Jersey Institute of Technology, University Heights, Newark, NJ 07102. *Exploring Open Educational Resources for Precalculus.* Preliminary report.

According to the Bureau of Labor Statistics, the cost of college textbooks has risen more than 1000% since 1977. This is not only of concern to students, but to society. With the ever-growing cost of college and the growing significant loans that pay this price, students and their families will be paying them back for years, if at all. In this study, I will examine more than 200 students currently enrolled in Math 107, University Mathematics BI (Precalculus) so see if there was any educational effect by switching their traditional textbook with an Open Educational Resource text. This is the preliminary work to study the effect of OER textbook on a Precalculus class will examine three things: How much money did students save because of the adoption of the OER materials? How was the curriculum and tests different with the new low cost textbook? Was the new curriculum more, equally or less effective than the former curriculum? Did students achieve different levels of academic success? At the conclusion of the study, I will request that the faculty who taught the course provide their reflection on the utilization of the new textbook. (Received September 13, 2018)

1145-97-716 **Adam J Castillo*** (adacasti@fiu.edu), 1170 NW 11th St., Apt. A-103, Miami, TX 33136. *Implementing Mathematical Modeling Practices in Calculus at a Hispanic-Serving Institution.* Preliminary report.

Mathematical modeling – using mathematics to represent, analyze, and provide insight into real-world phenomena – is a lens for supporting active learning in mathematics classrooms, particularly in the teaching and learning of calculus. However, new approaches to calculus that improve student outcomes at the postsecondary level are understudied. This talk will describe the first pilot year of a multi-year, NSF-funded, study that is being conducted to bring the authentic practices of mathematicians and mathematical modeling into the classroom. The pilot intervention involved the use of a studio-based approach complimentary to mathematical modeling, in which students learn content and the practices of mathematicians by actively doing mathematics in a lecture-reduced classroom with a focus on modeling processes themselves and the discourse employed by students working with peers. A summary of the impacts of this pilot intervention on student outcomes will be presented. This talk will also highlight the ongoing, cyclical process of evaluating, modifying, and implementing curricular materials and research instruments. (Received September 13, 2018)

1145-97-965 **Talithia Denese Williams*** (twilliams@hmc.edu). *A Seat at the Table: Equity and Social Justice in Mathematics Education.*

As mathematics educators, we pride ourselves in our ability to communicate the beauty of mathematics to our students. To watch a student's face light up over a clever proof or robust statistical model still gives me goosebumps. And it's often the students who are bright eyed and eager, that I invite to the metaphorical mathematical table: sending them REU announcements, financial analyst summer opportunities or graduate school suggestions. Over time, I realized that I wasn't allowing my students to engage in mathematics in ways that were meaningful to them. Although well intentioned, my classrooms were far from "mathematically inclusive". In recent years, I've learned to build upon my students' identity and lived experiences by incorporating rigorous, relevant mathematical experiences into the classroom environment. These experiences not only provide deep mathematical learning, but also give students the mathematical knowledge to advocate for justice in our communities. By creating inclusive classrooms and promoting classroom experiences that are equitable, we can change the culture of mathematics. In this talk, I'll share the tangible ways in which we can invite our students to have a seat at the mathematical table and in doing so, work to broaden participation in mathematics. (Received September 17, 2018)

1145-97-999 **Reinhard Laubenbacher*** (laubenbacher@uchc.edu). *From free-range advising to life coaching? The dynamics of mentoring.* Preliminary report.

Advisor/advisee relationships can range from occasional fleeting encounters to intense professional relationships. The appropriate level of mentoring depends on many factors and may need to change over the course of the relationship. This talk will present some themes based on a survey of advisees of the author, ranging from undergraduate and graduate students in a mathematics department to postdoctoral researchers and junior faculty in a private research institute and a medical school. (Received September 18, 2018)

1145-97-1099 **Luis Antonio Leyva*** (luis.a.leyva@vanderbilt.edu). *"I Don't Wanna Let Others Know That I Don't Know": Detailing Undergraduate Latinx Students' Reflections on Racialized-Gendered Instructional Moments in Entry-Level Mathematics Courses.*

Undergraduate mathematics instruction in entry-level courses, such as pre-calculus and calculus, contributes to marginalization among women and racially minoritized individuals. This report presents an analysis from a larger study that details how eight undergraduate Latinx college students (4 women and 4 men) perceived and responded to potentially marginalizing events in pre-calculus and calculus instruction. Findings reveal variation at intersections of the Latinx college students' race and gender identities in relation to: (i) features of pre-calculus and calculus instruction that left them feeling marginalized; (ii) reasons for why these instructional features were perceived as marginalizing; and (iii) responses to these classroom instances of marginalization. The intersectional variation in the findings informs implications for more race-and gender-conscious teaching practices in undergraduate mathematics that promote Latinx students' persistence in STEM and robust identity development in mathematics. (Received September 18, 2018)

1145-97-1233 **Yasanthi Kottegoda*** (ykottegoda@newhaven.edu), 300 Boston Post Rd, West Haven, CT 06516, and **Lochana Siriwardena**. *Assessing a curriculum for Calculus II with Bayesian networks.* Preliminary report.

Here we discuss some observations made by applying Bayesian networks to assess an inquiry based learning curriculum for Calculus II which took place in the Spring 2018. We model connections between different concepts and tasks as a Bayesian network to infer certain conditional probabilities that allows us to quantify multiple dependencies of different concepts and their impact on final assessment of the students. In addition, we also discuss some common student misconceptions we noticed when approaching key ideas in Calculus II, observed from the student responses on the tasks given. (Received September 20, 2018)

1145-97-1294 **Marianne Korten*** (marianne@math.ksu.edu), Department of Mathematics, 138 Cardwell Hall, 1228 N 17th. Street, Manhattan, KS 66506, and **Jamie Peabody** (jpeabody@math.ksu.edu), Department of Mathematics, 138 Cardwell Hall, 1228 N 17th Street, Manhattan, KS 66506. *Labs: The I-Center at Kansas State University, 12 years of trans-generational math research.*

In this talk we will describe the I-Center and its activities. We will show tracking of our scholars - undergraduate, graduate, and postdoctoral, as well as the mentoring of students from undergraduate to PhD and Postdoc through programs in the Geometry Labs United network. (Received September 20, 2018)

1145-97-1315 **Harrison Bray***, hbray@umich.edu, and **Mark Greenfield**. *LoG(M): making connection and community natural at Michigan.*

In an effort engineered almost exclusively by postdocs and graduate students, the Lab of Geometry at Michigan - LoG(M) - was born almost exactly two years ago on the date of these meetings. This talk, but really LoG(M) itself, serves as a testament to the empowering character of the geometry labs at every scale. As evidence, we share our origin story and an example project designed and co-supervised by a graduate student whose organizational efforts were a significant part of making the lab as it is today. (Received September 20, 2018)

1145-97-1358 **Aaron T Wilson*** (aaron.wilson@utrgv.edu), University of Texas Rio Grande Valley, School of Mathematical and Statistical Scienc, 1201 W University Drive, EMAGC 3.422, Edinburg, TX 78539. *The near-peer mathematical mentoring cycle: studying the impacts of outreach.*

College students may be seen as near-peers to high school students and high school students may often see themselves in the college students who are but one step ahead. This nearness in maturity and educational level places college students in a particularly powerful position when it comes to reaching out to high school students to promote interest in mathematics. In this study college student participants in the Experimental Algebra and Geometry Lab (EAGL) gave dynamic mathematics outreach presentations, MathShows, to minority and low-income high school students in a mid-sized public school district on the U.S. border with Mexico. The study investigated the impacts of this outreach work on high school students' attitudes towards mathematics using an attitude survey. Results, obtained from N=306 participants, showed statistically significant improvements in almost all components of mathematical attitudes, with less of an effect on the component of self-confidence in doing mathematics. Differences in impacts by specific student subgroups are all discussed. Additionally, anecdotal evidence suggests an even more powerful impact on the college student presenters in terms of confirming mathematical identity traits and promoting retention and achievement in collegiate mathematics. (Received September 21, 2018)

1145-97-1619 **Josephine Wairimu Kagunda*** (jwndirangu@uonbi.ac.ke), School of Mathematics, University of Nairobi, P.O. Box 30197-00200, Nairobi, 254, Kenya, and **Faraimunashe Chirove**, **Marilyn Chepkrui Ronoh** and **David Malonza**. *Modeling the effects of insecticides resistance on malaria vector control in endemic regions of Kenya.*

We present a model to investigate the effects of vector resistance to control strategies. The model captures the development of resistance as well as loss of resistance in mosquitoes and how these affect the progress in malaria control. Important thresholds were calculated from mathematical analysis and numerical results presented. Mathematical results reveal the existence of the disease free and endemic equilibrium whose existence and stability depends on the control reproduction number, $\mathcal{R}_c$. The disease persist when the $\mathcal{R}_c > 1$ and dies out when $\mathcal{R}_c < 1$. Control strategies use and adherence needs to be highly efficacious to thwart the effects of insecticides resistance. Moreover, it is not enough to just eradicate resistant mosquitoes. (Received September 23, 2018)

1145-97-1767 **S Lin*** (lins@savannahstate.edu), 902 Boxwood Dr, Savannah, GA 31410. *Motivating Students with Dynamic Modeling.*

Dr. Winkel, director of SIMIODE promotes using computer modeling to teach Differential Equations. Dr. Panoff, director of SHORDOR.COM promotes using computer modeling to unzipped student's potential. I had a chance to attend both SIMIODE and SHORDOR workshops. I learned how to develop models that can be used in classroom and how to use models to teach classes. I used Dr. Winkel M and M model at all my classes. Different level students have different reports. I started using modeling to motivate student at all level classes. I used Dr. Panoff Have = Had + change model to inspire student working on undergraduate research in the topic of dynamic modeling of real world cases. Since all students have different background. Dynamic modeling is the best way to encourage students working on interdisciplinary field. Differential Equations are the best way to describe the change of any phenomena. However differential equation is a spooky term for many students. If we use difference quotient that students learned in College Algebra to approximate derivative, then even lower level students can enjoy differential equation models. At this presentation, I will introduce some models that I used in my classes. Those are sequence of models of model development. (Received September 24, 2018)

1145-97-1770 **Rebecca A Segal*** (rasegal@vcu.edu), Department of Mathematics, PO Box 842014, Richmond, VA 23284. *Connecting Partner Disciplines with Mathematics through Applications in Differential Equations.*

Virginia Commonwealth University teaches an average of 28 sections of Differential Equations per year. The majority of the students in the course are majors in Engineering or Sciences. Anecdotally, students are not transfer knowledge content from the math course into courses within their majors. In order to improve knowledge retention, we have worked to establish conversations between Mathematics and the partner disciplines of Chemistry, Biology, Physics, and Engineering. Using the "Curriculum Foundations Project: Voices of the Partner Disciplines" report as source of discussion questions, a Fishbowl activity was held with faculty from Chemistry, Biology, Physics, and Engineering. There was good consensus about having the students explore a variety of application problems within each differential equation techniques. To further prioritize content for the course, a follow-up online survey was used to compile a topics wish list from the partner disciplines. Using this information, we began to move the instruction of Differential Equations to have a greater inclusion of application focused class activities and projects. Sample assignments will be discussed as well as preliminary student survey data on the impact of this effort. (Received September 24, 2018)

1145-97-1778 **David Burstein**, **Franklin Kenter*** (kenter@usna.edu) and **Feng Shi**. *Leveraging local network communities to predict academic performance.*

Existing models for predicting academic outcomes in the classroom typically assume that observations are independent, even though peer interactions can play a crucial role in the learning process. Consequently, we propose a collection of novel predictors that account for this dependence by identifying a student's learning community, consisting of the peers that are most likely to influence a student's performance in a course. We evaluate the importance of these learning communities by predicting academic outcomes in an introductory college statistics course with 103 students. In particular, we observe that by including these learning community predictors, the resulting model is substantially more likely to be the correct model than existing non-network and state-of-the-art centrality network models in the literature. (Received September 24, 2018)

1145-97-1810 **Ron Buckmire*** (ron@oxy.edu). *Who Does The Math?: On the Diversity and Demographics of the Mathematics Community.*

Mathematics is a human endeavor. In other words, mathematics is done, taught, discovered and learned by people. Of course, people have various identifying characteristics and experiences that affect how they interact with other people and *vice versa*. This presentation will discuss the diversity and demographics of the mathematics community (in the United States) and discuss the significance and implications of the underrepresentation of certain groups. Projects and practices that seek to broaden the participation of underrepresented groups will be included. (Received September 24, 2018)

1145-97-1884 **Brian J Winkel*** (brianwinkel@simiode.org). *Opportunities for Community in Using Modeling to Teach Differential Equations at SIMIODE.*

SIMIODE – Systemic Initiative for Modeling Investigations and Opportunities with Differential Equations (www.simiode.org) is an online and vibrant community of students and teachers interested in using modeling to motive the study of differential equations. SIMIODE, a no-profit organization, now in its fifth year, is also currently supported by a National Science Foundation grant and all of its resources are FREE and downloadable under the most generous Creative Commons license. SIMIODE presents the opportunity for publishing double-blind, peer-reviewed Modeling Scenarios and Technique Narratives as well as hundreds of potential modeling activities and additional resources. Collaboration on projects of mutual interest is supported in SIMIODE. SIMIODE sponsors an annual student based event, SCUDEM – SIMIODE Challenge using Differential Equations Modeling, for students to do modeling and faculty to participate in a faculty development program on modeling in differential equations. We will offer an overview of these features and discuss details of several specific published Modeling Scenarios which have proven very successful by colleagues. (Received September 24, 2018)

1145-97-2018 **Matthew Ando**, **Jennifer McNeilly** and **Jeremy T. Tyson***, 1409 West Green Street, Urbana, IL 61801. *Mathways: building a pipeline to undergraduate research in the Illinois Geometry Lab.* Preliminary report.

I will report on an NSF-funded initiative aimed at increasing the participation of underrepresented students in undergraduate mathematics research. The Mathways project builds a bridge between two successful programs in the Illinois Mathematics Department: the Merit Program for Emerging Scholars and the Illinois Geometry Lab (IGL). Targeted recruitment of Merit students and expanded research capacity within the IGL combine to increase both demand for and supply of undergraduate research opportunities. At the same time, Mathways creates new opportunities for postdocs to contribute to the IGL's mission of fostering a culture of undergraduate research. Merit students involved in IGL programs also participate in the lab's numerous outreach activities, particularly, in the Summer Illinois Math camp, an IGL-sponsored and Mathways-funded summer camp for middle and high school students. The outcome of this initiative has been greater engagement and interest in undergraduate research, as well as outreach activity at all levels from pre-college to postdoctoral researcher. (Received September 24, 2018)

1145-97-2084 **Riley Jayne Anderson*** (randers6@mail.umw.edu). *Implementing Machine Learning to Improve Bertini 2.0.*

The purpose of this research is to decrease the run time of Bertini, a program that approximates roots of polynomial systems. Bertini can be run more efficiently if it is known whether a polynomial is singular or non-singular. In this research, we focus on polynomials in one variable. We create a machine learning algorithm to classify polynomials in to these two categories. To do so, we create and use a training set of polynomials to train a neural network and create a model. Then, we create and use a test set to assess the accuracy of the model. Through a process of training, evaluating, and changing the hyper-parameters of the neural network, such as the network architecture and learning rate, the accuracy of the model is able to be increased.
(Received September 24, 2018)

1145-97-2176 **Emily Meehan*** (emily.meehan@gallaudet.edu). *Linguistic diversity in mathematics education.*

Discussions of diversity in undergraduate mathematics education often focus on a lack of racial and gender diversity in the classroom. At Gallaudet University, a bilingual institution where both American Sign Language (ASL) and written English are used for instruction, linguistic diversity is brought to the foreground. The University's mission emphasizes the "intellectual and professional advancement of deaf and hard of hearing individuals" and bilingualism is a particularly valued component of the students' educational experience. For me, a new professor at Gallaudet University and a hearing individual currently learning ASL, this environment has led me to reexamine my instructional practices. In this presentation, I will reflect on my recent experiences and discuss the impact of linguistic diversity on teacher-student relationships, the classroom experience, and assessment of student learning. (Received September 24, 2018)

1145-97-2301 **Matthew A Hawks*** (mhawks@usna.edu), 572-C Hollaway Rd, MS 9E, Annapolis, MD 21402. *The Daily Question: Building Student Trust and Interest in Undergraduate Introductory Probability and Statistics Courses.*

Introducing probability or statistics to disinterested undergraduate students is challenging. I share an unobtrusive way to build trust with students, creating a medium to both naturally create an intimate classroom atmosphere and have your students look forward to attending each class. The context is the United States Naval Academy, a four-year undergraduate institution with an emphasis on leader development. Based on a technique of daily questions suggested by Penn State University Lecturer Dr. Heather Holleman, I integrate daily questions with the course content. Anonymous midterm assessments and end-of-term student opinion forms demonstrate initial success of this method. (Received September 25, 2018)

1145-97-2639 **Samantha Kay Fairchild***, skayf@uw.edu. *Washington Experimental Mathematics Lab (WXML).*

The Washington Experimental Mathematics Lab (WXML) has been running since spring of 2016. We will discuss the history and structure of the lab and what we have learned about the running of WXML in these first years. Topics included are our work with undergraduate projects, the fabrication lab, as well as our outreach projects to the local community. (Received September 25, 2018)

1145-97-2738 **Cheryl M Adeyemi*** (cadeyemi@vsu.edu), Box 9068, 1 Hayden Dr, Petersburg, VA 23806, and **Gerald Burton** (gburton@vsu.edu), 1 Hayden Drive, Box 9068, Petersburg, VA 23806. *The Identification of Variables Associated with Student Outcomes on Praxis II Mathematics Content Exams at a South Central VA HBCU.* Preliminary report.

This study examined the outcomes of 20 pre-service teachers on the Praxis II math content exam, who were enrolled in the Central Virginia Undergraduate Mathematics Scholarship Program (CVUMSP) at a Southeastern HBCU. CVUMSP is a Phase 1, NSF Robert Noyce Grant project. CVUMSP has recruited, and prepared 24 undergraduate students to become future secondary math teachers. The passing of the required Praxis II Mathematics Content exam (P2) has presented itself as a major hurdle for these pre-service teachers, thus requiring a series of interventions to increase the passing rate for the (P2) Mathematics Content Exam. The data analysis of the mixed methodology research design was triangulated through the three primary data collection sources: Praxis Bootcamp (PBC) Reflections, Internship Praxis activities, and Researcher/Instructor Praxis-preparedness surveys / interviews. The study found three major categories of independent qualitative and quantitative variables: (a) Time Immersed in Mathematics (TIM), (b) Self Efficacy, and (c) Sociological, Technological, and Educational variables. It was found that those factors that were more directly related to test preparation were the most impactful, while those factors that related to physical and emotional wellness were less impactful. (Received September 25, 2018)

1145-97-2875 **Nadia Monrose Mills*** (nmonros@uvi.edu), 2 John Brewer's Bay, St. Thomas, VI 00802. *The UVI Growth Model: A model for retention and persistence for STEM undergraduates.* Preliminary report.

The University of Virgin Islands' (UVI) Growth Model was designed to address systemic inequities in undergraduate STEM education. The UVI model is based on the Tinto's models of student retention and persistence, which states that social integration and academic integration are predictors of students' success in completing their degree (Tinto, 1993). The UVI Growth Model builds self-efficacy by integrating Growth Mindset theory (Dweck 2006) into student and faculty professional development, as well as support activities utilizing formal and informal peer-to-peer interactions to enhance the undergraduate STEM environment. There are six essential components in the model that target content knowledge, attitudinal factors such as perceptions of intelligence, behavioral factors such as mathematics efficacy, and sense of belonging. Preliminary findings on the impact of one component, Peer-led Team Learning (PLTL) in foundations mathematics courses will be discussed. There was nearly a 40% increase in the course pass rate for STEM students participating in PLTL. Ongoing analysis supports improvement to the program's implementation. These improvements include changes in training materials of the peer leaders to address mathematics efficacy along with revisions to the curriculum. (Received September 25, 2018)

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 Invited Addresses, Presentations by Teaching Award Winners, and SIGMAA Guest Lecturers

1145-A0-15 **Emmanuel Candes***, Stanford University, Stanford, CA 94305. *Sailing through data: discoveries and mirages.*

For a long time, science has operated as follows: a scientific theory can only be empirically tested, and only after it has been advanced. Predictions are deduced from the theory and compared with the results of decisive experiments so that they can be falsified or corroborated. This principle formulated by Karl Popper and operationalized by Ronald Fisher has guided the development of scientific research and statistics for nearly a century. We have, however, entered a new world where large data sets are available prior to the formulation of scientific theories. Researchers mine these data relentlessly in search of new discoveries and it has been observed that we have run into the problem of irreproducibilty. Consider the April 23, 2013 Nature editorial: .Over the past year, Nature has published a string of articles that highlight failures in the reliability and reproducibility of published research.. The field of Statistics needs to re-invent itself to adapt to the new reality where scientific hypotheses/theories are generated by data snooping. We will make the case that statistical science is taking on this great challenge and discuss exciting achievements. In particular, we will introduce the method of knockoffs, which reliably selects which of the many potentially explanatory variables of interest (e.g. the absence or not of a mutation) are indeed truly associated with the response under study (e.g. the risk of getting a specific form of cancer). (Received May 31, 2018)

1145-A0-16 **Amanda Folsom***, Amherst College, Amherst, MA 01002. *Symmetry, almost.*

Some definitions of the word symmetry include “correct or pleasing proportion of the parts of a thing,” “balanced proportions,” and “the property of remaining invariant under certain changes, as of orientation in space.” One might think of snowflakes, butterflies, and our own faces as naturally symmetric objects– or at least close to it. Mathematically one can also conjure up many symmetric objects: even and odd functions, fractals, certain matrices, and modular forms, a type of symmetric complex function. All of these things exhibit a kind of beauty in their symmetries, so would they lose some of their innate beauty if their symmetries were altered? Alternatively, could some measure of beauty be gained with slight symmetric imperfections? We will explore these questions guided by the topic of modular forms and their variants. What can be gained by perturbing modular symmetries in particular? We will discuss this theme from past to present: the origins of these questions have their roots in the first half of the 20th century, dating back to Ramanujan and Gauss, while some fascinating and surprising answers come from just the last 15 years. (Received May 31, 2018)

1145-A0-18 **Pamela Harris***, Williams College, Williamstown, MA 01267. *A mathematical journey of culture, community, and collaboration.*

It wasn’t until the last year of my graduate program that I met another Latina Ph.D. mathematician. Before this I thought that I may be the only Latina working on a Ph.D. in the mathematical sciences. Of course this was silly, as I could have simply searched the words “Latinas in math” to discover Ruth Gonzalez, the first US born Hispanic woman who earned a Ph.D. in mathematics. The year? 1986 – during my lifetime.

As a first generation college student and a dreamer, the experience of not knowing people of similar cultural and socioeconomic backgrounds working in academia, affected my confidence and belief that I could become a mathematician. I often felt isolated and unsure of my abilities to succeed in this field. However, these experiences positively impacted my goals as an educator. In this talk I’ll share how, through my teaching, I aim to instill mathematical confidence in all students, and how learning and research communities help develop a culture of continuous improvement and collective responsibility.

(Received May 31, 2018)

1145-A0-19 **Deanna Haunsperger***, Carleton College, Northfield, MN 55057. *The Inclusion Principle: the importance of community in mathematics.*

It’s easy to think that what matters in mathematics is just the mathematics; we don’t always recognize the importance of feeling like we belong to a mathematical community. In this talk I’ll point out the existence and importance of many mathematical communities and how they function to support all mathematicians and help keep young mathematicians in the profession. (Received May 31, 2018)

1145-A0-20 **Cathy O'Neil***, ORCAA. *Big data, inequality, and democracy.*
We live in the age of the algorithm. Increasingly, the decisions that affect our lives–where we go to school, whether we get a job or a car loan, how much we pay for health insurance, what news we see on social media–are being made not by humans, but by mathematical models. The models being used today are opaque, unregulated, and uncontestable, even when they're wrong. The increase inequality and threaten democracy. What's worse is they're defended as fair and objective in the name of mathematics. What can the mathematical community do about this? How can we surface the moral questions and address the technical ones? Cathy will discuss some ideas along these lines.
(Received May 31, 2018)

1145-A0-134 **David Bressoud***, Macalester College, Saint Paul, MN 55105. *Reflections on teaching calculus for the first time, 45 times*
I first taught calculus as a graduate student in 1974. Over the years, I have continually renewed my understanding of how to teach it. This has been the result of insights gained through contact with the Calculus Reform movement, the AP Program, and some great high school teachers; by writing textbooks on advanced calculus and real analysis; with participation in Macalester's program of recasting calculus as a modeling course; from the MAA's national studies of calculus instruction; and via my personal dives into the history of the subject. This talk will be an invitation to join in this exploration of how calculus can-and maybe should-be taught. (Received August 07, 2018)

1145-A0-135 **Annalisa Crannell***, Franklin & Marshall College, Lancaster, PA 17603. *Drawing conclusions from drawing a square*
The Renaissance famously brought us amazingly realistic perspective art. Creating that art was the spark from which projective geometry caught fire and grew. This talk looks directly at projective geometry as a tool to illuminate the way we see the world around us, whether we look with our eyes, with our cameras, or with the computer (via our favorite animated movies). One of the surprising results of projective geometry is that it implies 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 applications of piece-wise planar cones, and of course for perspective art and projective geometry. (Received August 07, 2018)

1145-A0-139 **Ben Orlin***, Math and Bad Drawings. *Tic-Tac-Toe (or, What is Mathematics?)*
Once at a picnic, I saw some mathematicians playing the last game I would have expected: tic-tac-toe. With time, I realized that their version - more complex than the usual kind! - embodies the same magic as all of mathematics, from imaginary numbers to non-Euclidean geometry. (Received August 08, 2018)

1145-A0-211 **Michele Friend*** (michele@gwu.edu). *The Rigour of Proof.* Preliminary report.
What is a rigorous proof? When is a proof sufficiently rigorous? What is the importance of rigour in a mathematical proof?

To answer the first question, we begin with a comparison between a formal proof and a rigorous proof. A rigorous proof need not be formal, but it needs to be possible, in principle, to make it formal.

To answer the second, we start with the distinction between sufficiently rigorous for acceptance by other mathematicians, sufficiently rigorous to establish a result and sufficiently rigorous to elicit further questions.

The importance of rigour in a proof has several answers. A realist about the ontology of mathematics might well accept a non-rigorous proof since it establishes a truth guaranteed by the ontology of mathematics, in this case rigour is of psychological or epistemological importance at best. In contrast, constructivist philosophers and mathematicians would assert that the term 'rigorous proof' is redundant, since for them, a proof lacking in rigour is not a proof, it is at best a purported proof. Pluralists give a third, more nuanced answer. (Received August 19, 2018)

1145-A0-282 **Carl Lee*** (carl.lee@cmich.edu), PE 109, Department of Mathematics, Central Michigan University, Mount Pleasant, MI 48859. *Teaching statistics using real-time hands-on activities.*
In the modern society of Big Data, data are messy and complicated. It is critical to engage students to experience the entire process of statistical investigation as early as in an introductory course. The strategy of using hands-on activity is one of such strategies that allow students to experience the entire process of statistical investigation starting from defining problems, collecting data to reporting and presentation. However, such a process often takes long time, as a result, they are difficult to conduct in limited class time periods. This presentation shares

an active learning environment using real-time hands-on activities conducted by students. Some activities will be demonstrated in this presentation. (Received August 28, 2018)

1145-A0-947 **Jennifer Switkes*** (jmswitkes@cpp.edu), Department of Mathematics and Statistics, Cal Poly Pomona, Pomona, CA 91768. *When a mathematics department connects.*

When a Mathematics Department connects, a transformational community can develop and flourish. We are a large department of mathematics and statistics in a state university with about 23,000 students. Our department serves over 5,000 students each semester, including around 600 undergraduate mathematics majors and around 60 Master's students. We are diverse. Within what might be considered a large bureaucracy, through the intentional work of our leadership, a stunning community has grown up. From our compassionate and collaborative students, to our office staff who treat each student with undivided attention and care, to our faculty who mentor and teach with creativity and dedication, to our leaders who are visionary and focused on serving, we are on mission to help our students grow, dream big, accomplish their goals, and thrive. I will share some thoughts and stories of transformation in community from my career serving in this department that is committed to connecting. (Received September 17, 2018)

1145-A0-1603 **Edray Herber Goins*** (ehgoins@mac.com), 610 North College Avenue, Claremont, CA 91711. *A Dream Deferred: 50 Years of Blacks in Mathematics.*

In 1934, Walter Richard Talbot earned his Ph.D. from the University of Pittsburgh; he was the fourth African American to earn a doctorate in mathematics. His dissertation research was in the field of geometric group theory, where he was interested in computing fundamental domains of action by the symmetric group on certain complex vector spaces. Unfortunately, opportunities for African Americans during that time to continue their research were severely limited. "When I entered the college teaching scene, it was 1934," Talbot is quoted as saying. "It was 35 years later before I had a chance to start existing in the national activities of the mathematical bodies." Concerned with the exclusion of African Americans at various national meetings, Talbot helped to found the National Association of Mathematicians (NAM) in 1969.

In this talk, we take a tour of the mathematics done by African and African Americans over the past 50 years since the founding of NAM, weaving in personal stories and questions for reflection for the next 50 years. (Received September 23, 2018)

1145-A0-2114 **Suzanne I Dorée*** (doree@augsburg.edu). *Green pens, purple paper, whiteboards, and other stories: feedback structures that support student learning.*

How do we empower our students to include feedback in their own learning process? How do we facilitate peer feedback to encourage and include all students? How can we as instructors provide informal and formal feedback in a way that helps students learn? Throughout my career I have been developing efficient, effective, and supportive structures that provide feedback to students (and not just because I am avoiding grading). This talk will highlight some examples I have used. (Received September 25, 2018)

1145-A0-2162 **Paul E Seeburger*** (pseeburger@monroecc.edu), 1000 E. Henrietta Rd, Rochester, NY 14623. *Using CalcPlot3D to Create Dynamic Figures for OER Textbooks and to 3D Print Surfaces for Multivariable Calculus and Beyond.* Preliminary report.

CalcPlot3D is an interactive online 3D JavaScript app designed to enhance the teaching and learning of multivariable calculus, but with many applications in other math, engineering, and physics courses.

This tool makes it easy to visually explore concepts and relationships between them. Through visual verification and exploration of problems involving surfaces, contour plots, curves, velocity and acceleration, directional derivatives, gradients, vector fields/phase portraits, etc., our project seeks to improve students' geometric intuition so they more fully understand the application of these concepts in other STEM coursework.

CalcPlot3D can be used to create dynamic figures for online OER textbooks (e.g., LibreTexts and PreTeXt) as well as for ordinary web pages. This process takes a standard textbook figure and transforms it into a dynamic, user-interactive, rotateable figure.

CalcPlot3D can also be used to generate STL files to print surfaces and solids on 3D printers. So you can now not only view 3D surfaces, curves and vector fields in the app using 3D glasses, you can also 3D print the surfaces, knots, and solids to experience them in true 3D.

See https://sites.monroecc.edu/multivariablecalculus/ This project is funded by NSF-IUSE 1524968. (Received September 24, 2018)

1145-A0-3035 **Dave Kung***, St. Mary's College, Maryland , and **Kira Hamman**, Penn State University, Pennsylvania. *The Power of Quantitative Literacy in the Era of Alternative Facts*

The Quantitative Literacy movement has made impressive strides over the last few decades, not only toward helping students be more numerate but also toward making clear to a broad audience the social and political value of a numerate populace. However, recent seismic shifts in the way society understands evidence, fact, and truth require a response from the QL community. We suggest three ways the movement might move forward: Rethink the contexts in which quantitative tasks are presented to students, making them relevant in the current environment. Closely examine the implications of tracking some students into QL courses - and keeping other students out. Think deeply about how quantitative literacy can help foster an evidence-based approach to social and political issues.

In the spirit of the inquiry approach we advocate for students, participants will be interactively engaged in questioning and refining these ideas. (Received November 02, 2018)

1145-A0-3036 **Reinhard Laubenbacher*** (laubenbacher@uchc.edu), University of Connecticut School of Medicine, Jackson Laboratory for Genomic Medicine, Farmington, CT 06030.
Mathematics in medicine.

Biomedical research, as well as medical practice and healthcare are being rapidly transformed through the increasing availability of data, from the molecular to the population scale. This has opened up an opportunity for the mathematical and computational sciences to make a tremendous impact on medicine. This talk will present several examples of mathematical approaches in this field, and discuss the wide range of research and career opportunities that are available for quantitative scientists as a result.. (Received November 06, 2018)

1145-A0-3037 **Karen Hunger Parshall***, University of Virginia, Charlottesville, VA 22904. *Crossing the pond: European mathematicians in 1920s America.*

American mathematics was experiencing growing pains in the 1920s. It had looked to Europe at least since the 1890s when many Americans had gone abroad to pursue their advanced mathematical studies. It was anxious to assert itself on the international-that is, at least at this moment in time, European-mathematical scene. How, though, could the Americans change the European perception from one of apprentice/master to one of mathematical equals? How could Europe, especially Germany but to a lesser extent France, Italy, England, and elsewhere, come fully to sense the development of the mathematical United States? If such changes could be effected at all, they would likely involve American and European mathematicians in active dialogue, working shoulder to shoulder in Europe and in the United States, and publishing side by side in journals on both sides of the Atlantic. This talk will explore one side of this "equation": European mathematicians and their experiences in the United States in the 1920s (Received November 12, 2018)

Innovative Curricular Strategies for Increasing Mathematics Majors

1145-A1-2061 **Debra K. Borkovitz*** (dbork@bu.edu), Boston, MA 02215, and **Galina Dobrynina** (gid@bu.edu), Boston, MA 02215. *From Mathphobes to Math Majors: The Wheelock College Model.*

The mission of Wheelock College, which recently merged with Boston University, is "To improve the lives of children and families." Wheelock originally came out of the Kindergarten Movement, and it had a long history of using play and active learning in many courses, but no history of a traditional mathematics major. At Wheelock, all Elementary Education majors were also required to have an Arts and Sciences major, and we had majors in Math, Science, and Math/Science for prospective elementary teachers. In the last two years of Wheelock's existence as an independent college, majors from the Math/Science department were the most popular majors for prospective elementary teachers (more popular than Psychology and Human Development). Most of the students who eventually majored in math were mathphobic when they started Wheelock. In the talk, we'll describe the structure of Wheelock's program and offer thoughts on how a different type of math major can attract a different type of student to mathematics. (Received September 24, 2018)

1145-A1-2358 **Igor V. Minevich*** (minevich@rose-hulman.edu). *Students Need Yin!* Preliminary report.

Students need to see the beauty of math, have fun with it, get creative with it, and be proud of their work (these are the yin aspect of mathematics). For the first five minutes of class, I like to do little NP-complete puzzles with the students or talk about the things I find enjoyable about mathematics, such as pictures of fractals or simple combinatorial arguments. I also like to assign problems for extra credit where they need to get creative. This exposes them to a more balanced view of mathematics and suddenly they find that math is not nearly as boring/regimented/uncreative as they thought and start seriously considering majoring in the subject. (Received September 25, 2018)

Trends in Mathematical and Computational Biology

1145-AA-1734 **Anita T Layton*** (anita.layton@uwaterloo.ca), Department of Applied Mathematics, Waterloo, Ontario N2L 3G1, Canada. *Modeling and Simulation for Drug Development.*

Computational modeling can be used to reveal insights into the mechanisms and potential side effects of a new drug. Here we will focus on two major diseases: diabetes, which affects 1 in 10 people in North America, and hypertension, which affects 1 in 3 adults.

For diabetes, we are interested in a class of relatively novel drug treatment, the SGLT2 inhibitors (sodium-glucose co-transporter 2 inhibitors). E.g., Dapagliflozin, Canagliflozin, and Empagliflozin. We conduct simulations to better understand any side effect these drugs may have on our kidneys (which are the targets of SGLT2 inhibitors). Interestingly, these drugs may have both positive and negative side effects.

For hypertension, we want to better understand the sex differences in the efficacy of some of the drug treatments. Women generally respond better to ARBs (angiotensin receptor blockers) than ACE inhibitors (angiontensin converting enzyme inhibitors), whereas the opposite is true for men. We have developed the first sex-specific computational model of blood pressure regulation, and applied that model to assess whether the ”one-size-fits-all” approach to blood pressure control is appropriate with regards to sex. (Received September 24, 2018)

1145-AA-1837 **Jeff Knisley*** (knisleyj@etsu.edu) and **Debra Knisley**. *Identifying Biologically Relevant Structures: From Clustering to Manifold Learning.*

Protein tertiary structure determines protein function and is itself determined by the DNA sequence of the gene encoding the protein. However, the relationship between a gene's DNA sequence and the corresponding protein's tertiary structure is imperfectly understood. We can begin to address our understanding of this relationship using spectral clustering, which is a graph partitioning algorithm derived from the Laplacian matrix of a network. The method typically requires only a few of the eigenvectors of the Laplacian, and in fact, a true graph partition only requires a single eigenvector – the Fiedler eigenvector. However, the method can be generalized to use more than a few of the eigenvectors, in which case it is often interpreted as a nonlinear dimensionality reduction technique known as manifold learning. This talk explores the connection between spectral clustering and manifold learning as it can be applied to biological applications, such as for example how clustering can lead to manifold learning when applied to the study of a protein's tertiary structure. (Received September 24, 2018)

1145-AA-2567 **Mario Banuelos*** (mbanuelos22@csufresno.edu), **Suzanne Sindi** and **Roummel F Marcia**. *Mathematical -Omics Models in Error-Prone Data Regimes.*

Every time a cell divides, its entire DNA sequence is duplicated, and there is an opportunity for the introduction of errors, such as insertions and deletions. The introduction and accumulation of genomic variation are important evolutionary drivers of phenomena such as the creation of new species as well as the development of genetic diseases like cancer. As genome sequencing costs decrease, the volume of sequencing data has resulted in the need for advanced mathematical and computational methods. Unlike highly annotated reference genomes, sequenced genomes from large public repositories tend to suffer from errors in both sequencing and mapping.

In this talk, I will discuss mathematical models in noisy -omic data regimes used to represent and predict genomic variation in organisms. To model the proliferation of variants, we use the full spectrum of repetitive elements and develop a fragmentation equation model which describes non-actively replicating repetitive elements in an organism's genome. Additionally, we predict genomic variation between members of the same species by developing a constrained-optimization framework using gradient-based methods and constrain our solution with a sparsity-promoting ℓ_1 penalty to detect structural variants (SVs) in family lineages. (Received September 25, 2018)

1145-AA-2626 **Shelby N Wilson*** (shelby.wilson@morehouse.edu), 830 Westview Dr., Atlanta, GA 30314. *On the Collective Dynamics of Coupled Morris-Lecar Neurons.*

The spontaneous synchronization of certain groups of neurons is responsible for epileptic seizures as well as some of the motor symptoms of Parkinson's Disease. Hence, there is particular interest in understanding the conditions under which synchrony arises in neural networks. In this talk, we investigate the collective dynamics of a network of globally coupled Morris-Lecar neurons. We demonstrate how the collective dynamics strongly depend on the topological nature of the limit-cycle where the neurons are individually oscillating. Given that neural synchrony lies at the root of a number of neurological disorders, we will also highlight how time-delayed linear feedback can be used to avoid synchrony in an artificial neural network. (Received September 25, 2018)

1145-AA-2632 **Kamel Lahouel***, klahoue1@jhu.edu, and **Donald Geman**, **Laurent Younes** and **Cristian Tomasetti**. *A mathematical model of tumorigenesis.* Preliminary report.

We model and simulate the process of tumorigenesis in a tissue by modeling the evolutionary dynamics of all cells composing the tissue and their interactions. The stem cells belonging to the tissue can acquire different fitness advantages via driver mutations belonging to different pathways. We define the occurrence of cancer as the emergence of a surviving clone having a particular combination of driver mutations. Due to the complexity of the model, we use a stochastic approximation approach as an alternative to the analytical approach for the calibration of the model. The calibration is performed by fitting real colorectal cancer data constraints: The lifetime risk of colorectal cancer, the probability of having a polyp by 50 years old and the probability of having a polyp by 80 years old. In addition, we set a constraint ensuring the non explosion of the size of the tissue by the end of every simulation. Once the free parameters of the model are fixed, we test our model by simulating 4 different tissues, namely, colon, colon with a Familial adenomatous polyposis disorder, blood and pancreas. We compare the results of our simulations to real cancer data such as incidence curves for every tissue or the risk and number of polyps for colorectal cancer and FAP. (Received September 25, 2018)

1145-AA-2641 **Gerardo Chowell*** (gchowell@gsu.edu), Downtown Atlanta, Atlanta, GA 30033. *Mathematical and statistical approaches for forecasting Infectious Disease Epidemics Using Dynamic Modeling.*

Mathematical modeling offers a powerful toolkit to improve our understanding of infectious disease transmission and control. The increasing use of mathematical models for epidemic forecasting has highlighted the importance of designing reliable models that capture the baseline transmission characteristics of specific pathogens and social contexts. More refined models are needed however, in particular to account for variation in the early growth dynamics of real epidemics and generate improved forecasts. I will present recent disease forecasting efforts in the context of Ebola and Zika epidemics and review recent progress on modeling and characterizing early epidemic growth patterns from infectious disease outbreak data. (Received September 25, 2018)

Mathematical Thinking for Modern Data Science Problems

1145-AB-630 **James D Pleuss*** (james.pleuss@usma.edu), **Kevin Talty**, **Morse Steven**, **Patrick Kuiper**, **Michael Scioletti**, **Steven B. Heymsfield** and **Diana Thomas**. *A machine learning approach relating 3D body scans to body composition in humans.*

A long-standing question in nutrition and obesity research involves quantifying the relationship between body fat and anthropometry. To date, the mathematical formulation of these relationships has relied on pairing easily obtained anthropometric measurements such as the body mass index (BMI). Herein, we leverage 3D scanned anthropometry obtained from a population of US Army basic training recruits to derive four sub-populations of homogenous body shape archetypes using a combined principle components and cluster analysis. While the Army database was large and diverse, it did not have body composition measurements. Therefore, these body shape archetypes were paired to an alternate smaller sample of participants from the Pennington Biomedical Research Center that were not only similarly imaged by the same 3D scanning machine, but also had concomitant measures of body composition by dual energy X-ray absorptiometry body composition . With this enhanced ability to obtain anthropometry through 3D scanning quickly of large populations, our machine learning approach for pairing body shapes from large datasets to smaller datasets that also contain state of the art body composition measurements can be extended to pair other health outcomes to 3D body shape anthropometry. (Received September 11, 2018)

1145-AB-1401 **Mary Lynn Reed***, National Security Agency, 9800 Savage Rd, Suite 6844, Ft. Meade, MD 20755. *The Mathematics of Data Science with Applications to National Security.*

The National Security Agency (NSA) faces a wide variety of complex problems under both its signals intelligence and cybersecurity missions. Many of these problems involve analyzing data and applying rigorous mathematical thinking. In this talk we'll highlight some of the unique aspects of data science problems at NSA and the role that advanced mathematical thinking plays in their solutions. We'll feature NSA's two-pronged approach to advancing the state-of-the-art in data science: (1) building the science and advancing the mathematical underpinnings of machine learning, graph algorithms, and other statistical methods, while (2) engaging across disciplines with computer scientists, engineers, and domain experts to solve mission-critical problems and drive research forward. Time permitting, highlighted topics may include: detecting and predicting extremely rare phenomena, the analysis of puzzles and mysteries, advances in recommender-system theory, understanding models for high-consequence decision-making, graph algorithms for community detection, and adversarial machine learning. (Received September 21, 2018)

1145-AB-2016 **Rick Cleary** and **Talithia Williams*** (twilliams@math.hmc.edu). *Data Science for Mathematicians: What We Already Know and What We Need to Learn.*

Many mathematics departments and individual mathematicians, especially those at smaller colleges, are being encouraged to help prepare students for careers and/or graduate study in data science. Mathematics, in fact, underlies much of the theoretical underpinnings of data science. This invited paper session will demonstrate some ways that mathematicians have moved into the data science world. In this initial talk we will discuss some of the mathematical topics that are important in data science, and also the background and skills needed to be successful in starting a data science course. We conclude with applications of how these topics have shaped our experience with teaching and advising students. (Received September 24, 2018)

1145-AB-2071 **Bryan E Adams*** (bryan.adams@usma.edu), Department of Mathematical Sciences, 646 Swift Road, West Point, NY 10996. *Determining mathematically based thresholds from wearable sensors: Insights from NHANES accelerometer data.*

Wearable sensors frequently generate large datasets. To develop meaningful public health guidelines, these data need to be translated to easily understood thresholds. Receiver operating characteristic (ROC) curve analysis was applied to the National Health and Nutrition Examination Survey (NHANES) 2005-2006 accelerometer-derived step data to determine steps/d and peak 30-min cadence as diagnostic screening values (i.e., thresholds) for metabolic syndrome. Optimal thresholds for peak 30-min cadence and steps/d were derived that, when exceeded, predicted the absence of metabolic syndrome. A decision tree analysis was performed to delineate criteria for at-risk versus healthy populations. The area under the curve (AUC) used to classify the absence of metabolic syndrome was 0.65 for steps/d and 0.67 for peak 30-min cadence. The 95% confidence intervals for both AUCs were above 0.50. The optimal steps/d threshold was 5508 steps/d and the optimal peak 30-min cadence threshold was 70 steps/min. These applied methods demonstrate that data from wearable sensors can be used to create clinically interpretable daily physical activity goals. (Received September 24, 2018)

Using Research about Teaching and Learning to Inform the Preparation of Graduate Students to Teach

1145-AC-1124 **Cody L Patterson*** (cody.patterson@utsa.edu), 12330 Vance Jackson Road, Apartment 17202, San Antonio, TX 78230, and **Carlos Acevedo** (carlos.acevedo@utsa.edu). *An activity on aligning calculus problem session tasks to learning objectives.*

We will present an activity, used in teaching assistant professional development at our institution, that engages participants in selecting tasks for a calculus problem session. In the activity we provide participants with a selection of problems on classifying critical points of functions and ask them to select and sequence several tasks for an hour-long problem session and develop a possible plan for a whole-class debrief of these tasks. In selecting tasks, we ask participants to consider the alignment of each task to a specified learning objective and use the cognitive demand framework of Stein et al. (1996) to evaluate the level of demand of each task. In our presentation we will briefly engage session participants in the task selection part of the activity and share results from the use of the activity in our own TA professional development. (Received September 19, 2018)

1145-AC-1357 **Natasha Speer*** (speer@math.umaine.edu). *Selecting and Creating Mathematical Tasks to Promote Student Engagement.*

The mathematical tasks that instructors choose have a significant influence on the learning opportunities provided to their students. The education research community has amassed important findings about the characteristics of tasks that promote and inhibit student engagement and learning. In addition, researchers have documented various ways that instructors reduce and enhance the difficulty level of tasks both intentionally and unintentionally. In this presentation, findings from this area of research will be presented along with examples to illustrate how instructors can use these findings when selecting and creating mathematical tasks for their students. (Received September 21, 2018)

1145-AC-1766 **Kimberly Cervello Rogers*** (kcroger@bgsu.edu). *An Activity for Unpacking Different Features of Mathematical Tasks.*

In this talk, audience members will consider a sample activity from a professional development course for mathematics graduate teaching assistants (GTAs) at my institution, which develops GTAs' ability to select and modify mathematical tasks in alignment with learning objectives. From this sample activity, session participants will explore how contrasting kinds of mathematical tasks provide different opportunities for students to be able to do and understand mathematics. When engaging with this activity, audience members will be expected to solve a few algebraic questions, consider what mathematics a student would need to know to successfully answer these questions, and explore ways that students' incorrect responses to these questions could inform an instructor's understanding about what students do or do not understand. Through these experiences, session participants will consider strategies for selecting and modifying tasks to align with learning goals and discuss ways to use this activity in professional development for GTAs. (Received September 24, 2018)

1145-AC-2305 **Mary Beisiegel***, 368 Kidder Hall, Department of Mathematics, Corvallis, OR 97331. *Activities for Building and Honing MGTAs' Abilities to Foster Student Engagement.*

Research shows that adopting unfamiliar teaching practices can be difficult for novice and experienced teachers alike. Research also shows that teachers who are most successful in learning how to foster student engagement in mathematical thinking and reasoning begin with small-scale teaching strategies (e.g., open-ended questions) and, over time, build up to larger-scale teaching strategies (e.g., interactive lecture). Success in implementing small-scale changes provides teachers with the confidence to make larger changes. Mathematics graduate teaching assistants (MGTAs) should have multiple opportunities to learn about and practice various teaching strategies that foster student engagement. I will describe three activities for helping MGTAs learn small-scale strategies and build to larger-scale teaching strategies. The first activity presents small-scale strategies and has MGTAs posing open-ended questions, reading canned responses, and practicing different ways of replying. The second activity has MGTAs focus on mid-scale strategies, such as think-pair-share, and how to maintain cognitive demand of tasks. The third activity has MGTAs create prompts in their lecture notes in order to design interactive lectures and whole-class dialogues. (Received September 25, 2018)

1145-AC-2657 **Kelly MacArthur*** (macarthur@math.utah.edu). *Activities to Build Department Culture that Supports Engaged Learning Classroom Culture.*

Many GTAs enter graduate school with exposure primarily to traditional lecture-style teaching practices. Asking GTAs to teach in ways that are new to them, using various student-engaged techniques, can be daunting and confusing for many of them. To help bridge that gap, we, as faculty members, need to continuously model student-engaged teaching and build a respectful teaching environment/culture for GTAs to flourish. A necessary condition of building a culture of student-engaged practices includes modeling, by experienced faculty, in our own teaching of undergraduate courses, that GTAs can observe. But that is not a sufficient condition to building a culture of best teaching practices. We need to, additionally, utilize engaged practices in our actual mentoring of GTAs. In this session, I'll present several activities that can be incorporated into a mathematics department to ensure the ongoing culture of the department supports GTAs in fostering student engagement in their classrooms throughout their graduate school years. (Received September 25, 2018)

1145-AC-2819 **Shandy Hauk*** (shauk@wested.org). *Research Sampler for Learning to Foster Student Engagement.*

The teaching strategies instructors select can deepen student engagement and improve mathematical learning. What does it mean to say students are engaging in mathematical thinking, reasoning, or problem-solving? Part of the answer is what students might know or learn about mathematical ideas (cognitive engagement), another part is in what students might feel while using knowledge (affective engagement such as interest, anxiety, frustration), and part is in what students do (behavioral engagement like attentiveness, diligence, effort). This session digs into research on teaching strategies that productively influence these core aspects of engagement. The session includes research-based examples of effective approaches, in context, to illustrate the variety of ways college instructors choose and use strategies that foster student engagement. (Received September 25, 2018)

Beauty and Art from Research Mathematics

1145-AD-436 **Jasmine Powell***, jtpowell@umich.edu. *Fungal fractals from post-critically finite polynomials.*

Complex quadratic polynomials give rise to all sorts of beautiful mathematical pictures, the most well-known, perhaps, being the Mandelbrot set. We work in this same framework, focusing specifically on the post-critically finite quadratic polynomials – that is, those whose unique critical point has finite forward orbit under the map. If you were to take all such polynomials and plot every point in their critical orbits on the same plane, what sort of a picture would arise? What sort of properties would it have? We investigate these questions while admiring the intricate fractal-like images that appear when studying the iteration of complex functions. (Received September 06, 2018)

1145-AD-631 **Daniel E. Martin*** (daniel.e.martin@colorado.edu). *Galactic vistas from imaginary quadratic fields.* Preliminary report.

For a Euclidean imaginary quadratic field K, continued fractions have been used to give K-rational approximations to complex numbers since the late 19^{th} century. We will see how this can be done in any imaginary quadratic field. The tool that illuminates our path is a fractal arrangement of circles arising from an action of $\mathrm{PSL}_2(\mathcal{O}_K)$ on the Riemann sphere. These galactic vistas prove to be the road map leading us to the desired approximations. Along the way we will find surprising connections to the class group of $\mathcal{O}_K$ and the study of Apollonian circle packings. (Received September 11, 2018)

1145-AD-1627 **Julie Barnes*** (jbarnes@email.wcu.edu) and **Beth Schaubroeck** (beth.schaubroeck@usafa.edu). *Crafting contours of complex functions based on dynamical properties.*

Julia sets of complex polynomials are the well-known sets of points where the functions are bounded under iteration. Roughly ten years ago, we began exploring two sets related to Julia sets: the set of points bounded in the real direction under iteration and the set of points bounded in the imaginary direction under iteration. This led us to look at the surfaces obtained by the real part and the imaginary part of iterated complex rational functions. To better analyze the dynamical properties of the functions behind these surfaces, we started generating the associated contour plots. Stunning artistic designs appeared. This has led us back to the mathematics to learn more about what the contour lines themselves indicate, and what properties are necessary to produce more intricate designs from contours. We end this presentation by discussing how this research turned into a coloring book and how we are working to produce more images for a mathematical calendar. (Received September 23, 2018)

1145-AD-1636 **Sophia T Santillan*** (sophia.santillan@duke.edu), 144 Hudson Hall, Durham, NC 27708. *Sunsets from Heavy Cantilever Oscillations.*

A cantilever beam, or a beam that is fixed against translation and bending at one end while remaining free at the other end, is called ‘heavy’ in structural analysis if the weight of the beam itself is included in the analysis. Here, large amplitude vibration of a vertical, heavy cantilever was investigated. The natural frequencies of a cantilever actually change at large amplitudes, and only nonlinear partial differential equations can be used, without linear approximations, to study this behavior. Here, governing arclength equations were derived to model dynamic and static behavior and then numerically solved using a finite-difference method to solve the boundary value problem. A spectrogram was generated to illustrate the relationship between amplitude of motion and vibration frequencies, and this was done by including damping in the system model. After generating a time series of motion with a large initial deflection of the cantilever, a short-time fast Fourier transformed was performed to determine the powers over a frequency range as the amplitude of motion decayed. What resulted was a series of images showing feather-like structures, or, with a particular coloring scheme, a stack of sunsets that change for a range of amplitudes. (Received September 23, 2018)

1145-AD-1709 **Kathryn A Lindsey*** (lindseka@bc.edu), Maloney Hall, Department of Mathematics, Boston College, Chestnut Hill, MA 02467. *Rings of fire from postcritically finite interval self-maps.*

William Thurston created a plot in the complex plane of the set consisting of all Galois conjugates of all growth rates of postcritically finite unimodular self-maps of an interval. The visually stunning result revealed a set with rich and complicated geometry - resembling a ring of fire. We now call this set the Thurston set. Together with H. Bray, D. Davis and C. Wu, I am investigating the properties of the Thurston set and related sets. I will show some images and movies of these sets and explain some of the theory behind them. (Received September 24, 2018)

1145-AD-1984 **Jessica M. Libertini*** (libertinijm@vmi.edu), 65 Pinnacle Lane, Lexington, VA 24450. *Artistic Patterns from the Universe Projected onto the Unit Sphere.*

A central premise of the field of cosmic crystallography is the idea of the universe being finite yet unbounded, such as a 3-torus or similar construction with rotated or reflected gluing of the faces of the torus. After presenting these ideas in my Mathematics for Space Applications course, students wondered what percentage of the sky we would need to search to guarantee seeing a replication of ourselves, or our galaxy supercluster. In pursing answers to this question, we explore projections of lattice points, or shifted lattice points, onto the unit sphere and the resulting Delaunay triangulations, which give rise to beautiful patterns as well as provide insights about the nature of possible shapes of space. (Received September 25, 2018)

Modular Forms: Aesthetics and Applications

1145-AE-635 **Madeline Locus Dawsey*** (madeline.locus@emory.edu) and **Riad Masri**. *The Andrews Smallest Parts Partition Function.*

The partition function $p(n)$ has been a testing ground for some of the deepest phenomena about modular forms in number theory. For example, the study of its size gave birth to the "circle method" in analytic number theory, and the delightful congruence properties discovered by Ramanujan offered glimpses of the theory of Hecke operators and Galois representations, which are now pillars in modern mathematics. A few years ago, Andrews defined the smallest parts partition function, $\mathrm{spt}(n)$, and researchers have discovered that its properties are dictated by functions called *harmonic Maass forms*, generalizations of modular forms. In this talk, we recall some of the startling properties of $\mathrm{spt}(n)$, including some of the speaker's own work in the subject. (Received September 11, 2018)

1145-AE-646 **Ken Ono*** (ken.ono@emory.edu), Dept Mathematics, Emory University, Atlanta, GA 30322. *Ramanujan and Recent Work on the Riemann Hypothesis and Related Problems.* Preliminary report.

Hardy and Ramanujan famously invented the "circle method" in their work on partitions. They gave the first asymptotic formula for p(n), the number of partitions of integers of size n. Despite further advances by Rademacher and others, some of the simplest questions about partitions remained open. One of these problems relates to log-concavity, a property that was not completely confirmed for p(n) until 2013 with the work of DeSalvo and Pak. Inspired by this work, mathematicians have been investigating refinements and generalizations for partitions. By working on these questions, the speaker (together with Griffin, Rolen and Zagier) has made an unexpected connection with the celebrated Riemann Hypothesis. This lecture will tell this fascinating story, culminating with new evidence and theorems about RH. (Received September 12, 2018)

1145-AE-668 **Larry G Rolen*** (larry.rolen@vanderbilt.edu), Department of Mathematics, 1420 Stevenson Center, Vanderbilt University, Nashville, TN 37240. *Congruent numbers and modular local polynomials.*

There are many right triangles with integer side lengths, like the well-known triangles with side lengths 3-4-5 or 5-12-13; examples of *Pythagorean triples.* It has been known since the ancient Greeks how to write down all such Pythagorean triples in a beautiful manner. The famous congruent number problem modifies this question slightly, and simply asks for a given integer n, whether there are any right triangles with *rational* side lengths and area n. This problem turns out to be much more subtle, and a simple criterion for which n are "congruent" remained out of reach for centuries until a celebrated result of Tunnell in the 1980's.

In this talk, I will discuss recent joint work with Stephan Ehlen, Pavel Guerzhoy, and Ben Kane, where we study so-called *locally harmonic Maass forms* and their applications to congruent numbers and related objects. We will also review famous modern results on this classical problem such as Tunnell's Criterion which gives a fast procedure for checking whether any number should be congruent, and their connections to big ideas in number theory and the $1 Million Birch and Swinnerton-Dyer conjecture. (Received September 12, 2018)

1145-AE-900 **George E Andrews*** (gea1@psu.edu), 306 McAllister Bldg., Math Dept, Pennsylvania State University, University Park, PA 16802. *Ramanujan's Lost Notebook: The Continuing Mystery.*

In the spring of 2018, Bruce Berndt and I completed the fifth of five volumes providing proofs of the assertions in Ramanujan's Lost Notebook. The book was published in September, 2018. The final chapter in Part V is titled, The Continuing Mystery. It is our belief that there remain many open mathematical questions about Ramanujan's discoveries. This talk will discuss a few of these challenges. (Received September 17, 2018)

1145-AE-1125 **Nickolas Andersen*** (nandersen@math.ucla.edu) and **William Duke**. *Modular billiards and Diophantine approximation.*

The classical problem of determining the worst approximable irrational numbers was famously solved by Markov in 1880 using the theory of binary quadratic forms and continued fractions. This set of badly approximable numbers, known as the Markov spectrum, has an elegant interpretation in terms of hyperbolic billiards in the modular triangle. I will review the classical theory in this setting and describe some recent results characterizing other Markov-like spectra. This is joint work with Bill Duke. (Received September 19, 2018)

1145-AE-1946 **Marie Jameson*** (mjameso2@utk.edu). *Congruences for modular forms and generalized Frobenius partitions.*

The partition function is known to exhibit beautiful congruences that are often proved using the theory of modular forms. In this paper, we study the extent to which these congruence results apply to the generalized Frobenius partitions defined by Andrews. In particular, we prove that there are infinitely many congruences for $c\phi_k(n)$ modulo ℓ, where $\gcd(\ell, 6k) = 1$, and we also prove results on the parity of $c\phi_k(n)$. Along the way, we prove results regarding the parity of coefficients of weakly holomorphic modular forms which generalize work of Ono. (Received September 24, 2018)

The Past 50 Years of African Americans in the Mathematical Sciences

1145-AF-534 **Talitha M Washington*** (talitha.washington@howard.edu), Howard University, Washington, DC 20059. *Hidden Figures: The Mathematics of Katherine Johnson and Rudy Horne.*

What's the mathematics that Katharine Johnson used to send John Glenn into orbit and bring him back safely? Who was the mathematician that created the mathematics in the "Hidden Figures" Hollywood movie? Come and uncover the essential ideas created by Johnson during the Space Race and how the mathematical consultant, Dr. Rudy Horne, created the mathematics for the movie. We will also explore how other 'Hidden Figures' helped Johnson become a research mathematician in a racially segregated era. (Received September 09, 2018)

1145-AF-1404 **Fern Y Hunt*** (fern.hunt@nist.gov), Mail Stop 8910, National Institute of Standards and Technolog, Gaithersburg, MD 20899. *Finding Nodes for Fast Communication in Small and Large Networks.*

The identification of nodes in a network that will enable the fastest spread of information is an important if not fundamental problem in network control and design. It is applicable to the optimal placement of sensors, the design of secure networks and the problem of control when network resources are limited. We consider a discrete time model of information spread that is associated with a random walk in a graph with a set of nodes V and a subset $A \subseteq V$ of spreaders. The most effective set of nodes is identified by finding or approximating a set A that minimizes the sum of the expected first hitting times of random walkers starting outside the set. Minimization is over all sets of some constrained cardinality. Two approaches to the solution of this problem are discussed. The first uses the supermodularity of the function to be minimized. The second scalable approach is suitable for networks with millions of nodes, producing approximate solutions in a fraction of a second. (Received September 21, 2018)

1145-AF-2299 **Michael Young*** (myoung@iastate.edu), Ames, IA 50010. *A random walk with a black graph theorist.*

In this talk, I will discuss my journey into the world of discrete mathematics and graph theory. We will also discuss the contributions of some black mathematicians to the area. (Received September 25, 2018)

1145-AF-2347 **William A Massey*** (wmassey@princeton.edu), ORFE Department, Sherrerd Hall, Princeton University, Princeton, NJ 08544. *A Uniform Acceleration Trilogy for Dynamic Rate, Single Server Queueing Transience.*

The dynamic rate $M/M/1$ queueing system is a time-inhomogeneous, Markovian birth-death process. Both the birth and death rates here vary over time but stay constant over changes in the state. An asymptotic scaling of these rates called *uniform acceleration* was developed in the PhD thesis of the author. This approach was shown for the $M/M/1$ queue to be the natural generalization to the steady state equilibrium analysis of time-homogeneous Markov processes.

Over a period spanning three decades, this analysis also engaged the author into developing a trilogy of publications on the transience or stochastic evolution of this single server queueing system. This talk tells that larger story. We show how each successive paper yields new interpretations for the asymptotics of uniform acceleration. (Received September 25, 2018)

1145-AF-2501 **Scott W. Williams*** (bonvibre@yahoo.com). *On Mathematicians of the African Diaspora.* Preliminary report.

I created the website Mathematicians of the African Diaspora in 1997 on SUNY at Buffalo's website so it is now 21 years old. Why was it created? How has it been received? What problems were encountered? Should its existence continue in current or mutated form? I will speak about these and other questions. (Received September 25, 2018)

Inspiring Diversity in Mathematics: Culture, Community, and Collaboration

1145-AG-592 **Chad M. Topaz*** (cmt6@williams.edu) and **Shilad Sen** (ssen@macalester.edu). *Diversity in mathematics through a data science lens.*

Concerned by the grievous underrepresentation of women in many scientific fields, we quantify gender representation on mathematics journal editorial boards. Using crowdfunding and crowdsourcing, we amass a database of over 13,000 journal editors and deduce the group's gender breakdown. While women are known to comprise approximately 16% of tenure-stream faculty positions in doctoral-granting mathematical sciences departments in the United States (as of 2016), we find that 8.9% of the editorships in our study are held by women. We also describe group variations within the editorships by identifying specific journals, subfields, publishers, and countries that significantly exceed or fall short of this average. (Received September 11, 2018)

1145-AG-593 **Alicia Prieto Langarica*** (aprietolangarica@ysu.edu). *Undergraduate Research as the Greatest Equalize.*

For most faculty, graduate school prepares us in mathematics and exposes us to mathematics research. While this is necessary and the main purpose of a graduate degree, for the many of us that end up with careers in academia, it might not be sufficient. In this talk, we will talk about an aspect of academic life often left as an exercise to the reader: directing student in research projects. The talk will motivate research as a tool to engage students of all levels (from middle school to undergraduates) and of all different backgrounds. We will discuss how research can be used to attract populations underrepresented in mathematics and we will provide many examples of different projects. We will end by discussing some issues that might arise when directing students and some advice that might help with this task. (Received September 11, 2018)

1145-AG-1266 **Aris Benjamin Winger*** (aris.winger@gmail.com), 1012 Jonathan Lane, Tucker, GA 30084. *Facing the Mirror: Acknowledgement in our Practices.*

In this talk, we will be discussing the role of acknowledgement in our continued process to be better teachers. Using research conducted at the high school level and work done at the college level, strategies and methods will be shown to help ourselves do what is arguably the most important part in improving ourselves as teachers: becoming aware of and acknowledging our past mistakes in all areas and in particular with regard to bias. Implicit bias is an major impediment to the success of students and one of the major strategies in fighting bias is to become aware that it exists. In this talk we will outline some tools of acknowledgement that will help to fight bias and improve the classroom context for marginalized students. (Received September 20, 2018)

1145-AG-1303 **Becky E. Hall***, hallb@wcsu.edu, and **Carrie Diaz Eaton**, cdeaton@bates.edu. *Two Math Mamas Tell Their Stories.*

This talk is given by two of a 400+ member support group for mathematician mothers who are balancing career and family. *Math Mamas* is a self-organized group, creating a community of support for mothers in the professional mathematics community. We have gathered autobiographical stories from this diverse set of women who have found success and balance in their academic careers and motherhood. These stories have been published in a recent Special Issue on Mathematics and Motherhood for the Journal of Humanistic Mathematics. In this talk, we will discuss our mathematician mother community and its impact on our lives. We will also read selected passages from our contributions to the special issue. (Received September 20, 2018)

1145-AG-1419 **Gabriel E Sosa*** (gsosa@amherst.edu), **Alexander Diaz-Lopez**, **Pamela Harris** and **Alicia Prieto-Langarica**. *LATHISMS: showcasing the contributions of Latinx and Hispanics to the mathematical sciences.*

Lathisms, founded in 2016, originated from the need to provide a platform where the research, teaching and mentoring of latinx and hispanic mathematicians was prominently featured. In this talk, we will present the achievements of this project in the three years since its inception, highlight the challenges and successes in the sustainability of the program and preview some of the plans for the future of this initiative. (Received September 21, 2018)

1145-AG-1733 **Helen G. Grundman*** (hgg@ams.org), 201 Charles St., Providence, RI 02904. *Working to inspire diversity-skeptics.*

Incredible work is being done to help inspire young people to pursue mathematics, to convince them that they do not have to fit the stereotypes of mathematicians in order to join the community. But if we truly believe in creating an inclusive mathematics community, then we also need to figure out how to inspire the skeptics to see that diversity does not have to be a threat. I will talk about ideas and strategies for making progress in this direction. (Received September 24, 2018)

1145-AG-2285 **Michael Young*** (myoung@iastate.edu), Ames, IA 50010. *Equity in the mathematics classroom.*

Many students grow a distaste for mathematics, while others just choose to completely avoid it all together, because of their experiences within the subject. The mathematics classroom is not always an effective place of learning. This is particularly true for women and students of color. This talk will discuss the ideas and research of the "Designing Equity by think in and about Mathematics" and the NSF INCLUDES "Building on Strengths" projects and how these projects are disrupting inequities in the mathematics classroom. (Received September 25, 2018)

Mathematics and Policy

1145-AH-1063 **Jonathan K Hodge*** (hodgejo@gvsu.edu), Department of Mathematics, Grand Valley State University, 1 Campus Drive, Allendale, MI 49401. *Mathematical arguments in Dudum v. Arntz.* Preliminary report.

In a 2011 court case, Dudum v. Arntz, the Ninth Circuit Court of Appeals upheld the city of San Francisco's use of restricted Instant Runoff Voting (IRV)—a version of IRV that allows voters to rank at most three candidates. We will explore the mathematical arguments and reasoning that arose in this landmark case. Which types of arguments were persuasive, which were not, and what lessons can be learned about the role of mathematics in litigation involving voting and democracy? (Received September 18, 2018)

1145-AH-2012 **Catherine Paolucci*** (paoluccic@gmail.com), 134 Roberts Ln #303, Alexandria, VA 22314. *Partnerships and Pathways to Inform Policy.*

This presentation will discuss some of the pathways and strategic partnerships through which the mathematics community can help to inform policy. It will highlight ways in which mathematics can provide important information for both the initial drafting of legislation and the critical analysis that influences policymakers' decisions on key issues. Advice and guidance will be offered regarding ways in which the mathematics community can identify opportunities to share their work with key policy stakeholders, including strategic engagement in relationship building, collaboration, and communication with organizations that have an active presence on Capitol Hill and established relationships with members of Congress and Congressional committees. The discussion will also explore ways in which interdisciplinary collaborations with other scientific fields can strengthen the link between the work of the mathematics community and the policies that can shape the future of our economy, environment, healthcare, and education. (Received September 24, 2018)

1145-AH-2442 **Karen M. Bliss*** (blisskm@vmi.edu), 404 Mallory Hall, Lexington, VA 24450. *Modeling to Engage Students in Policy Issues.*

Instructors have long used applications to provide context and relevance to the mathematical concepts in their classes. We can increase our students' interest even more by encouraging them to apply their mathematical skills to issues currently being addressed by policy makers. Real-world issues tend to be messy and not well-defined, so students' judgements about which factors to include matter, and they need to justify their decisions. Students also have the opportunity to practice verbal and written communication skills. Examples of modeling scenarios involving policy issues will be provided. (Received September 25, 2018)

1145-AH-3003 **J Michael Pearson*** (pearson@maa.org). *Disciplinary Societies and Federal Policy for Support of Research and Education.*

The mathematical sciences community depends on federal support through the National Science Foundation, and, to a lesser extent, agencies such as the National Security Agency, the Department of Energy, and NASA. The MAA and our sister societies engage with policy makers directly and in collaboration with other STEM disciplinary societies, government relations officers representing colleges and universities around the country, and other organizations such as the National Academies and AAAS. The roles and relationships we play have their origins in the collaboration between academic, corporate, and government entities through World War II. I will offer a thumbnail sketch of this history, with a particular view of how mathematics (and mathematics organizations) participated in this history, and discuss what we are doing now to ensure that our voices remain central to ongoing conversations regarding future support. (Received September 26, 2018)

1145-AH-3018 **Vanessa Escobar*** (vanessa.m.escobar@nasa.gov). *Stakeholder Engagement and Analysis of CMS Data Products in Decision Making and Policy Frameworks.*

The overarching objective of the CMS applications effort is to broaden and strengthen the knowledge and engagement of the research and applications communities within NASA's Carbon Monitoring System (CMS) initiative. The focus of the activity is to engage with the environmental and climate community, including operational agencies, non-governmental organizations, academia and the private sector, to ensure that the current and planned CMS science outcomes and data products are used in decision-making contexts. Community engagement will allow both scientists and stakeholders to explore areas where CMS might contribute to addressing key data gaps relevant to societal needs across many scales. (Received September 26, 2018)

1145-AH-3024 **Mira Bernstein*** (mirabernstein@gmail.com). *In defense of democracy: mathematical tools for fighting gerrymandering.*

Gerrymandering is the practice of drawing boundaries of electoral districts in a way that unfairly benefits or hurts a particular group of voters. Common targets of gerrymandering include supporters of a political party (*partisan gerrymandering*) or members of a racial minority (*racial gerrymandering*). In the US, these two types of gerrymandering have very different legal status, so the mathematical tools required to combat them are completely different as well.

In this talk, I will describe statistical approaches to fighting both types of gerrymandering. In the case of partisan gerrymandering, the main difficulty lies in articulating a quantitative standard of partisan fairness and finding ways to measure deviations from this standard. In contrast, for racial gerrymandering, the legal standard is relatively clear; the challenge is to show that race is a relevant variable at all. Racial gerrymandering can only occur if voters of different races tend to vote differently, which is extremely difficult to prove when we have no way of knowing how *any* individual voted. I will describe existing statistical tools for detecting racially-polarized voting and conclude with my own work on increasing the power of these techniques by combining data from multiple elections. (Received September 26, 2018)

Research in Undergraduate Mathematics Education: Highlights from the Annual SIGMAA on RUME Conference

1145-AI-67 **Stacy A. Brown*** (brown@cpp.edu), Department of Mathematics and Statistics, California State Polytechnic University, Pomona, CA 91768. *E-IBL: An Exploration of Theoretical Relationships Between Equity-Oriented Instruction and Inquiry-based Learning.*

The purpose of this talk is to further current discussions of the relationships between Equity-Oriented Instruction (EOI) and Inquiry Based Learning (IBL) pedagogies. Specifically, it proposes a framing of Equity-Oriented Inquiry Based Learning (E-IBL) that foregrounds equitable practice, as opposed to viewing equitable practice as a gratuitous outcome of IBL pedagogies. Drawing on data from teaching experiments conducted in IBL-Introduction to Proof courses, the inter-relationships between knowledge, identity and practice (Boaler, 2002), Pickering's 'dance of agency,' Gutiérrez's dimensions of equity, and Bourdieu's notion of habitus, this talk explores why intentional attention towards the critical axis of equity – that which links identity and power – is necessary, if IBL pedagogies are to promote equity. (Received July 18, 2018)

1145-AI-699 **Paul Dawkins**, **Matthew Inglis** and **Nicholas Wasserman*** (wasserman@tc.columbia.edu). *The use(s) of 'is' in mathematics.*

This paper analyzes some of the ambiguities that arise among statements with the copular verb 'is' in the mathematical language of textbooks as compared to day-to-day English language. We identify patterns in the construction and meaning of 'is' statements using randomly selected sample statements from corpora representing the two linguistic registers. In particular, for the grammatical form "[subject] is [noun]," we compare the relative frequencies of the subcategories of semantic relations conveyed by that construction. Specifically, we find that this construction – in different situations – conveys a symmetric relation, an asymmetric relation, or an existential relation. The intended logical relation can only sometimes be inferred from the grammar of the statement itself. We discuss the pedagogical significance of these patterns in mathematical language and consider some strategies for helping students interpret the intended meaning of the mathematical text they hear or read. (Received September 13, 2018)

1145-AI-1628 **Christine Andrews-Larson** and **Shelby McCrackin*** (slm14c@my.fsu.edu). *The next time around: Scaffolding and shifts in argumentation in initial and subsequent implementations of inquiry-oriented instructional materials.*

Considerable learning is entailed in adopting an inquiry-oriented approach to teaching an undergraduate mathematics class. In this analysis, we examine classroom video data of three instructors' initial implementation of an inquiry-oriented instructional unit and their implementation of the same unit one year later. We document consistent increases in instances of eliciting and building on student contributions across tasks and instructors. We then use Toulmin's argumentation scheme to offer an illustration of how classroom discussions became more mathematically robust and student-centered from initial to subsequent implementations. Implications for instructor learning will be discussed. (Received September 23, 2018)

1145-AI-2090 **Vicki L Sealey*** (sealey@math.wvu.edu), **Nicole M Infante**, **Matthew P Campbell** and **Johnna Bolyard**. *The Generation and Use of Examples to Promote Authentic Engagement in Calculus Classrooms.*

In this talk, we present analysis of video data of five instructors teaching the Mean Value Theorem in a first-semester calculus course. Throughout the lessons, graphical examples were provided by the instructors and/or the students of functions that satisfied or did not satisfy the conclusion of the Mean Value Theorem. Through the use of thematic analysis, we identified four themes related to emergence and use of examples: who generated the example, who evaluated the example, the precision of the example, and how and when the example was used. We show that instruction that leverages student generated examples provided a great deal of richness and depth in a mathematics lesson and created opportunities to engage students in authentic mathematical activity. This work contributes to an evolving notion of what is entailed in students' active learning of mathematics and the role of the instructor. (Received September 24, 2018)

1145-AI-2237 **Kathleen Melhuish*** (melhuish@txstate.edu), **Anna Marie Bergman** and **Jennifer Czocher**. *Revisiting Reducing Abstraction in Abstract Algebra.*

Concepts arising in advanced mathematics are often described as "abstract." However, it is often unclear what is meant when we apply that term to mathematical thinking – either as an adjective or a verb. In this presentation, we revisit Hazzan's (1999) foundational work on student's reduction of abstraction as they learn abstract algebra. We applied the reducing abstraction framework to a new set of student-generated work. Through both analysis of empirical data and theoretical analysis, we expand and refine Hazzan's framework to identify meanings for "abstract." Examples of student work are provided to illustrate dimensions for "abstract" in relation to familiarity, context, complexity, connections, and formality. We conclude by considering how to use dimensions of abstraction as a lens not only for classifying student errors, but as a means to characterize productive mathematical activity. (Received September 25, 2018)

Building Successful Communities in Mathematics

1145-AJ-66 **David Goldberg*** (goldberg@purdue.edu), Executive Director, Math Alliance, Department of Mathematics, Purdue University, 150 N. University Street, West Lafayette, IN 47907, and **Philip C Kutzko**. *Building a national mentoring community.*

The National Alliance for Doctoral Studies in the Mathematical Sciences (The Math Alliance) is focused on increasing the number and proportion of US PhDs awarded to underrepresented US minorities. The Alliance is a community of over 770 faculty mentors at over 280 campuses, and over 800 students. The Alliance started as a much smaller entity, involving only the three Iowa Regents universities, and four HBCUs (the NSF funded Alliance for the Production of African American PhDs in the Mathematical Sciences). The Math Alliance has grown organically, and until recently, mostly by word of mouth. One key to the Alliance's success has been its attention, at every stage, to building community. In this talk we'll describe the development of the Alliance community, and discuss how what we have learned can help others build communities in other settings. (Received July 18, 2018)

1145-AJ-68 **Stacy A. Brown*** (brown@cpp.edu), California State Polytechnic University, Pomona, Department of Mathematics and Statistics, Pomona, CA 91768. *Advancing Research on Undergraduate Mathematics Education.*

In 1997, Ed Dubinsky gathered a small group of people to hold the first conference on research on undergraduate mathematics education (RUME). This small collective went on to become the MAA's first SIGMAA and what is now a thriving research community. In this talk, I will share the steps taken by myself and other coordinators, as well as our conference chairpersons, to further develop, promote and sustain our research community. I will also share information about current and emerging efforts to foster connections between research and practice, develop relationships across disciplines, and disseminate research- based instructional innovations. (Received July 18, 2018)

1145-AJ-70 **Judith Covington*** (covingtonj@nsula.edu), Northwestern State University, Natchitoches, LA 71497. *Successful Section?*

What makes a Section successful? In this talk I will discuss ways that I believe the Louisiana/Mississippi Section has been successful. One of the most important ways this has happened is that the members in our section form a true community. We support each other and we reach out to involve others. We have a plan to reach out to those we have not seen in a while and we want to make sure those that have not attended a section meeting are invited as well. When someone attends our section meeting, we want it to feel like a family reunion. (Received July 18, 2018)

1145-AJ-71 **David T. Kung*** (dtkung@smcm.edu) and **Alissa S. Crans** (acrans@lmu.edu). *MAA Project NExT: A community for new faculty.*

Since 1994, MAA Project NExT has welcomed over 1,800 new mathematics faculty from a wide variety of institutions. Each year we recruit a cohort of 80-90 enthusiastic, dedicated professors to discuss innovative teaching, inclusive practices, and being responsible citizens of the discipline. While the individual sessions are important and interesting (we hope!) the most important aspect of the program is the community building that occurs throughout the experience. We'll discuss the many ways we intentionally cultivate community both horizontally (within each cohort) and vertically (between the new group and more experienced mathematicians), all with the goal of fostering successful mathematicians who move our community forward toward a more inclusive future. (Received July 18, 2018)

1145-AJ-72 **Michelle Manes*** (mmanes@math.hawaii.edu). *Women in Numbers: A research community.*

Women in Numbers (WIN) was one of the first Research Collaboration Conferences for Women (RCCW). In this workshop model, mathematicians from various career stages come together for both research collaboration and mentorship. The first WIN conference was held in 2008 at BIRS, and there have been (so far) a total of four conferences at BIRS and two in Europe. These workshops provide a powerful model for combatting the "old boy's network" by building a network of our own. The focus is on both creating new high-quality research (senior mathematicians design and lead projects that involve early career researchers and graduate students) and on building a professional community that supports its members through all career stages. Growing out of WIN, the "Women in Numbers Network" — including a website, mailing list, and a web of personal and professional contacts — has impacted the careers of those of us lucky enough to participate and may be having a lasting effect on the broader number theory community. (Received July 18, 2018)

1145-AJ-75 **Raegan Higgins*** (raegan.higgins@ttu.edu), Texas Tech University, Dept of Mathematics & Statistics, Box 41042, Lubbock, TX 79409, and **Ami Radunskaya**. *EDGE: Building a thriving community of women mathematicians.* Preliminary report.

For over twenty years, the EDGE Program has provided a mathematics ecosystem in which a widely diverse group of women has thrived both academically and personally. We will discuss the philosophy on which the EDGE Program is built, as well as outcomes and perspectives on which program features foster success in women, and in particular, women of color. We consider some of the professional and personal benefits that participants seem to derive from a community of this kind and the value EDGErs add to the mathematics community. (Received July 21, 2018)

Research in Improving Undergraduate Mathematical Sciences Education: Examples Supported by the National Science Foundation's IUSE: EHR Program

1145-AK-786 **Wendy Smith*** (wsmith5@unl.edu), **Chris Rasmussen** (crasmussen@sdsu.edu), **David C. Webb**, **Robert Tubbs**, **Matthew Voigt** and **Howard Gobstein**. *Student Engagement in Mathematics through an Institutional Network for Active Learning (SEMINAL).* Preliminary report.

Student Engagement in Mathematics through an Institutional Network for Active Learning (SEMINAL) is investigating departmental commitments –particularly active learning strategies- that improve student learning in the Precalculus to Calculus 2 (P2C2) sequence. Changing department culture, norms, and practices to support widespread use of active learning is notoriously difficult, and case studies of departments that have successfully made such changes are rare. We will highlight practices and policies of six, research-oriented mathematics departments that have made and sustained considerable progress in infusing active learning into this sequence. In particular, we note how departmental and institutional leadership; P2C2 structures such as course coordination; use of data; student resources such as learning or tutoring centers; and professional development have been mutually supportive to initiate, implement, and sustain active learning in P2C2 courses. However, there is little attention to equity and inclusive practices and hence we call for departments to address these issues. Now in a second phase, we have added nine institutions to our network to study how we might adapt our knowledge to enable success in efforts to incorporate active learning into their P2C2 sequence. (Received September 14, 2018)

1145-AK-1106 **Jack Bookman*** (bookman@math.duke.edu) and **Natasha Speer**. *Evolution of the College Mathematics Instructor Development Source (CoMInDS) Project: What We Learned and How Things Changed.*

Historically, faculty in the mathematical sciences have received little formal preparation for teaching. Today, the professional development (PD) of novice college mathematics instructors is receiving more attention in our community. However, although some resources are available to guide these efforts, faculty who wish to start or enhance a program may find it challenging to locate instructional materials or faculty with experience in this area to learn from. The purpose of CoMInDS is to provide better access to such resources and to create more accessible versions of existing informal networks. CoMInDs is developing an online resource suite of instructional materials and research products related to instructor PD, offers workshops to faculty who are preparing graduate students to teach and is establishing a professional community of practice of people interested in these issues. In this presentation we will discuss how our ideas about how to best achieve our goals have changed. We will present what we have learned about supporting faculty as they use PD for teaching activities with graduate students. We will then describe how we are leveraging technology to provide virtual assistance to faculty as they use particular activities and facilitate discussions about teaching. (Received September 19, 2018)

1145-AK-1382 **Estrella Johnson*** (strej@vt.edu), **Nicholas Fortune**, **Karen Keene** and **Christine Andrews-Larson**. *Report on TIMES Grant: Characterizing, Supporting, and Evaluating Inquiry-Oriented Instruction in Undergraduate Mathematics.*

Inquiry-oriented instruction has shown promise in regards to many features of student success, including conceptual understanding, affective gains, and persistence in STEM degrees. However, instructional change is difficult and the research literature has documented a number of specific challenges instructors face when implementing inquiry-oriented materials. Our NSF funded project, Teaching Inquiry-oriented Mathematics: Establishing Supports (TIMES) is a research and development project focused on improving undergraduate mathematics instruction. As part of this project we designed, investigated, and evaluated a system of supports for mathematicians interested in instructional change. Here we provide an overview of our instructional support model and present preliminary evaluation findings, drawing on a national sample of content assessment data, collected from 513 students at 46 different institutions. Here we will present our findings and, in an effort to make sense of them, we present related research literature on gendered experiences in collaborative settings and preliminary analysis into the experiences of our students in these inquiry-oriented classes. (Received September 21, 2018)

1145-AK-2181 **Robert A. Beezer*** (beezer@ups.edu), **David W. Farmer**, **Thomas W. Judson**, **Susan Lynds**, **Vilma Mesa** and **Kent Morrison**. *UTMOST: Undergraduate Teaching of Mathematics with Open Software and Textbooks.*

UTMOST designs and implements tools for authors and publishers of open source textbooks, and studies the use of these textbooks by teachers and students in undergraduate courses.

We will describe some of the novel features of the online versions of textbooks authored in PreTeXt, especially those supporting, and encouraging, established active learning techniques. We will present findings from our educational research, along with the design of our upcoming, larger, study. A theme of the presentation will be the ways in which our development effort and research studies complement each other. (Received September 25, 2018)

1145-AK-2319 **Aaron D Wangberg*** (awangberg@winona.edu), 322 Gildemeister Hall, Winona State Universit, 175 W. Mark St., Winona, MN 55987, and **Brian Fisher** (brian.fisher@lcu.edu), **Jason Samuels** (jsamuelsbmcc@gmail.com), **Tisha Hooks** (thooks@winona.edu) and **Elizabeth Gire** (giree@oregonstate.edu). *Raising Calculus to the Surface: Using physical manipulatives to discovering multivariable calculus concepts.*

The Raising Calculus to the Surface project (NSF DUE-#1246094) utilizes physical manipulatives to help students explore the fundamental concepts behind multivariable calculus. Using dry-erasable 'surfaces', contour maps, and tools, students are able to draw, measure, make conjectures, and discover properties of new mathematical objects. Contextualized small group activities ask students to investigate key ideas and relationships before a formal introduction in lecture, thereby helping students develop geometric understanding of multivariable calculus, imbue meaning in the algebraic formulas, and practice applying mathematics to scientific settings. Professional development workshops supported by the project have helped instructors at more than 50 institutions utilize the materials.

In this presentation, we will describe the project's key features, its impact on instructor teaching beliefs and practices, and highlight how the materials are helping us understand how students learn multivariable calculus concepts. (Received September 25, 2018)

1145-AK-2450 **Naneh Apkarian***, naneh.apkarian@gmail.com, and **Jessica Hagman**, **Chris Rasmussen**, **David Bressoud**, **Estrella Johnson**, **Sean Larsen**, **Jessica Gehrtz**, **Kristen Vroom** and **Matthew Voigt**. *The Progress through Calculus Project: A National Study of Precalculus through Calculus 2 Programs.*

In this presentation we report on findings from the five-year Progress through Calculus project. This project, begun in 2015, is a national investigation of the factors that influence student success over the university precalculus through single-variable sequence required of most STEM majors. The project is being conducted in two phases. Phase 1, now complete, was a survey of all mathematics departments that offer a graduate degree in mathematics. From this, we report the viewpoints of departments about features shown to support students' success, as well as the extent to which these features are being implemented across the country. Phase 2, currently underway, consists of 12 in-depth longitudinal case studies to explore the nuanced relationship between student success and departmental implementation of features shown to support student success. From these data, we report descriptive statistics from repeated instructor and student surveys that cover a range of student attitudes and beliefs, instructional practices, and departmental norms and culture. Lastly, we will discuss our ongoing analysis of cross cutting themes such as department change efforts, course coordination, course variations, and diversity, equity and inclusion, and related data collection to these four themes. (Received September 25, 2018)

Integrating Research into the Undergraduate Classroom

1145-B1-31 **Thomas Gilsdorf*** (gilsd1te@cmich.edu), Department of Mathematics, Central Michigan University, Mount Pleasant, MI 48859. *Teaching ethnomathematics courses to a variety of student audiences.*

In this talk, I will discuss observations I have made regarding the teaching of courses in ethnomathematics in a variety of settings. The observations come from my experiences teaching an ethomathematics course to the following: mathematics and science majors, mathematics education majors, honors students, students at a foreign university. In some instances, graduate students have also enrolled in the course, leading to some other implications. Observations will include different formats and grading policies that I have used and students' perceptions of the course. Not surprisingly, students of these different types of backgrounds perceive the course and the content of the course in distinct ways. I will discuss some of those perceptions as well as positive and negative experiences I have had with teaching to different student audiences. In addition, I will discuss how an instructor could incorporate undergraduate research in ethnomathematics into ethnomathematics and mathematics courses. (Received June 26, 2018)

1145-B1-158 **Jenny Switkes*** (jmswitkes@cpp.edu), Department of Mathematics and Statistics, Cal Poly Pomona, 3801 West Temple Avenue, Pomona, CA 91768. *Mini Research Projects in a Collaborative Classroom Environment.*

During the second course in my senior-level Mathematical Modeling sequence, the students spend almost two months working in teams on mini research projects. My goal is to provide my students with the opportunity to experience many components of genuine mathematical research in a team setting, including literature review, choosing and refining a topic, receiving and providing feedback, personal and team accountability, combinations of analytical and simulation techniques, professional-level oral presentations in a classroom research symposium setting, and a written final project. In a structured manner, the students experience the very different rhythms of research compared to regular classroom settings. And we all, both professor and students, experience the unique comradery of sharing the research life together as a class. I will share my structure for this course, as well as new changes I made this time around, along with examples of student projects and discussion of student impact. (Received August 13, 2018)

1145-B1-1182 **Maria M Franco***, mfranco@qcc.cuny.edu. *Student Learning Gains Derived from Research embedded in a Statistics and Probability Course.* Preliminary report.

In this talk, I will present an overview of the impact of a research-like project embedded in an Intro to Statistics & Probability course for non-majors. Student learning outcomes were assessed using varied tools during three runs of the course. On one hand, student responses to Lopatto's CURE survey showed significant gains in course-specific learning outcomes (e.g. ability to collect and analyze data, presenting results in written papers or reports, using technology) and in outcomes specific to the research experience (e.g. tolerance for obstacles faced in research, self-confidence, working independently, understanding the research process). On the other hand, student artifacts were included in college-wide assessments of general education learning outcomes. Student artifacts from this course fared well on these college assessment. One semester in particular, the student artifacts from this class scored, on the average, the highest in all dimensions of the rubric for analytic reasoning (the highest among 478 student artifacts from 39 courses across levels and disciplines). Instructor-designed reflections and tests questions showed gains consistent with the above assessments and offer additional insights about the gains for students who engage in classroom research. (Received September 19, 2018)

1145-B1-1694 **Peri A Shereen*** (pshereen@csumb.edu). *A course pathway implementing research experiences in an introductory proof class.*

This session is designed to accompany the sessions regarding CURE pilots at California State University, Monterey Bay (CSUMB). A Course-Embedded Undergraduate Research Experiences (CURE) is a practice currently taking place across scientific disciplines which embeds authentic research experiences into the classroom therefore broadening access to undergraduate research. However, the number of CUREs developed in mathematics are fewer. This talk will discuss a pilot implementation of a CURE experience in the introductory proof course taught at CSUMB as part of a larger CURE pathway that is being developed. Our larger goal is to prepare our students early to participate in research experiences such as an REU. We will discuss reasons to implement a CURE. We will discuss the specific CURE project for the pilot implementation in an introduction to mathematical proofs course. As well as provide early anecdotal results on what worked well and what changes we anticipate making moving forward. (Received September 23, 2018)

1145-B1-1865 **Dandrielle C Lewis*** (lewisdc@uwec.edu), Hibbard Humanities Hall 508, 124 Garfield Avenue, Eau Claire, WI 54701. *The Development and Implementation of a Mathematics Research Methods Course.*

The University of Wisconsin-Eau Claire (UWEC) mathematics department expanded the undergraduate mathematics curriculum by creating a new comprehensive mathematics major focused on undergraduate research, graduate school preparatory courses, and by partnering with the University of Wisconsin-Milwaukee to engage underrepresented students in mathematics research and training with the support of an NSF funded grant titled "Partnership for Undergraduate Research: Enhancing the Mathematics Curriculum." I will discuss the development and implementation of a mathematics research methods course and how this course and the research emphasis at UWEC incorporates formal instruction in research skills and ethics, training in writing and presentation skills, and provides a sustained undergraduate research experience. (Received September 24, 2018)

1145-B1-1923 **Erika L Ward*** (eward1@ju.edu) and **Daniel Moseley**. *Contests as Inspiration: Research in the Undergraduate Classroom.*

Jacksonville University requires all students to fulfill an Experiential Learning requirement, and one way to do that is to take a "Research Intensive" course. Such courses are described by the university as engaging with primary literature, having students create original work or engage in original research, submitting those works to a public forum, and including instruction in research methods. The mathematics department has chosen to offer research intensive courses that use the Putnam Exam and the Mathematical Contest in Modeling as foci for students engaging in mathematical research.

In these classes, students grapple with problems that are outside of the scope of their usual classroom experiences, and develop tools and techniques to help them solve them. This exploration beyond the sorts of questions they know how to answer, and which may not have solutions, is at the core of mathematical research. A secondary goal of these courses is to encourage the students to engage in traditional undergraduate research either through a capstone project or an REU. Overall, from these we hope that the students get some of the benefit that the high-impact practice of undergraduate research provides. (Received September 24, 2018)

1145-B1-1947 **Jeffrey O Wand*** (jwand@csumb.edu). *A Course-Embedded Undergraduate Research Experience in a Linear Algebra/Differential equations course.* Preliminary report.

This talk will be part of a three talk series about implementing CURE-based projects into a set of math classes at CSUMB. A CURE (Course- Embedded Undergraduate Research Experience) is a project that gives students a taste of research inside the classroom. CURE's are well-defined and developed in many sciences, but they have not been fully fleshed out for mathematics (at least not that this author could find). Over the summer, we have worked on developing CURE's for certain prerequisite math courses in the hopes that any student who participates in our CURE's will gain the necessary background to take part in other research experiences. This talk is part of a series of talks that will specifically focus on a CURE implementation in a linear algebra and differential equation course. (Received September 24, 2018)

1145-B1-2072 **Aihua Li*** (lia@montclair.edu), 1 Normal Avenue, Montclair, NJ 07043. *Sample Class Projects that Provide Research Experience in Undergraduate Classrooms.*

In this presentation, the speaker will demonstrate several class projects she recently brought to her classrooms. All of these projects can be considered as mini research projects. Some of them were given by industrial people and some were directly extracted from related mathematics concepts. Students worked in groups on the projects throughout the semester. Class products include oral presentations, poster presentations, and written reports. Some results were presented in the departmental seminars and regional or national mathematics meetings (student paper or poster sessions). Some students continued on the projects after the class. The speaker will share her experience in mentoring student research in classrooms, students' engagement through doing project-based research, and feedback from the students. (Received September 24, 2018)

1145-B1-2099 **Malcah Effron**, **Andreas Karatsolis**, **Suzanne Lane**, **Ari Nieh** and **Susan Ruff*** (ruff@mit.edu). *Mathematics reasoning diagram: a pedagogical tool for classroom teaching of mathematics research and communication.* Preliminary report.

Undergraduate research commonly occurs with undergraduates paired with faculty advisors in an apprentice model. When assigning undergraduate research in a class, the scaffolding provided by apprenticeship has to be abstracted across many different projects and topics. We have addressed this need by developing a mathematics "reasoning diagram" in order to demystify mathematics research for undergraduates. By interviewing mathematicians in diverse sub-disciplines of mathematics: number theory, geometry, PDE, physical applied mathematics, combinatorics, and quantum computation, we have identified similarities in research process and in reasoning patterns across sub-disciplines. Our reasoning diagram encompasses both "pure" and "applied" mathematics, and elaborates different parts of the iterative research process (e.g., choice of research question, building understanding, making a conjecture, attempting a proof, and adding to the body of knowledge of mathematics). After revising based on interviewee feedback (in progress), we will use the diagram to help undergraduates in the classroom to research and to communicate mathematics.

This project is funded by the Davis Educational Foundation, as part of a larger project to diagram the reasoning of several STEM disciplines. (Received September 24, 2018)

1145-B1-2320 **Kassie Archer*** (karcher@uttyler.edu), 3900 University Blvd., Tyler, TX 75799, and **L.-K. Lauderdale**. *Student research in the algebra classroom.*

During Fall 2017, we split the students in (undergraduate) Algebra II into small groups and assigned them graduate mentors from the Master's-level graduate algebra class. Students met each Friday during class, and on their own outside of class, to make progress on an open question in algebra or a related field. In this talk, I'll describe our goals, timeline, weekly routine, and outcomes. (Received September 25, 2018)

1145-B1-2789 **Jordan O Tirrell*** (jtirrell@mtholyoke.edu). *The Collaboratory: An Undergraduate Introduction to Research.*

Mount Holyoke College offers a project-based course dedicated to preparing students for academic and industry research in the mathematical sciences. Groups of students are prompted to explore, make conjectures, gather computational evidence, and find proofs. As the semester progresses, they are expected to take on gradually larger roles in steering this process. They are evaluated primarily by the papers they write at the end of each project. Some projects have also included presentations at local conferences and 3D printed mathematical art. In this talk, I will share some insights from teaching this unusual and exciting course. (Received September 25, 2018)

1145-B1-2829 **Malgorzata Marciniak** (mmarciniak@lagcc.cuny.edu), **Marina Nechayeva*** (lamaga0@yahoo.com) and **Vladimir Przhebelskyi**. *From aerodynamics to wind data, genetics algorithm and 3D printing.*

Few years ago, our team of mentors began research projects in aerodynamics. We were very excited about our students' progress and energy. Every year we brought few improvements to the projects to broaden the topics and make them more "modern." Last year our attention was focused on using the genetics algorithm for the purpose of optimizing the parameters of a micro wind turbine that would hypothetically be placed on the roof of our college. Inspired by satisfying theoretical results we proceeded to print a 3D model of the turbine to test it in the wind tunnel. The project contains an additional aspect of statistical analysis and modeling of the wind data on the roof of our college. (Received September 25, 2018)

Mathematics and Sports

1145-B5-126 **Stanley Rothman*** (stanley.rothman@quinnipiac.edu), 15 stacy ct, Cheshire, CT 06410. *New Applications of the Linear Regression Formulas to the MLB, NBA, and NFL.*

In my talk last year, using properties common to teams in the MLB, the NBA, and the NFL, I created a new General Linear Theorem (GLTH). From this GLTH, I produced three new linear regression equations, one for the MLB, one for the NBA, and one for the NFL, to predict a team winning percentage for any completed season using its run and point difference for an entire season. In this year's talk, I produce three new linear regression equations to predict a team winning percentage, after any fixed number of games during any season. Using these new linear regression equations, we can determine a team's performance, over or under, at any point in a season. Finally, I demonstrate a technique to compare parity between seasons in one league and seasons in another league by comparing the NBA 2017-18 season with the MLB 2017 season. (Received August 06, 2018)

1145-B5-754 **Michael A Furuto*** (mfuruto@hawaii.edu) and **Ryan Orphan** (orphanr@hawaii.edu). *NCAA Basketball Conference Champions: Does it Help with the Madness?*

While many students traditionally struggle in college mathematics, this study aims to engage students by connecting mathematics and data analytics to college basketball. We performed a statistical breakdown of how far conference champions in comparison to non-champions advance in the NCAA March Madness Basketball Tournament. Our research focused on the conferences that had both a conference champion and at least one non-champion compete in the Tournament. This allowed us to focus strictly on the question at hand: does being a conference champion help a team progress deeper into the Tournament? The March Madness Tournament has been held annually with at least 64 teams since 1985, so we statistically analyzed every bracket for the past 34 years to determine that conference champions had an average of 1.687 wins per tournament, while non-champions had an average of 1.117 wins. During the course of our research, we highlighted the top 6 conferences (ACC, Big East, Big 12, Big 10, Pac-12, and SEC) because those conferences consistently send the majority of the tournament's participating teams. Our research findings indicated that there is a statistically significant difference between the advancement of the conference champions over the non-champions. (Received September 14, 2018)

1145-B5-1027 **David Miller***, 200 Bloomfield Ave, Department of Mathematics, Dana Hall, West Hartford, CT 06117. *Applied Sabermetrics: Using math to help a Divison I baseball team win.*

Analytics have been on the forefront of baseball research recently, ranging from player evaluation to in-game strategy. As the "Director of Baseball Analytics" at a mid-major Division I school, I tailor my research specifically to the our team's needs in hopes to win more games. In this talk, I will give my methods of using data science to build predictive models and present important data to the coaching staff in a meaningful way, including building an interactive Shiny application using R. (Received September 18, 2018)

1145-B5-1076 **Reza O Abbasian*** (rabbasian@tlu.edu), 1000 W. Court St., Dept of math-CS-IS, Texas Lutheran University, Seguin, TX 78155, and **John T Sieben** and **Apryl Canales**. *A probability model for predicting the outcome of International soccer games in overtime and beyond.* Preliminary report.

In this presentation, we will explore the statistical models, which can be used to determine the probability of winning in an international soccer game as a function of the difference in ranking (FIFA and Elo) for matches which either ended at the overtime or penalty kicks. We intend to show that the probability of winning for a higher ranked team decreases as the games goes beyond the standard ninety minutes. For a more complex model we will introduce other variables such as home field advantage. We have used logit regression and over twenty four years of data (six world cups, and six European, Asian , African cup of nations, Copa America and UEFA Euro championships) to create our model. (Received September 18, 2018)

1145-B5-1093 **Andrew B Perry*** (aperry@springfieldcollege.edu). *Potential Referee Bias Inferred from Statistical Anomalies in Sports Play By Play Data.*

Substantial information about the results of individual plays is now available from professional baseball, basketball, and football leagues. By publishing the data, the leagues benefit from increased interest in their respective sports. However, uncomfortable truths can be uncovered in the data. For example, basketball referees call fewer violations on the home team during clutch situations. These abnormalities are statistically significant and it's hard to explain them except as unconscious (or conscious) referee bias. Another oddity is football penalties. They are not called with uniform frequency throughout the games as one might expect. This presentation will consider the above discoveries as well as other statistical curiosities related to officiating in baseball, basketball, and football. (Received September 18, 2018)

1145-B5-1156 **Kristopher A. Pruitt*** (kristopher.pruitt@gmail.com) and **Michael A. Brilleslyper**. *Getting to the top: less pain, more gain.*

Many hikers have experienced switchbacks zig-zagging their way up the side of a mountain. The grade of the switchbacks are often much less than the alternative grade of attempting to hike directly towards the top. In real life, switchbacks' grades and lengths are often determined by the local topography. But what if you could design the switchbacks with any parameters to work their way up a broad steep hill? How many would you use and, more importantly, what grade would you choose to minimize the total energy output of the hiker in getting to the top? This talk takes this seemingly complicated problem and presents a solution using nothing more than differential calculus methods. The result is surprising and has an unexpected simple connection to horizontal and vertical energy output. (Received September 19, 2018)

1145-B5-1545 **Diana S Cheng*** (dcheng@towson.edu), Department of Mathematics, Towson University, 8000 York Road, Towson, MD 21286, and **Peter Coughlin** (coughlin@econ.umd.edu), Department of Economics, University of Maryland, College Park, College Park, MD 20742. *Applications of hypothetical competition analysis for figure skating team events.*

The International Skating Union conducts a figure skating team event at some major international events, including at the Winter Olympic Games. We provide a fantasy-type method to tabulate the results of a figure skating team event. We show how this method is correlated with the results of the 2014 and 2018 Winter Olympic Games team events that were actually conducted. We also show how this method can be applied to assist with team roster decision making for future competitions and to answer hypothetical questions about past competitions. (Received September 23, 2018)

1145-B5-1546 **Robert Nedwick*** (rnedwi1@students.towson.edu), Department of Mathematics, Towson University, 8000 York Road, Towson, MD 21252, and **Diana S Cheng** (dcheng@towson.edu), Department of Mathematics, Towson University, 8000 York Road, Towson, MD 21252. *Determining the radius of a figure skate blade: A Model-Eliciting Activity.*

We present a Model-Eliciting Activity (MEA) used in a course that was cross-listed for undergraduate mathematics content course for middle school pre-service teachers and in-service secondary teachers. Students were given physical sets of figure skate blades and were asked to determine the radius of the circle that was used to construct the blade. The student's various geometric and algebraic solutions used will be shown. We will also identify the Universal Design for Learning instructional principles incorporated within the activity and the

Common Core State Standards for Mathematical Practice that participants used in the activity. (Received September 23, 2018)

1145-B5-1681 **Lauren Hall*** (lh649428@sju.edu) and **Tetyana Berezovski** (tberezov@sju.edu), 5600 City Ave, Philadelphia, PA 19131. *Sports-Based Learning: Volleyball.*

Bringing sports modeling into the mathematical classroom will inspire young minds to think mathematically about the world around them.

For this project, we created an animated design for defensive passing in volleyball. This animation simulates the elements of the volleyball game and physical movements of a volleyball player. We analyzed this animation for its applications and developed a sport-based mathematical curriculum with appropriate mathematical and physical content relevant to high school students and college freshmen. Mathematical and physical tasks were designed in the context of the volleyball court, the volleyball, the bodily movements of the player, and the winning strategy of the match. The designed tasks were carefully aligned with the CCSS M and the PA standards for Physical Education grades 7 to 12. This cross curricular marriage of mathematics, mathematics education and physical education is aimed to connect the mathematical concepts to the physical world around us, resulting in maximized student engagement. Sporthematics, a field where mathematics meets sports, sparks a greater curiosity from a broader range of students into understanding of mathematical content. (Received September 23, 2018)

1145-B5-2003 **Megan Olivia Powell*** (mpowell4@unca.edu), One University Heights, Asheville, NC 28804. *What would eliminating the kickoff in the NFL mean?* Preliminary report.

The concern for the safety of NFL players has risen significantly lately due to increasing evidence of long-term consequences to head injuries sustained by players. Kickoffs account for 15-20% of all concussions with the highest rate of concussions of any type of play with 7-9 concussions per 1000 kickoffs. As a result, the NFL has been looking for ways to decrease head injuries to players, while maintaining the integrity of the game. While the league has currently only modified kickoff rules, continued pressure to make the game safer may result in an elimination of the kickoff altogether. In this talk we explore how an elimination of the kickoff could potentially affect drive success and specifically overtime outcomes, considering multiple replacements for the kickoff including the Schiano Proposal of teams starting at their own 30 with fourth down and 15 yards for a first down. (Received September 24, 2018)

1145-B5-2098 **Tetyana Berezovski*** (tberezov@sju.edu), Saint Joseph's University, Department of Mathematics, 5600 City Ave, Philadelphia, PA 19131. *Mathematical Models in Rhythmic Gymnastics (RG).* Preliminary report.

Over the past several decades mathematics was used in many different sports for various purposes. RG is a kind of sport where creativity of movement plays an important role. The aim of RG is to express emotions and feelings by the mean of bodily movements, performed at the highest level of technical difficulty. The aesthetic of this sport makes it attractive to spectators. In this presentation you will learn about mathematical models that were developed and used to improve training, artistry, the performance of routines, dietary assessments, and quality of judging in RG. (Received September 24, 2018)

1145-B5-2312 **Luke Wiley*** (lw250971@muhlenberg.edu), 1854 Fox Run Terrace, Warrington, PA 18976, and **James Russell**. *A Statistical Analysis of Muhlenberg College's Fourth Down Strategy.*

This project aims to mathematically suggest whether a coach should go for it on 4th down by using generalized linear regression models to help probabilistically make the decision. We use the recent offensive data from Muhlenberg's football team. Most of the data is from the 2017 season; however, we also use previous years to supplement the kicking data. The data consists of decisions made on 3rd and 4th down play. Since 4th down usually means suggests a change of possession, 3rd down becomes critical of this decision. Benefits to Division III football include providing an edge over their competitors. The impact of 4th down decisions were recently on display in the past Super Bowl LII where the Eagles elected to employ a more aggressive, nuanced 4th down strategy while the Patriots followed a more conservative, traditional strategy. (Received September 25, 2018)

1145-B5-2318 **R Drew Pasteur*** (rpasteur@wooster.edu), 311 Taylor Hall, 1189 Beall Ave, Wooster, OH 44691. *Playing to Win? Two-Point Conversion Decisions in Major College Football.* Preliminary report.

In American football, there is a long-standing debate over the circumstances in which a two-point conversion attempt is advisable following a touchdown. Much of the study of this problem has involved NFL football, in which both kickers and passers have high levels of skill. We will consider major collegiate (NCAA Division I FBS) football, which has lower rates of success on two-point conversions and greater uncertainty in the kicking game. Using a decade's worth of data, we discuss the observed two-point decision behavior of college coaches in the 4th quarter, and develop a model to suggest optimal choices. (Received September 25, 2018)

1145-B5-2323 **Zach A. Hollis** (zahollis16@my.trine.edu), Trine University, 1 University Ave, Campus Box 730, Angola, IN 46703, and **Dylan A Kunce*** (dakunce16@my.trine.edu), 610 E Gilmore St, Angola, IN 46703. *When Do You Call the Bullpen?*

A baseball team has two goals: to avoid making outs on offense; and force the other team into making outs on defense. One can think of an opponent successfully reaching base as a temporary setback to achieving this second goal. We build a Markov chain model of baseball from the defensive point of view (we are only concerned with innings, outs, and number of baserunners; not location of baserunners) and apply our model to analyze modern trends in the usage of starting pitchers. In one application we find the expected number of outs a pitcher will achieve in two and three trips through the opposing teams batting order, essentially answering the question: When Do You Call the Bullpen? (Received September 25, 2018)

1145-B5-2428 **Roland Minton*** (minton@roanoke.edu). *When Good Golfers Go Bad.* Preliminary report.

On the PGA Tour, golfers have good weeks and bad weeks and, sometimes out of the blue, fantastic weeks. Each player has strengths and weaknesses. In a fantastic week, have the weaknesses suddenly improved? Have the strengths become dominant? Has every skill been elevated? Strengths and weaknesses can be measured using Strokes Gained, a metric that compares every shot on Tour with an average shot using units of strokes. My Strokes Gained system comes from ShotLink data provided by the PGA Tour, with separate computations for 21 skills including putting, fairway shots from 100-150 yards, shots from the primary rough from 0-50 yards, and so on. Each skill is rated according to strokes better or worse than "par" (an average PGA Tour player) so that strengths and weaknesses are quantified for a year's worth of play. Season averages serve as proxies for "true" skill rating, and Strokes Gained in single tournaments (which typically oscillate erratically week to week) are compared to these skills to measure how much strengths/weaknesses improve in a top 10 or winning week and how much strengths/weaknesses deteriorate in a week when missing the cut. (Received September 25, 2018)

1145-B5-2511 **Robert Franzosa*** (franzosa@maine.edu). *Using baseball simulation software to investigate d(wins)/dx for various statistics x.*

The Baseball Simulator is a baseball simulation program developed by the author that replays Major League Baseball (MLB) games and seasons using team (rather than individual player) statistics. We introduce the program, demonstrating its accuracy recreating past MLB seasons. Then we show how–by modifying statistics–we can answer questions like the following: With all other statistics unchanged, how many more wins could we expect a team to attain if they drew one extra walk per game, or if they hit one more double every three games, or if they hit one more home run per week, etc? Furthermore, we present results from investigating some of these questions. (Received September 25, 2018)

1145-B5-2687 **Stephen Devlin** and **Molly Creagar*** (mcreagar@dons.usfca.edu), Department of Mathematics and Statistics, University of San Francisco, 2130 Fulton Street, San Francisco, CA 94117, and **Thomas Treloar** and **Sam Cassels**. *An iterative Markov ranking method.*

Ranking and rating methods for teams using paired comparisons generally fall into two categories. Global, or accumulative, methods compile season results into a matrix and solve a linear system to find ratings and rankings, while iterative, or adjustive, methods update ratings and rankings after each competition and evolve over the course of the season. Examples of the former include the many variations of the Markov method (e.g., PageRank) while the latter include Elo's method, commonly used in the rating of chess players. In this paper, we introduce an iterative version of the Markov method, and show that it converges, in a natural sense, to the global Markov method. Moreover, we show that there is a close connection between the iterative Markov method, Elo's method, and the Bradley-Terry model for paired comparisons. We illustrate concepts with empirical examples from real and simulated data sets. (Received September 25, 2018)

1145-B5-2707 **Peter Staab*** (pstaab@fitchburgstate.edu), 160 Pearl Street, Fitchburg, MA 01420, and **Richard Cleary**. *Consecutive Same-Score Streaks in MLB games.* Preliminary report.

The same score over consecutive games occurs in many sports despite this being a rare event. We define a *same-score streak* as a sequence of games in which one team has the same score in each game and its opponents score is the same in each game. Due to the ease and availability of Major League Baseball data, we examine the probability of same-score streaks of length 2 and 3 games, for instance wins by the score of 3 to 2. The distribution and basic statistical analysis of such games using historical data is studied. In addition, a model for this is developed and a simulation of the model is created to compare to the historical data. (Received September 25, 2018)

1145-B5-2855 **James Brian Hall*** (james.hall@intel.com) and **Dante Salas**. *A Geometric Method for Corresponding Images of Athletes from a Camera Array.* Preliminary report.

As virtual and augmented reality technologies mature, there has been growing interest in developing camera systems that can capture content suitable for presentation in 3 dimensions. Intel Sports is a pioneer in the field of these next generation capture technologies, using arrays of cameras to produce sports content suitable for display in 3D. One challenge for these camera arrays is reliably corresponding athletes across different images captured by this array of cameras. In this talk, we will discuss an approach to solving this problem, which utilizes a novel combination of classical techniques from machine vision and numerical linear algebra. (Received September 25, 2018)

1145-B5-2928 **Jeffrey W Heath*** (jeffrey.heath@centre.edu), 600 W Walnut St, Danville, KY 40422, and **Chase Cavanaugh** (chase.cavanaugh@centre.edu), 600 W. Walnut St., Danville, KY 40422. *Basketball Shooting Efficiency and the Shot Clock.* Preliminary report.

Basketball teams take a different distribution of shots depending on their personnel, opponent, style of play, and even the score and time remaining of the game. In general teams should be attempting the shots that have a high expected points per possession. However, the time remaining on the shot clock plays a key role in this shot selection. We investigate how shooting efficiency in basketball relates to the shot clock, specifically in NCAA basketball. (Received September 25, 2018)

Undergraduate Student TAs in Mathematics

1145-C1-81 **Klara J. Grodzinsky***, School of Mathematics, Atlanta, GA 30332-0160. *Undergraduate Teaching Assistant Preparation Program at Georgia Tech.*

The Teaching Assistant (TA) training program in the School of Mathematics began as a pilot in the Fall 2000 term. After running a successful pilot, the faculty of the School of Mathematics approved a one-credit hour, pass/fail course, for training our new undergraduate TAs. This course has been used as a model for training TAs in other departments at Georgia Tech, and currently runs through the Center for Teaching and Learning (CTL) as the course CETL 2000 MAT. We employ approximately 45-60 undergraduate TAs each term. Undergraduate TAs undergo a rigorous application process, and enroll in our TA training course concurrent with their first teaching assignment. As part of the training, each new TA is videotaped in his/her classroom at least once in the first teaching term. We measure the effectiveness of our TAs through midterm surveys, the institute's official Teaching Assistant Opinion Survey (TAOS), faculty evaluations, and classroom observations. (Received July 24, 2018)

1145-C1-102 **Maria Wesslen*** (maria.wesslen@utoronto.ca). *Cultivating high quality undergraduate math TAs at the University of Toronto Mississauga.* Preliminary report.

The University of Toronto Mississauga is a primarily undergraduate campus. It relies heavily on undergraduate TAs (UGTAs). Their duties range from preparing and leading weekly review and study sessions for 15-40 students, to grading assignments and tests, as well as staffing our Math Help Centre where students can drop in and receive individual help. In addition, UGTAs help with some of the administration of the department's largest courses, some of which have almost 2000 students.

Given the substantial responsibilities of the math department UGTAs, the department has developed a range of training tools. These include training before the semester starts, followed by several group training sessions throughout the semester. In addition, the department arranges tutorial visits and in-course mentoring with both formal and informal feedback. This training has enabled UGTAs to become an integral part of the successful delivery of the department's programs.

This session will provide an overview of the training the department uses to ensure a high quality of instruction, how the training is integrated throughout the year, incentives used to promote participation in skills training as well as some lessons learned during the development of the curriculum over the years. (Received July 29, 2018)

1145-C1-1222 **Jeremiah Hower*** (jhower@fiu.edu) and **Roneet Merkin** (rmerkin@fiu.edu). *Incorporating Learning Assistants in the Redesign of Critical Math Courses.*

Florida International University utilizes learning assistants (LAs) in varied ways in a number of disciplines. In particular, the lower division math courses within our Mastery Math Program employ LAs both within the

Math Labs, as well as in class to help facilitate active learning. We will touch on the training, planning and organization in place for them, as well as discuss how they have been key in improving student learning outcomes and success rates. (Received September 20, 2018)

1145-C1-1232 **Richard J Brown*** (brown@math.jhu.edu), Department of Mathematics, 3400 N. Charles Street, Baltimore, MD 21218. *The Undergraduate Teaching Assistantship (UTA) in Hopkins Math.*

With a steady linear increase in the undergraduate enrollment in mathematics courses over the last 15 years at Hopkins, coupled with a fixed graduate student population, the use of upper-level undergraduate mathematics majors as teaching assistants running recitation classes has increased from a novelty of 1 or 2 a semester running perhaps 3 classrooms, to upwards of 10 undergraduates managing 15-16 classroom sections. Our full service UTA position in math includes classroom time, homework and exam grading, office hours and more, and has become a sought after part of the undergraduate math major experience. In this talk, we focus on the design and implementation of the position to date, including training, mentoring, oversight and assessment of UTAs, along with the challenges and rewards of placing undergraduates in front of undergraduates in the classroom. (Received September 20, 2018)

1145-C1-1375 **Justine Chasmar*** (justine.chasmar@goucher.edu), 1021 Dulaney Valley Road, Goucher College, Julia Rogers Building- Staff, Towson, MD 21204. *Developing a Tutor Training Course for Goucher's Quantitative Reasoning Center.*

The Quantitative Reasoning (QR) Center at Goucher College is in its second year supporting students' mathematical, QR, and data analytics skills by providing tutoring, study materials, workshops, and other math-focused learning initiatives. The director has created a required, one-credit course devoted to training QR Center tutors which combines education, mathematics, and data analytics curriculum and focuses on the intersection of teaching pedagogy within each realm. Students enrolled in the course learn about quantitative tutoring skills and put them into practice, including a mixture of reflection and practical exercises. Individual, scaffolded lessons range from basic teaching pedagogy such as questioning techniques and positive reinforcement, to reviews on essential quantitative content. The course is primarily set within the context of quantitative content, making it different, and inherently more meaningful, than traditional tutor training. In this session, the presenter will discuss the QR Center at Goucher, the development of the tutor training course from ideation to implementation, and outcomes from the first-semester of the course. (Received September 21, 2018)

1145-C1-1438 **Martina Bode*** (bodem@uic.edu), Department of Mathematics, University of Illinois at Chicago, 322 Science and Engineering Offices (M/C 249), Chicago, IL 60607-7045. *Training of Undergraduate Learning Assistants in developmental math, pre-calculus and calculus classes.* Preliminary report.

Learning Assistants (LAs) are undergraduate students with great communication and math skills that we hire to help students in and outside the classroom. The UIC Learning Assistant (LA) program was started in 2015 and has grown to 40 LAs in four courses. In our efforts to improve passing rates, we integrated active learning in our discussion sections and in our large classes. The average class size ranges from120-140 students. LAs assist with hands on activities during lectures, and outside of class LAs hold drop in sessions in the learning center. Training of the LAs is an integral part of the program. LAs participate in weekly content meetings. Content meetings are separated by course and are led by course coordinators or instructors in the course. In addition, during their first semester of being an LA, LAs participate in a one-credit pedagogy class. The purpose of the pedagogy course is to help learning assistants (or tutors) in mathematics, better understand how to help students in one-on-one and one-on-few teaching situations, either in the learning center or in lecture.

This course discusses what mathematical learning entails, how to engage with students and diagnose their needs and abilities, and how to make pedagogical decisions when helping students. (Received September 21, 2018)

1145-C1-1814 **Sarah N Bryant***, bryants@dickinson.edu, and **Emily Marshall**, marshaem@dickinson.edu. *Quantitative Reasoning Associates at Dickinson College: Supporting Teaching and Learning.*

In this talk, we will describe Dickinson College's Quantitative Reasoning Associates (QRA) program. Sarah Bryant, Visiting Assistant Professor of Mathematics, and Emily Marshall, Assistant Professor of Economics and Co-Director of the Quantitative Reasoning Center will share the planning strategies and initial outcomes of the first semester of this program at a small liberal arts college.

The recruitment, training, mentoring, support, and evaluation methods for the undergraduate QRAs in this new program are based on the model of Dickinson College's highly successful Writing Associates (WA) Program. Together with the Quantitative Reasoning Center tutoring program, piloted in 2015 and formally launched in 2016, the QRA program acts as a bridge between professors and students to enhance teaching and learning. The QRAs are contracted for 30 hours per semester, with expectations ranging from holding study sessions before exams, to leading mini lessons on special quantitative topics, to visiting the classroom to provide professor observation and feedback. The flexibility of the model allows professors to best mentor and guide each QRA in a way that is tailored to the individual course. (Received September 24, 2018)

1145-C1-2057 **Galina Dobrynina*** (gid@bu.edu), Boston, MA 02215, and **Debra K Borkovitz** (dbork@bu.edu), Boston, MA 02215. *An Inquiry-Based Study Group Program with Undergraduate Math Leaders (TA's).*

Wheelock College, which recently merged with Boston University, had an inquiry-based philosophy for its entire math program. Virtually all introductory mathematics courses included a mandatory study group, led by an undergraduate "Math Leader," who was expected to support inquiry-based learning. The Math Leaders were required to attend a bi-weekly seminar where they reflected on both math content and pedagogy. In addition, Math Leaders wrote online reflections about each study group session. Appointed Senior Math Leaders mentored new math leaders and responded to the online reflections. Over time, a student culture around mathematics developed, where math study groups were visible all over campus, and Math Leaders learned from each other and encouraged math phobic students to give "Wheelock Math" a try. In our talk, we'll describe the design of the Study Group/Math Leader program at Wheelock and reflect on our twenty plus years of mentoring math leaders. (Received September 25, 2018)

1145-C1-2248 **Natasha Speer*** (speer@math.umaine.edu), **Erin Vinson**, **MacKenzie Stetzer** and **Laura Millay**. *The University of Maine's Program to Incorporate Undergraduate Teaching Assistants into Faculty Course Reform Efforts.*

We created the Maine Learning Assistant (MLA) program based on positive outcomes of Learning Assistant (LA) programs at other institutions and sought ways to incorporate the program into other course reform efforts on our campus. Our program combines the LA model with a faculty course reform grant program. Faculty propose to introduce research-based, active learning instructional practices or enhance use of those practices already in place. As with other LA programs, undergraduates new to the program enroll in a teaching seminar. In addition, MLAs participate in weekly course preparation meetings with faculty instructors for the course. The program has run for seven years with a total of 45 STEM faculty and 344 MLAs. Courses involved include pre-calculus and three courses in our calculus sequences. We will provide an overview of the program design and a description of the professional development MLAs receive via the combination of the seminar and course preparation meetings. A particular focus will be challenges and opportunities we encountered when implementing the program with multiple mathematics faculty and in multi-section coordinated courses. We will also share findings from our program evaluation efforts and lessons we have learned about professional development needs. (Received September 25, 2018)

1145-C1-2611 **Ian Pierce*** (ian.pierce@usafa.edu), Department of Mathematical Sciences, Suite 6D-100, 2354 Fairchild Drive, USAFA, CO 80840. *A Teaching Practicum Course at the United States Air Force Academy.*

While the Air Force Academy does not have a traditional UGTA program, students pursuing a major in mathematics at the Academy do have the opportunity to participate in an elective Teaching Practicum course. Participants are matched with experienced faculty mentors and complete a variety of activities. These include classroom observation of their mentors' teaching, preparing and delivering several classroom lessons, formal and informal tutoring activities, writing several short papers based on research in teaching and learning, and keeping a journal of reflections on their observations and activities throughout the course. Like all graduates from the Academy, participants will go on to careers as Air Force officers, where the instructional and interpersonal skills they develop in this course are put to good use. In addition, as part of their career progression, some practicum students may return to our department as military faculty members later in their career. We will discuss some of these key elements in our Teaching Practicum course, how they are implemented, and how they contribute to our desired outcomes in student development. (Received September 25, 2018)

1145-C1-2751 **D. Levermore**, **K. Okoudjou**, **R. Rosca**, **K. Williams** and **J. Wyss-Gallifent*** (jow@math.umd.edu). *University of Maryland Undergraduate Teaching Assistantships.*

The University of Maryland has several undergraduate teaching assistant opportunities. They are housed under a number of umbrella programs and span various academic disciplines. For undergraduate students with strong mathematics skills, assistantships come in multiple forms, listed in decreasing order of responsibility: being the teaching assistant of record for one section/semester; organizing and running problem/help sessions for which they have developed the curriculum based upon a specific faculty member's lectures; in-lecture peer assistance under the tutelage of the course's instructor; and general tutoring or office hours for courses in which they have usually received a grade of A or better. Of the five math-related assistantships only the Strauss Teaching Assistant Program is completely managed at the level of the Mathematics Department and as such we will dedicate most of the presentation to describing it, comparing and contrasting with the external programs. (Received September 25, 2018)

Discrete Mathematics in the Undergraduate Curriculum - Ideas and Innovations in Teaching

1145-C5-285 **Marilyn Reba*** (mreba@clemson.edu), Department of Mathematical Sciences, O-110 Martin Hall, Box 340975, Clemson, SC 29634, and **Doug Shier**. *Puzzles, Games, and Problem-Solving in Discrete Mathematics.*

For the last 10 years, we have explored several topics of discrete mathematics in an honors course for undergraduates. Our primary pedagogical approach has been to develop the representations, strategies, and algorithms used to solve puzzles and games and then to extend these techniques to real-world problems. In the realm of graph theory, we solve mazes and other puzzles and then move on to analyze social networks, GPS systems, DNA sequences, and kidney exchanges. In logic, we move from logic games and truth tables to building and simplifying digital circuits. Game theory is used to model soccer strategies as well as military applications. In probability, we explore lotteries and the misuse of conditional probabilities (e.g., in the media and in the courtroom). Another instructional strategy has been to ask students throughout the course to consider how these new problem-solving techniques might be applied to their own fields of interest. Groups of two to three students form teams to construct joint presentations that build, via a new application or a new algorithm, on what was covered in class. In addition to discussing some entertaining puzzles and their implications for problem-solving, we will report on the success and diversity of these end-of-semester projects. (Received August 28, 2018)

1145-C5-564 **Leah Childers*** (lchilders@pittstate.edu). *Implementing a capstone project in an introduction to proof course.* Preliminary report.

Basic proof writing skills are essential to students' success as a math major. However, students often fail to recognize this when taking their first proof course and fail to retain the necessary skills for future course work in the major. To address this issue, a capstone project was introduced. Students create a notebook summarizing the various proof methods and collecting sample proofs of each major type of proof introduced in the course. The goal of the project is that students will have a resource to use in future courses to remind them of basic proof techniques. We will discuss successes of the project as well as discuss challenges that arose during implementation. (Received September 10, 2018)

1145-C5-648 **Joseph Malkevitch*** (jmalkevitch@york.cuny.edu), 86 Garden St., Garden City, NY 11530. *A Required Discrete Mathematics Course is No Less Important for Mathematics Majors than Calculus I.*

Many mathematics departments still regard an introductory discrete mathematics course as a service course for Computer Science and not as important as Calculus I for all mathematics majors. Discrete mathematics (DM), here, taken to entail basic combinatorics, graph theory (special attention to trees and optimization questions), solving difference equations (recursions), metrics, (Hamming distance, edit distance), modular arithmetic, etc., is especially important for future teachers (K-16). DM has increasing importance in mathematical modeling and applications for questions involving fairness (voting, apportionment, fair division, matching markets), codes, digital processing, etc. A course entailing such important ideas and applications deserves a place among required mathematics major courses. (Received September 12, 2018)

1145-C5-824 **Elise Lockwood*** (elise.lockwood@oregonstate.edu), 064 Kidder Hall, Corvallis, OR 97331. *Investigating the role of computing in solving counting problems: Four Python commands that correspond to four common problem types.*

Computational thinking and activity are increasingly important aspects of scientific and mathematical work. In mathematics education, there is a need to investigate the ways in which students' computational activity affects how they reason about mathematical concepts. In this talk, I present results from a study in which undergraduate students engaged with Python programming tasks designed to elicit particular combinatorial ideas. I demonstrate how four simple Python commands correspond to four common types of counting problems, and I provide examples from student interviews to illustrate how they reasoned about combinatorics in a computational setting. These results suggest that even elementary programming activity can illuminate important combinatorial distinctions for students. I conclude by providing some practical implications and suggesting avenues for further research investigations. (Received September 15, 2018)

1145-C5-1293 **Edmund A Lamagna*** (eal@cs.uri.edu), University of Rhode Island, Department of Computer Science & Statistics, 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 on 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 topic 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 20, 2018)

1145-C5-1550 **Elizabeth G Arnold*** (arnoldeg@jmu.edu), **Elizabeth A Fulton** (elizabeth.fulton@montana.edu) and **Elizabeth A Burroughs** (burroughs@montana.edu). *Connecting Discrete Mathematics to School Mathematics.*

Future high school teachers are among the population of undergraduates frequently enrolled in Discrete Mathematics courses, so it is appropriate to address topics that attend to the needs of future teachers. For example, the Binomial Theorem has direct connections to multiplying polynomials, a skill students use throughout their mathematical studies. In this session, we will share an annotated lesson plan on the Binomial Theorem that emphasizes student thinking and highlights connections between the mathematics content and content used in secondary teaching. This lesson motivates the Binomial Theorem and examines how it arises in various contexts such as Pascal's Triangle, multiplying polynomials, and binomial coefficient identities. The lesson offers an opportunity for undergraduates to learn combinatorial proof techniques and compare them to the algebraic techniques they are often more familiar with. (Received September 23, 2018)

1145-C5-1858 **Brant Jones*** (jones3bc@jmu.edu). *An easy proof of quadratic reciprocity for an undergraduate number theory course.*

There are many proofs of quadratic reciprocity. In this talk, we present one which we believe deserves to be better known. It relies on a simple counting argument and reinforces the use of the Chinese Remainder Theorem. (Received September 24, 2018)

1145-C5-1969 **Mohamed Jamaloodeen*** (mjamaloo@ggc.edu), Georgia Gwinnett College, 1000 University Center Lane, Lawrenceville, GA 30043. *Using an open source platform like Scilab or Octave as a framework to introduce students of discrete mathematics to computer programming.*

In discrete mathematics, students are challenged when asked to analyze/implement algorithms. One possible reason is that basic computer programming is not integrated into the general mathematics curriculum as is done in high schools in France. Students enrolled in discrete mathematics are expected to be familiar with programming, yet most have not even had a rudimentary exposure to it. Many students first see programming using advanced object-oriented program languages like Java or C++. They have to master concepts such as algorithms, and program flow, in addition to the advanced syntax of object oriented programs. Historically, students learned computer programming using high level languages like FORTRAN. Now, many open source high level computational programming environments can be used to expose introductory mathematics students to programming, including Python, Scilab, and the statistical programming environment R. We present a framework for integrating programming concepts in a discrete mathematics course using a platform like Scilab. We discuss sample programming assignments and projects consistent with this framework, aimed at teaching students to analyze as well as design algorithms and their corresponding pseudo-code, and to implement these writing Scilab programs. (Received September 24, 2018)

1145-C5-2258 **William T Mahavier*** (ted.mahavier@lamar.edu), W. Ted Mahavier, 155 Manor St., Beaumont, TX 77706. *Discrete Mathematics as a Potential Gateway Course.* Preliminary report.

Over the years, various mathematicians have proposed replacing Calculus with Discrete Mathematics as a gateway course to collegiate mathematics. When Lamar University's Computer Science Department asked the Mathematics Department to address the content of Discrete Mathematics, the CS faculty wanted their students to be able to understand and produce proofs. Discrete Mathematics was redesigned to emphasize depth over breadth, and after a decade of refining my course I believe that if this emphasis is retained, then Discrete Mathematics can be a better starting point than Calculus. In this talk we will discuss the notes I co-authored and some surprises I have experienced teaching from them. These notes are free, written in PreTeXt, accessible on any mobile device, and available on-line at www.jiblm.org/mahavier/discrete/html/index.html. (Received September 25, 2018)

1145-C5-2402 **Oscar Levin*** (oscar.levin@unco.edu), University of Northern Colorado, School of Mathematical Sciences, Greeley, CO 80639. *A discrete math course with early graph theory.* Preliminary report.

Where does graph theory belong in the discrete math curriculum? A popular choice (at least consistent with many textbooks) is to include it near the end of an introductory course. While there are good reasons for arranging topics this way, students often find graph theory more interesting and more approachable than other topics, especially counting. Perhaps then, it would be reasonable to start a course by studying graphs to warm up to the more challenging concepts in combinatorics. In this talk I will describe an attempt to use graph theory to motivate both students and the remainder of material in an introductory discrete math and proofs course, and reflect on its efficacy. (Received September 25, 2018)

1145-C5-2452 **Kristi Meyer*** (kristi.meyer@wlc.edu). *Proofs? But I Can't Do Proofs!*

Discrete Mathematics is a course that varies widely from institution to institution. It can serve as a bridge course to upper level mathematics or a course for non-majors, a rigorous course intent on teaching proof techniques or a "hands-on" course completely devoid of proofs. At Wisconsin Lutheran College, Discrete Mathematics falls somewhere in the middle: it is required for our computer science students and is also an option for our mathematics majors (but is not the primary bridge course). Because of this diverse audience, a happy medium on a number of Discrete Mathematics topics is crucial – in particular, proof techniques. This talk will discuss how proof techniques are handled and taught, the proof writing expectations for students, and various pedagogical methods for dealing with a variety of student interests and ability levels. (Received September 25, 2018)

1145-C5-2548 **Christopher S Shaw*** (cshaw@colum.edu), Science and Mathematics Department, 600 S Michigan Avenue, Chicago, IL 60605. *Unifying sets and logic with the real world in a Liberal Arts Mathematics course.*

This talk will highlight some activities designed to introduce students to logical reasoning as a tool to decode the confounding language of legal jury instructions. These have been implemented within a small number of sections of a Liberal Arts Mathematics course. (Received September 25, 2018)

1145-C5-2654 **Emily J. Olson*** (ejolson@millikin.edu), Decatur, IL. *Group Work in a Discrete Mathematics Course with Proof-Writing.* Preliminary report.

We will discuss one successful implementation of group work in a discrete mathematics course. Using Levin's *Discrete Mathematics: An Open Introduction* as a guide, this course covered counting, graph theory, sequences, logic, and proof-writing. We committed every Friday to group work; the regularity contributed to its success. Many examples of appropriate problems will be included in the talk. (Received September 25, 2018)

1145-C5-2718 **Miriam Harris-Botzum*** (mharrisbotzum@lccc.edu), 4525 Education Park Drive, Science Hall, Office 7D, Schnecksville, PA 18078. *Using Games and Puzzles to Teach Discrete Mathematics.*

In this session, I present some classroom tested activities and lesson ideas for an introductory Discrete Mathematics course. In my Discrete Mathematics class, I use games and puzzles, such as the Tower of Hanoi, Set Game(R), Frogs and Toads, Chinese Rings, and many more, to teach many concepts. I weave them throughout my course, starting with simple concepts like set unions and intersections, and building up to advanced counting techniques. Using these games, students learn how to form conjectures, test those conjectures, and eventually prove or disprove them. (Received September 25, 2018)

Mathematics and the Arts

1145-D1-267 **Mike Huber*** (huber@muhlenberg.edu). *The Sierpinski Triangle's Italian Ancestors.* Preliminary report.

The Basilica di San Vitale, in the city of Ravenna, Italy, was consecrated in the sixth century. It joins other churches and baptisteries in Ravenna which contain some of the finest Byzantine mosaics in Italy and Europe. While tourists flock to the church to see the famous mosaics of early Christendom, the Basilica also contains several examples of fractal patterns. In particular, shapes recognizable as the Sierpinski Triangle, with iterations of various degrees, appear on the walls and in the pavimento's octagonal marble floor. This presentation will provide mathematical details and photographs of variations of the recursive triangles, which were constructed up to 1350 years before Sierpinski published his 1915 paper. (Received August 27, 2018)

1145-D1-624 **Satyan Devadoss*** (devadoss@sandiego.edu) and **Diane Hoffoss**. *Unfolding Humanity: Burning Man Mathematics.* Preliminary report.

"Unfolding Humanity" is a massive interactive metal dodecahedral sculpture, standing 12' tall and unfolding to 33' wide, showcased in Burning Man 2018. The exterior faces are dark green acrylic etched with characters illuminated by 17,000 programmed LEDs invoking the iconic Matrix animation, whereas interior faces of reflective acrylic mirrors create a kaleidoscopic image of people. It alludes both to Dürer's 500-year old unsolved problem on unfolding polyhedra, as well as pointing towards the Poincaré dodecahedral sphere and the shape of our universe. The work was supported by fundraising $40,000 and executed in deep partnership with dozens of students, alums, and members of the San Diego arts community. (Received September 11, 2018)

1145-D1-858 **David Plaxco*** (davidplaxco@clayton.edu), University Center 428, 2000 Clayton State Blvd, Morrow, GA 30260. *Cubes Underscore Art: Exploring How Algebraic Structures Support Aesthetic Patterns on nxnxn Rubik's Cube-type Puzzles.*

The Cubes Underscore Art project is an exploration of the possibilities of and techniques for producing patterns on Rubik's cube-like twisty puzzles, as well as larger (nxnxn) versions of the puzzle. In the 1970s and 80s, Ernö Rubik's magic cube became one of the most ubiquitous toys in the world. Recently, it has regained its popularity, even leading to the development of "speed cubing" as a competitive sport. However, the Rubik's cube has also led to puzzling mathematical questions, such as the quest for determining god's number - the diameter of the group of the cube's positions. The Rubik's cube has proven a ready example of a group for algebraists teaching introductory group theory. One branch of exploration of the cube's properties is the production of states of the puzzle that do not result in each side being a single color ("solved"), but instead produce aesthetic patterns on the cube. This talk will include an introduction to the project, a discussion of group theoretic concepts that can be used to generate patterns on cubes, and a presentation of a variety of the designs already generated through the project, including actual cubes, a photo gallery, and slow-motion and stop-motion videos. (Received September 16, 2018)

1145-D1-974 **Douglas Dunham*** (ddunham@d.umn.edu), Department of Computer Science 320 HH, University of Minnesota Duluth, 1114 Kirby Drive, Duluth, MN 55812, and **Lisa Shier**. *Embroidery of a Hyperbolic Fish Pattern.* Preliminary report.

We have investigated the possibility of using embroidery to render hyperbolic patterns using the Poincaré circle model. In particular we have created a pattern of fish inspired by M.C. Escher's "Circle Limit III" print which was based on the regular {8,3} tessellation.

This fish pattern presents considerable challenges for the embroiderer. The features become smaller as the bounding circle is approached and not all features can be included. The detail level drives a desire for the largest possible scale of the embroidery, which comes with a cost in complexity of implementation. The stitches must also be oriented to maintain the symmetry of the original design.

Our pattern has different combinatorics than Escher's, being based on the {10,3 tessellation, and has five fish meeting at right fin-tips instead of four as in Escher's print. This also requires more colors, six instead of four, to achieve (perfect) color symmetry. In fact the color symmetry group is the symmetric group A(5). (Received September 23, 2018)

1145-D1-1043 **Anil Venkatesh*** (anilvenkatesh@ferris.edu). *Enumeration of Internal Symmetries in Musical 12-Tone Rows.*

In music, a 12-tone row is any of the 12! possible orderings of notes in the Western chromatic scale. The musical notes of a 12-tone composition must always arise in the same order, cycling repeatedly through a predetermined "row" of twelve notes. The repetitive structure of 12-tone music lends itself to mathematical study. In 2003, Hunter and von Hippel investigated symmetry in 12-tone rows, using group theory to enumerate equivalence classes of rows under a group of music-theoretic symmetries. They found that highly symmetric rows constitute just 0.13 (Received September 18, 2018)

1145-D1-1304 **Susan A. McBurney*** (smcburney108@gmail.com), IL. *Finding the Way with More Mathematics.*

From silicon chips to satellites to GPS and beyond, navigational abilities have developed at an ever-accelerating rate and mathematics has played a fundamental role in this development. This presentation builds upon one given at JMM17 entitled "Finding the Way with Mathematics". It continues the timeline and focuses on the rapidly escalating technologies that not only enrich scientific progress, but bring these enhancements to the general public world-wide in ways that could hardly have been imagined a relatively short time ago. (Received September 24, 2018)

1145-D1-1648 **Maureen T. Carroll** and **Elyn Rykken*** (elrykken@muhlenberg.edu). *Geometry mined from architectural design.*

As an author and high-school mathematics teacher in the early twentieth century, Mabel Sykes had a passion for mathematics that continues to reveal itself through her books on geometry and algebra, and her articles on pedagogy. In her 1912 *Source Book of Problems for Geometry*, she uses complex and beautiful architectural designs, in her own words, "the best in historic ornament," as her inspiration for exercises on proof, construction and computation techniques. As she writes in the preface to this volume, "Geometry gives, as no other subject can give, an appreciation of form as it exists in the material world." In over 1800 exercises, Sykes analyzes geometric patterns found in tile and parquet floor designs, mosaics, Gothic windows, trusses and arches. In this talk, we discuss how to incorporate these beautiful designs and the accompanying exercises into introductory and advanced geometry courses. (Received September 23, 2018)

1145-D1-1682 **Robert A Bosch*** (rbosch@oberlin.edu), 291 Oak Street, Oberlin, OH 44074, and **Ari Smith**. *Hamiltonian Cycles on Möbius Strips and Other Surfaces.* Preliminary report.

We present the results of our ongoing research into constructing Hamiltonian cycles on graphs embedded in Möbius strips and other surfaces. One of our methods starts by employing a modification of MacQueen's algorithm to position points on the surface. It then connects the points into a cycle by solving an instance of the Traveling Salesman Problem (TSP). Our other methods work by taking aesthetically pleasing Hamiltonian paths and cycles on grid graphs and mapping them onto the surface.

We also present 3D printed artwork that we designed using our methods. Some of it can be thought of as 3D TSP Art. Other pieces were inspired by the line drawings of the architect Waclaw Szpakowski. (Received September 23, 2018)

1145-D1-1815 **John R Jungck*** (jungck@udel.edu), 221 Academy St., ISE Lab 402, University of Delaware, Newark, DE 19716. *Exploring Nanobiological Structures with 3D Nanotomography, 4D Printing Via Self-Assembly, and Graph Theory.* Preliminary report.

How does a viral capsid self-assemble? While Olson, Tibbits, and colleagues demonstrated self-assembly of dodecahedral viral capsid models via 4D printing, most capsids are icosahedral. We used Dürer nets, Schlegel diagrams, and CAD software to design triangular pieces which self-assemble into a icosahedron. A crucial design problem was realizing the importance of convex properties of the surface of the 3D printed equilateral triangular pieces interacting with the concaveness of the interior of the vessel used to assemble the pieces into the final icosahedral shape. We also have been printing 3D radiolarian representations built upon our 3D X-ray nanotomography data, analyzing them with medial axial transforms, and digital dissection. Using our software: Ka-me: A Voronoi

Image Analyzer we not only re-examine Haeckel's illustrations, but compare them with the geometry and topology of actual specimens. A web site of our radiolarian work is at: (¡https://spark.adobe.com/page/lm464/¿). By sharing our data via an open science depository: MorphoSource, other investigators will be able to analyze the raw data and/or print their own 3D models based upon the 3D voxel data. The artist Bathsheba Grossman used our 3D file to build embedded crystal glass representations of our radiolaria. (Received September 24, 2018)

1145-D1-1930 **Mark A Branson*** (mbranson@stevenson.edu), Stevenson University, 11200 Ted Herget Way, Owings Mills, MD 21117. *Mathematics and Art in Spain: Planning a Faculty-Led Travel Course.* Preliminary report.

Mathematics and art courses can come in many different forms. I will present details of the planning process for a course focused on Mathematics and Art centered around an 8 day trip to Spain. I will discuss how I chose to integrate travel and classroom experiences with mathematical topics, and discuss my process for building a syllabus syncretically from desired travel experiences, classroom art creation, and mathematical content knowledge. (Received September 24, 2018)

1145-D1-1994 **John Nicholson*** (nicholsonja@apsu.edu). *Curve stitching as a two-dimensional density plot.*

In curve stitching, a combination of lines or a single two-dimensional shape, e.g. a circle or hexagon, are drawn with evenly placed points located along the lines or around the shape's perimeter. Line segments connect pairs of points leading to the emergence of additional curves and patterns. Examples include a parabola emerging from two lines at right angles, and a cardioid emerging from a circle. Normally, the number of points and segments is kept low, allowing both the line segments and the emergent patterns to be seen in the final result. In this talk, I demonstrate how the basic curve stitching process can be extended in two ways. First, the number of line segments is increased to large values of N, stochastically choosing which line segments to draw, resulting in a final image that is similar to a two-dimensional density plot. Secondly, a computational approach allows for a wider variety of curves and combinations of curves. This approach leads to aesthetically pleasing patterns that are not regularly seen in the traditional curve stitching methods. (Received September 24, 2018)

1145-D1-2022 **Thomas Britt*** (tbritt@gmu.edu), 4400 University Drive, MS 5D8, Fairfax, VA 22030. *Profiles of Prime Suspects.*

I submit this abstract to report on a project that "explore[s] interactions between mathematics and the arts" in an "unexpected context" (quoted from your call for papers). As a filmmaker, for the past decade, I have documented the development of a multiplatform arts project with mathematics at its center. The genesis of the project was "Math Sciences Investigation (MSI): The Anatomy of Integers and Permutations," a script written by Andrew Granville (Canada Research Chair in Number Theory at the University of Montreal) and Jennifer Granville (award-winning producer, screenwriter, and director). The project has evolved to include a stage play of that script, an unorthodox musical score composed by a mathematician (Robert Schneider, Lecturer in the Department of Mathematics at the University of Georgia) and "Prime Suspects," a graphic novel from Princeton University Press (forthcoming February 2019). My report uses observational video footage and interviews with all of the participants as well as present-day testimonials solicited for this report, to present the way that the arts theory of medium specificity interacts with Granville's forensic examination of "the extraordinary similarities between the fine details of the structure of integers and of permutations." (Received September 24, 2018)

1145-D1-2110 **Susan Goldstine*** (sgoldstine@smcm.edu). *Self-Diagramming Lace: Minimalist Edition.*

Over the past year, I have knitted, written, and spoken about diagramming symmetries in knitted lace by incorporating color-coded markings into the fabric with beads. This talk showcases the latest phase in this oeuvre, in which all seven frieze symmetries are knitted and beaded using the same simple fundamental region. Since some frieze patterns require more copies of the fundamental region than others, the results are streamlined artworks which highlight the varying complexity levels of the different groups. (Received September 24, 2018)

1145-D1-2159 **Aiden Steinle*** (steinlea@southwestern.edu), 1001 E. University Ave, SU Box 7153, Georgetown, TX 78626, and **Fumiko Futamura** (futamurf@southwestern.edu), 1001 E. University, Georgetown, TX 78626. *The Treachery of Geometric Images.* Preliminary report.

In the link below is a drawing of a rectangular solid drawn in two-point perspective above the phrase, "Ceci n'est pas une cube" ("This is not a cube"). Much like René Magritte's surrealist painting *Ceci n'est pas une pipe* (also known as *The Treachery of Images*) which features a painting of a tobacco pipe above the titular French phrase "This is not a pipe", the drawing plays on ideas of object and representation, taking what we can perceive to be a cube literally to its limits. To do this, we will focus on understanding the all important viewpoint, the point in space where we will need to stand in front of the drawing to view the rectangular solid correctly as a cube.

Link to the drawing: https://bit.ly/2zqPpXY (Received September 24, 2018)

1145-D1-2190 **Fumiko Futamura*** (futamurf@southwestern.edu), 1001 E. University Ave, Georgetown, TX 78626, and **Marc Frantz** and **Annalisa Crannell**. *Factoring homographies to analyze perspective distortions.*

Usually when we see a planar object in perspective or project its shadow onto the ground, its shape is distorted in some way. The image of a square may be a trapezoid, the shadow of a circle is often an ellipse. But under the right conditions, a small square tile of a tiled floor can actually look nearly square even when viewed in perspective, and the shadow of a circle can actually be a circle. These types of mappings from a plane to a plane are examples of *homographies*. In this talk, we present a factorization of a non-affine homography to derive a function that measures perspective distortion. We will use this function to find distortion-free points as well as infinite families of undistorted circle pairs, and connect these results to conformal points, stereographic projections and Apollonian circles. (Received September 25, 2018)

1145-D1-2218 **Chamberlain Fong*** (chamberlain@alum.berkeley.edu), San Francisco, CA. *Elliptification of Rectangular Imagery.*

We present and discuss different algorithms for converting rectangular imagery into elliptical regions. We will mainly focus on methods that use mathematical mappings with explicit and invertible equations. The key idea is to start with a mapping between the square and the circular disc then extend it to handle rectangles and ellipses. This extension can be done by simply removing the eccentricity and reintroducing it back after using a chosen mapping. In addition, we will discuss how the Fernandez-Guasti squircle plays an important role in many mappings. (Received September 25, 2018)

1145-D1-2228 **Karl H. Schaffer*** (karl_schaffer@yahoo.com), 325 Lucinda St., Scotts Valley, CA 95066. *Three-dimensional Symmetries in Dance and Other Movement Arts.*

Choreographers characteristically use both symmetry and asymmetry as part of the palette with which they compose movement sequences, and dance floor patterns and formations often display a variety of planar symmetries. Three-dimensional symmetries also appear, especially in acrobatic compositions, but also in movement arts that overlap with athletic events, such as formation skydiving. We will examine some of these three-dimensional symmetries and the ways that transitions are designed to move from one such symmetric formation to another. These explorations can provide an engaging introduction to a variety of mathematical concepts. (Received September 25, 2018)

1145-D1-2241 **Jennifer M Wilson***, 20A Prospect Ave., Plainsboro, NJ 08536. *Darboven: Writing Time.*

Hanne Darboven was a German conceptual artist who used the physical act of writing—words, numbers, patterns—as both representation and actualization of time. In works such as Month III (1974), she juxtaposed symbolic, physical and graphical representations of each day, using "checksums" to encapsulate the dates. In this talk we will look at a number of her works, relating them both to those of other conceptual artists, as well as mathematical practices such as check digits. We will also explore a number of simple mathematical problems arising from her methods that are applicable to the classroom. (Received September 25, 2018)

1145-D1-2336 **Edmund Harriss*** (eharriss@uark.edu). *Curvahedra, Making Manifolds.*

Curvahedra is a simple system, pieces with several branches connect together so the connections remain flat. Each piece is itself flat so this gives a manifold condition, locally the surface produced is smooth. Controlling the angle turned (or holonomy) around a loop introduces curvature. A huge variety of surfaces from spheres to hyperbolic planes, toruses to triply periodic minimal surfaces can then be generated. In this talk I will explore the artistic possibilities of this free-form but mathematically curious system. (Received September 25, 2018)

1145-D1-2493 **Kerri Cushman**, Theatre, Art, and Graphic Design, and **M. Leigh Lunsford***, Mathematics and Computer Science, Longwood University. *Creating an Art+Math Upper-Level General-Education Mathematics and Studio Art Course.* Preliminary report.

Longwood University is undergoing a major change to its general education curriculum. As such it has encouraged its faculty to develop team-taught interdisciplinary upper-level courses. We, an art professor and a mathematics professor, are in the process of developing such a course in art and mathematics. In addition to exploring key intersections between art and mathematics in human culture and history, the course will also have a substantial studio component in which students will use mathematical concepts learned in the course in their artistic expression. In this presentation we will discuss the challenges of developing the course, which will run in Spring 2019, and our rationale for specific course content. (Received September 25, 2018)

1145-D1-2494 **Faina Berezovskaya*** (fberezovskaya@howard.edu), Howard University, Washington, DC 20059, and **Georgiy Karev**. *Arnold's weak resonance equation in modeling of Greek ornamental design.*

We consider a complex differential equation that describes a vector field invariant with respect to rotation to the angle $2\pi/n$ that was proposed by V. Arnold (1983) as a model of the loss of stability of self-sustained oscillations. Cases for "strong resonance" were discussed in many works. Here, we study the cases of "weak resonance". The equation is Hamiltonian at some values of parameters; its equilibria are saddles and centers. Due to the symmetry the saddles create n-separatrix cycles and the centers create n-center rings. We show that the equation demonstrates different kinds of phase behaviors depending on whether n is even or odd. Phase portraits of the equation have patterns that mimic the qualitative features of some of Greek ornamental designs that one can see in historical museums of Crete and Athens. We analyze the role of equation parameters in the genesis of patterns and repeated designs for different n and discuss approaches to modeling these designs. (Received September 25, 2018)

1145-D1-2549 **Margaret Kepner*** (renpek1010@gmail.com). *Visualizing Integer Sequences.* Preliminary report.

Integer sequences, such as the primes or the Fibonacci numbers, convey mathematical concepts in a compact form. The patterns within integer sequences can be revealed by displaying them in various visual formats. One example is the Ulam Spiral, where the prime numbers are plotted on a square spiral, producing unexpected patterns. In this talk, I will explore integer sequences displayed in various formats. I will show how several of the resulting images resemble pieces of modern art. Finally, I will explain how I have used patterns generated by integer sequences in my own artistic work. (Received September 25, 2018)

1145-D1-2617 **Donald Spector*** (spector@hws.edu), Department of Physics, Hobart and William Smith Colleges, Geneva, NY 14850. *Images Produced via Modular Multiplicative Inverses.*

In recent work, I explored the use of modular multiplication to modify musical themes and create new harmonic structures. Here, I take the same basic methodology and apply it visual art, manipulating images with rules based on pairing colors corresponding to inverses with respect to multiplication modulo a prime number. By selecting the number of subdivisions into which the gray scale or various individual color scales (e.g., R, G, and B, or C, M , Y, and K), one can employ different modular groups, obtaining different visual effects; the most compelling images arise from groups whose order is neither too small nor too large. Working interactively with this method allows an exploration of a range of possible images, which provides some insight into the structure of the relevant multiplicative groups as one examines a variety of aesthetic outcomes. (Received September 25, 2018)

1145-D1-2686 **Kurt E Ludwick*** (keludwick@salisbury.edu), Salisbury, MD 21801. *De Brujin Sequences for Change Ringing.* Preliminary report.

In change ringing, a "change" on n bells is equivalent to a permutation of n objects, and allowable ringing methods amount to sequences of permutations of order 2 from the symmetric group S_n. An "extent" on n bells is a method that generates each of the $n!$ changes on n bells, without repetition.

In this talk, we explore the notion of relaxing the definition of "extent," by viewing change ringing patterns on n bells as sequences of individual bell ringings rather than as the usual disjoint blocks of length n. For example, the list of changes

$$\begin{matrix}1234\\1324\end{matrix}$$

would be considered instead as the sequence

$$12341324,$$

which includes not only the changes 1234 and 1324, but also 2341 and 4132. In adopting this convention, an "extent" on n bells would be a sequence of bell ringings that includes each permutation of $\{1, 2, ..., n\}$ exactly once.

Our objective is to construct something analogous to a *de Brujin sequence* for change ringing. In particular, we wish to find a method for ringing n bells that generates a *sequence* of ringings, within which each permutation of n bells occurs exactly once, preferably without repetition. (Received September 25, 2018)

1145-D1-2772 **Sandy M. Spitzer*** (sspitzer@towson.edu), 8000 York Road, Mathematics Department, Towson University, Towson, MD 20705, and **Julia M. Daniel** (danie22@students.towson.edu) and **Alexandria H. Wilhelm** (awilhe5@students.towson.edu). *Transformed by Escher: Discovering the Art and Mathematics in a Regular Division of the Plane.*

M. C. Escher's artwork involving tessellations has intrigued students alike for generations, and has the potential to spark students' interest in mathematics through its connection to the visual arts. Escher drew inspiration for his artwork from Islamic tiling that he found in the Alhambra, a Moorish stronghold in Granada, Spain. Just as Escher unraveled the underlying geometric properties of Islamic art, this presentation will illuminate the mathematics behind Escher's artwork. We will explore regular tilings of the plane and engage participants in an investigation into how the interior angles of a polygon are related to whether and how it can tessellate. Then, we will demonstrate how Escher created modified polygons to tessellate a plane through a series of transformations. We use three of Escher's images (Pegasus, #105; Horsemen, #67; and Flying Fish, #99) to illustrate how translations, rotations, and glide reflections can create a recognizable figure. Finally, we will challenge participants to test their skills as they examine examples of Escher's iconic tessellations to decipher the underlying polygon and type of transformation that he used to create each piece of art. (Received September 25, 2018)

1145-D1-2896 **Karl Kattchee*** (kkattchee@uwlax.edu). *Grid-Based Closed Paths from de Bruijn Sequences.* Preliminary report.

In recent years, I have experimented with different ways of drawing closed paths on $n \times n$ square grids. In 2016, Craig Kaplan (University of Waterloo) and I worked out convenient notation to describe what we call NLT paths. The notation is a $2 \times n$ array, where each row is a so-called "alternating" permutation of the set $\{0, 1, 2, \cdots, n-1\}$. In principle, any permutations can be used to construct the array. In my talk, I investigate the mathematics and art of the closed paths which arise when the permutations are derived from de Bruijn sequences, which are binary strings having certain special properties. (Received September 25, 2018)

1145-D1-2916 **Radmila Sazdanovic*** (rsazdan@ncsu.edu), Department of Mathematics NC State Univeristy, Raleigh, NC 27695. *Tess-celestial.* Preliminary report.

This talk focuses on mathematics behind Tess-celestial: an exhibit that features tessellations of the hyperbolic plane. It explores the interplay of art, nature, culture, shape, perspective, and mathematics in everyday life. Created using the software Tess and KnotPlot, these tessellations show symmetries of hyperbolic space, convey the beauty and subtlety of mathematical objects and concepts, and how they can be combined to obtain beautiful visualizations. (Received September 25, 2018)

1145-D1-2962 **Mara Alagic***, mara.alagic@wichita.edu. *Learning to Love Math through the Exploration of Art in Culturally Responsive Context.* Preliminary report.

Existing research demonstrates that students more easily make sense of mathematical concepts and phenomena when their understanding of it is linked to meaningful cultural referents, it is connected not only to their cultural knowledge but even cultural knowledge of others they are curious to explore. This statement, emerging from cultural anthropology, captures the essence of a culturally relevant perspective. Preservice elementary teachers completed a project whereby they created an artistic representation of a mathematics concept of their choice reflective of a cultural context. In this paper, we illustrate how they are beginning to rethink their ways of conceptualizing mathematical ideas by developing visual, creative representations of familiar mathematical concepts. Their MathArt project is a part of a longitudinal study focused on developing math-related pedagogical content knowledge in the culturally responsive learning environment. An eclectic collection of produced works demonstrated various interpretations of the assignment. In this paper, a very brief theoretical background for this work is provided as well as a sample of preservice elementary teachers' works with the accompanying reflections. (Received September 25, 2018)

1145-D1-2989 **David A Reimann*** (dreimann@albion.edu), Mathematics and Computer Science, Albion, MI 49224. *Simultaneously Visualizing Symmetry Subgroups.*

Symmetric patterns can be understood mathematically as the resulting action of a symmetry group on a base motif. Using the subgroup structure of a base symmetry group, patterns can be created that have some integration into the overall symmetry. Examples of this process are shown for several symmetry groups. In addition to being a design tool, this concept can be used to help students explore groups and subgroup structures, providing insight and intuition, especially with more complex concepts such as normal subgroups and stabilizers. (Received September 26, 2018)

The Scholarship of Teaching and Learning in Collegiate Mathematics

1145-E1-90 **Anita M. Shagnea*** (shagnea@cua.edu), **Joshua L. Himmelsbach** and **Kiran R. Bhutani**. *Getting Students on Track: experience with a newly developed self-paced online pre-calculus review course at The Catholic University of America.*

Retention in STEM programs is a serious and complex issue. Many studies have shown that math competency and students' first semester GPAs in college are significant factors in student success. Much media attention lately has also been given to remedial classes and their possible negative effects on student population diversity and retention. To address these issues the Mathematics Department at The Catholic University of America has developed a set of asynchronous, instructor-supported online pre-calculus review courses for incoming freshmen with low scores on an in-house placement test. Students who pass the online review are placed into Calculus I. Our self-paced online review serves the needs of a mid-size private university with a non-local student population. In this talk, we will discuss our experience from offering this set of courses for two years. Additionally, we will look at the factors which went into developing these courses, and a study of the results. (Received July 26, 2018)

1145-E1-442 **Nicole Juersivich*** (njuersi9@naz.edu), njuersi9@naz.edu, and **Matt Hoffman**. *Data Integration in Undergraduate Mathematics Education.* Preliminary report.

We will describe our efforts in creating and evaluating the impact of teaching modules based on real-world data so that students have authentic experiences that support and motivate the investigation of concepts and techniques in calculus and linear algebra. Specifically, we looked at (1) how student disposition toward real-world data and the use of technology as a mathematical tool evolved in a course that used the modules and (2) how the completion of the data-driven and technology-integrated modules impacted student achievement in the course. We are currently in year 2 of this 3 year research study and have collected data from pre and post-module student surveys, pre and post-module student focus groups, student final exam scores, instructor journals, and instructor interviews from multiple courses across both a large technical university (RIT) and a small comprehensive college (Nazareth College). (Received September 07, 2018)

1145-E1-587 **Kristin A Camenga*** (camenga@juniata.edu) and **Kimberly A Roth**. *Effective Practice and Feedback Methods in Calculus I.* Preliminary report.

How do students learn most effectively in Calculus? Research suggests that the time students spend practicing problems and the feedback that they receive have a positive effect on student learning. However, there are many ways to accomplish this practice and give feedback, so what is most effective? In the context of a small private liberal arts college with Calculus 1 sections of about 30 students, we are studying the effects of three types of practice and feedback on student achievement on exams. The methods of practice and feedback include WeBWorK, textbook homework with students self-checking, and teacher-designed homework with a student grader. Preliminary results will be shared; the treatments will be repeated in the Spring 2019 section in a different order. (Received September 10, 2018)

1145-E1-1122 **Lake Ritter**, **Jennifer Vandenbussche*** (jennifer.vandenbussche@kennesaw.edu) and **Christina Scherrer**. *A study of student perceptions of office hours and the impact of required and elective attendance on those perceptions.*

Numerous studies have confirmed the positive effect of faculty-student interaction on a variety of student outcomes. Office hours are well-accepted as an essential component of the faculty-student relationship. However, there are few rigorous studies available to guide faculty who wish to implement best practices in office hour implementation. In this talk, we report on a study conducted to address three questions related to this area: How do students entering into an introductory course like Calculus I understand office hours (how they are used, their value, their academic role) and how do those perceptions change over the semester? What impact does office hour attendance, both required and elective, have on student perceptions of office hours? Are there demographic factors, such as gender or race, that affect the answers to these first two questions? (Received September 19, 2018)

1145-E1-1260 **Aimee J Ellington***, ajellington@vcu.edu. *A Detailed Analysis of Two Methods of Instruction in College Precalculus: The Pros and Cons for Students and Instructors.*

For three semesters, Virginia Commonwealth University (VCU) offered Precalculus in two different instructional formats: (1) a traditional large-lecture instructor-driven format and (2) a format using an artificial intelligence web-based learning system with small group lectures on an as-needed basis. The purpose was to address the question: Which instructional method was most effective for students completing the course? This presentation describes the two course formats and presents the results of a detailed assessment to determine how each instructional method had an impact on student understanding of Precalculus concepts and, more broadly, on student achievement. The assessment included the following: (1) success rates in the course, (2) performance on common final exam questions, (3) performance in a subsequent course, and (4) student feedback during focus groups. The pros and cons for students and teachers will be discussed. And, based on the results of this assessment, VCU's plans for future changes to Precalculus instruction will also be presented. (Received September 20, 2018)

1145-E1-1741 **Katherine J. Mawhinney*** (mawhinneykj@appstate.edu), 121 Bodenheimer Dr., ASU Box 32092, Boone, NC 28608, and **Katrina Palmer**, **Sarah Greenwald** and **Vicky Klima**. *Supporting the Algebraic Reasoning of Calculus Students.* Preliminary report.

The Department of Mathematical Sciences at Appalachian State University is developing co-requisite courses to support students enrolled in both the first and second semesters of calculus. This talk will share the design of these courses, and the preliminary results of student success from the first calculus support course. The majority of students who enroll in *Calculus 1 with Analytic Geometry* at Appalachian, are not mathematics majors. Over half intend to major in biology, environmental science, or computer science. The structure of these support courses will be shared within the framework of all the recent initiatives by the Department, including a revision of the calculus placement test, the use of online adaptive learning programs, and the support courses. (Received September 24, 2018)

1145-E1-2157 **Jane F. Reed, Ed.D.*** (waytosucceed@mail.com) and **Thomas W. Reed** (reedconsultingllc@mail.com). *Improving success in introductory mathematics courses: A metacognitive growth approach.* Preliminary report.

Many college students arrive on campus unprepared for the level of academic scholarship needed for success in first-year math classes. Administrators have focused on changing school factors–curriculum changes, pedagogy, placement tests, and tutoring centers–but poor academic outcomes persist. Effective learning practices also influence academic achievement. Unsuccessful students may not have developed personal self-regulating practices essential for success. If students were informed of effective learning practices, became aware of their own levels, and ways to improve, would they be more successful in first-year college math classes? This study, modeled after methods in the author's dissertation, will examine a practical analysis of individual student learning practices, strategy use, and metacognitive awareness in math classes, provide prescriptive feedback reports with suggestions for improvement, encourage increase in student awareness and use of learning behaviors, and foster growth in effective learning practices. Instructors can access their students' learning scores to identify and assist at-risk students. Evidence for success will include grade, DWF, and dropout data compared to historical data. Seven reasons for the effectiveness of this approach are explored. (Received September 24, 2018)

1145-E1-2361 **N. Paul Schembari*** (schembari@esu.edu), ESU Mathematics Department, 200 Prospect Street, East Stroudsburg, PA 18301. *Student Impressions of Online Mathematics Homework.* Preliminary report.

Our goal is to determine the effectiveness of online mathematics homework (OMHW) provided by a large publishing company in undergraduate mathematics classes, especially in comparison to traditional printed homework. To help answer this question, we will report the results of surveys taken in the Fall 2018 semester to gauge student impressions of the OMHW. The students are currently enrolled in a public comprehensive university and are either taking mathematics for general education or as a major requirement. The courses range from General Statistics, College Algebra, and up to Calculus. The students were asked for general information such as the reasons for taking the class, and whether or not they viewed themselves as hard-working. Then the OMHW was evaluated by the students, in terms of how often it was assigned, the time spent working on it, and its value as preparation for class or exams. We also asked whether or not the OMHW provided valuable feedback, whether or not it was worth the price paid, and compared OMHW to traditional printed homework. These comparisons asked the students if they prefer OMHW, if they learn more from OMHW, and which they felt was better overall. Finally, the students were asked if they believe our courses should continue to use OMHW. (Received September 25, 2018)

1145-E1-2545 **Robb Sinn***, Department of Mathematics, University of North Georgia, Dahlonega, GA , and **Karen Briggs**, Department of Mathematics, University of North Georgia, Dahlonega, GA. *Mathematics Immersion Eases the Transition to Proof.* Preliminary report.

The Mathematics Immersion Project at the University of North Georgia includes four bundled courses and targets the transition to proof for undergraduate mathematics majors. Immersion students must concurrently be enrolled in all four courses: Introduction to Proofs, Abstract Algebra, Linear Algebra and Probability and Statistics. The preliminary results from this pilot study indicate teaching and learning are both significantly different from traditional, stand-alone courses and may support the transition to proof better than traditional coursework. The common enrollment allows flexibility in teaching and a focus on cross-cutting topics. The transition to proof is aided by introductory level proofs from material in Linear Algebra and Probability and Statistics. Integrated topics addressing three or more courses at once foster improved acquisition of conceptual understanding in all the courses. Students learn proofs in multiple contexts all of which support a successful outcome in the proof-intensive Abstract Algebra course. The transition to proof from introduction all the way to success in Abstract Algebra in a single semester seems daunting, yet the intensive approach provides unique opportunities to improve learning outcomes for undergraduate mathematics majors. (Received September 25, 2018)

1145-E1-2656 **Megan J Breit-Goodwin***, Megan.Breit-Goodwin@anokaramsey.edu. *Transforming the Teaching and Learning in Introductory Statistics.* Preliminary report.

The Guidelines for Assessment and Instruction in Statistics Education College Report (American Statistical Association, 2016) set forth the challenge to transform introductory statistics into a conceptually connected, contextually meaningful course that engages students in authentic statistical thinking and processes. This study investigated the impact of implementing reform teaching and learning methods on student learning and confidence in an introductory statistics course at a two-year college. Do students build understanding and operation between multiple representations and descriptive measures of data? Does student confidence in their statistical thinking, reasoning and operation change? Student learning was measured using pre and post assessments that addressed conceptual understanding, contextual interpretation, and flexible operation with data. Student self-confidence was measured using a pre and post knowledge survey. Learning gains were demonstrated and increases in student confidence were documented. Study results are descriptive of the experiences and outcomes of the classes in which the inquiry was conducted and suggest opportunity for further inquiry into the impacts of reform statistics teaching and learning methods across diverse postsecondary contexts. (Received September 25, 2018)

1145-E1-2692 **Paran R Norton*** (pfisch@clemson.edu), **Karen A High** and **William C Bridges**. *Investigating students' progression through a mathematics course sequence based on instructional methods used in introductory calculus.*

In this study we examined how students' progression through the mathematics course sequence of Calculus I, II, III, and Differential Equations is related to the instructional method they experienced in Calculus I and II. We tracked cohorts of students through the course sequence during three instructional periods, which correspond to departmental policy changes at our institution: Traditional (Fall 2003-Spring 2005), SCALE-UP (Active Learning) (Fall 2011-Spring 2013), and Return to Traditional (Fall 2014-Spring 2016). We calculated the number of students who progressed to the next course, repeated the same course, or left the course sequence the following semester. Only around 19% of students starting in Calculus I successfully progress "on-track" through the four-course sequence during subsequent semesters. Chi-squared tests revealed a significant difference in the proportion of students progressing through the course sequence between the traditional methods and active learning periods. Specifically, a higher proportion of students progressed to Calculus III in the SCALE-UP period. However, of those students who successfully progressed to Calculus III, a higher proportion progressed to and then completed Differential Equations in the traditional methods period. (Received September 25, 2018)

1145-E1-2818 **Eric Simring*** (eis108@psu.edu). *Better Calculus through Biology: The Biocalculus Sequence at Penn State University.*

The first-year calculus program at Penn State University serves more than 2000 students each semester at the University Park campus, but the curriculum has been left unchanged since the 1990s. Penn State's new biocalculus sequence is the first large-scale attempt to renovate the calculus program in 25 years. In the four years since its creation, the success rates for life science majors have become significantly higher than in the standard calculus course, with no loss in mathematical standards. The course has grown from 100 students to nearly 500 per semester during its four years. A recent $1M NSF S-STEM grant awarded to the Eberly College of Science has targeted this biocalculus sequence to triple in size, including expansion to the 19 commonwealth campuses.

In this talk, we'll outline several important factors that we believe contribute to this success: an updated curriculum, student-centered pedagogical practices, and a strong community of practice among teaching and research faculty. We'll also talk about the opportunities and challenges posed by our expected expansion.

This is joint work with Amine Benkiran, Andrew Baxter, Russ deForest, Matthew Willyard, and Andrew Belmonte. (Received September 25, 2018)

1145-E1-2930 **Joshua A Cole*** (colej@wabash.edu). *Teaching the Mean Value Theorem to students not intending to major in math.* Preliminary report.

Which of the more theoretical elements of Calculus can I realistically teach to students who do not plan to major in Mathematics? Some relevant factors include: students' abilities, what will help students in other courses or applications, what will help students gain deeper intuitions about calculus, and what will stretch minds and mold students into better thinkers. I argue for an answer exemplified by two choices: to omit all epsilon/delta references, but to teach the Mean Value Theorem. In this choice, my vision of Calculus (for my students), is roughly an idealized version of the Calculus of Cauchy. I argue for these points with reference to the history of Calculus and my experience in the classrooms of small liberal-arts colleges. (Received September 25, 2018)

1145-E1-3025 **Yevgeniya Rivers***, 300 Boston Post Rd, West Haven, CT 06516. *Mindset and Developmental Math: an Embedded Curricular Approach to Demystifying and Illuminating Mathematical Ideas.*

In this talk, I will discuss a pilot program that incorporated six weeks worth of mindset modules into a developmental math curriculum. Qualitative and quantitative data from two semesters will be included in the discussion. Assignments promoted reflection and introspection while also encouraging students to find the relevance of their mathematical studies. Included in this talk are final grade comparisons between students in sections with mindset modules and control groups that used common assessments. (Received September 26, 2018)

Humanistic Mathematics

1145-E5-187 **Beverly L. Wood*** (woodb14@erau.edu) and **Debra Bourdeau**. *Developing a Humanistic STEM Minor.* Preliminary report.

We will focus on how a team-developed Humanistic STEM minor will enhance critical thinking, create opportunities for improving writing beyond general education courses, and develop an "interdisciplinary mindset" that allows for multiple solutions to problems. We define Humanistic STEM as the study of science, technology, engineering, and mathematics that combines with concern for human affairs, welfare, values, or culture. Goals include an understanding of the humanities through the lens of the STEM disciplines that would not exist without human focus on the progress of society in the areas of rhetoric, literature, history, philosophy, art, religion, and ethics. Students in STEM programs can be resistant to taking humanities courses; showing relevance of humanities to STEM will enhance appreciation of both. We will discuss why a humanistic STEM minor would benefit graduates, including the reality that such an interdisciplinary approach is becoming a hot topic both within academia and industry as alarm spreads over the defunding of Humanities. There is growing consensus that the employment of the future will drastically change as the human workforce is replaced by AI/robots for routine tasks, resulting in a need to understand both humans and machines to remain employed. (Received August 17, 2018)

1145-E5-473 **Emelie A. Kenney*** (kenney@siena.edu), Department of Mathematics, Loudonville, NY 12211. *Polish Émigré Mathematicians and Their American Colleagues: Effects of the Great Depression and World War II on Employment in the Mathematical Sciences.* Preliminary report.

Many mathematicians who left Poland for the United States in the period surrounding World War II generally left not as émigrés per se, but as visitors to other nations. Once in these nations, most mathematicians were unable or chose not to return to their homeland. With a great influx of talented and highly educated foreign mathematicians into the United States and limited opportunities for citizens and newcomers alike as a result of the Great Depression, hiring became a hurdle for everyone, and it was exacerbated by non-academic and non-economic issues. In this talk, we discuss those issues and the background in which they are situated, mention several notable Polish émigrés, and raise some questions for possible future work. (Received September 07, 2018)

1145-E5-477 **Alexander J Barrios*** (abarrios@carleton.edu), Carleton College, Department of Mathematics and Statistics, One North College Street, Northfield, MN 55057. *Humanizing Calculus.*

In this talk, we will discuss a slight restructuring of the standard calculus curriculum to incorporate the historical progression of the subject. We view calculus as it was originally discovered by reconsidering two questions from ancient Greece: what is the area of a geometric object and how to compute tangent lines at a point on a curve. These two questions were at the forefront of mathematical research in the 1640's following the introduction of Cartesian coordinates by Descartes and Fermat. This, in turn, shows students that Leibniz and Newton did not discover calculus single-handedly as is usually believed. In addition, we trace the development of the subject throughout the term to emphasize the 200-year journey that it took calculus to achieve its rigorous foundation. (Received September 07, 2018)

1145-E5-812 **J. Travis Shrontz*** (travis.shrontz@gmail.com). *The Rhetoric of Mathematical Logicism, Intuitionism, and Formalism.*

Rhetoric and mathematics have often been cast as opposing fields, operating independent of one another. Only recently have rhetorical scholars begun to develop an understanding of the connections between the two subjects. In this paper, I argue that not only are mathematics and rhetoric intimately connected, but that mathematics is necessarily rhetorical. I do so through an analysis of the foundations of mathematics in the philosophical schools of logicism, intuitionism, and formalism using Kenneth Burke's pentad. I then establish a method for analyzing mathematical artifacts based on their philosophical foundation. (Received September 15, 2018)

1145-E5-1252 **JoAnne Growney*** (japoet@msn.com), 7981 Eastern Ave, #207, Silver Spring, MD 20910. *Add Poems to Math Class.*

Mathematics gains value each time one of us interacts with it – a conservationist calculates changing ocean temperatures, an algebraist sees symmetry patterns and discovers structures that match them, a child names the positive integers aloud as she learns to count. Important, too, are our feelings about mathematics – our achievements or frustrations as we encounter the subject, our admiration for its creators, our appreciation for our teachers. Poems can be a concise way of bringing math attitudes and math personalities – such as Sophie Germain (who dressed as a man so she might attend mathematics classes) or a demanding teacher or an anxious student – into focus for brief but thoughtful consideration. Samples will be offered in this presentation of a variety of such poems– samples collected and freely available to all in the blog "Intersections – Poetry with Mathematics" at https://poetrywithmathematics.blogspot.com. The presentation also will offer samples of the ways that mathematical patterns give structure to poetry: in sonnets – and also in snowballs and squares, in the Fib and the Skinny, and in Pilish. (Received September 20, 2018)

1145-E5-2104 **Della Dumbaugh*** (ddumbaugh@richmond.edu), Department of Mathematics & Computer Science, Richmond, VA 23173. *Art, Literature & Letters in the Calculus Classroom: An Overview.*

In his A Scream Goes Through the House: What Literature Teaches Us About Life, Arnold Weinstein emphasizes an education "not about facts and data." Instead, he suggests literature and art as a way to see our world "though lenses not our own." This talk explores creative ways to view the traditional concepts of Calculus through the lenses of art, literature and letters. It shows, through example, how the Calculus classroom provides the perfect space to connect mathematics with the innovative 16th century art of Giuseppe Arcimboldo, the concise correspondence of Richard J. Duffin and other letter writers, the popular Me Before You contemporary novel and movie by Jo Jo Moyes, and the children's literature of Bernard Waber and his contemporaries. (Received September 24, 2018)

1145-E5-2339 **Kyle Evans*** (kyle.evans@trincoll.edu) and **Adam Giambrone** (agiambrone@elmira.edu). *Mathematics and Fairness: Using Gerrymandering to Connect Mathematics to Sociopolitical Issues.*

If we work under the assumption that mathematics cannot be separated from its social and political contexts, then we enter a realm where mathematics becomes a tool for change. Specifically, with recent Supreme Court decisions and the upcoming 2020 U.S. Census, the topics of redistricting and gerrymandering have become increasingly prevalent in political discourse. In this talk, we will discuss ongoing work to connect mathematics to current and relevant sociopolitical issues in undergraduate general education mathematics courses. We will discuss a student project on gerrymandering where students work towards synthesizing numerical information, geometric information, and sociopolitical considerations to construct their own definition of "fairness" with regard to redistricting. We will also discuss ongoing scholarship and plans for future courses and scholarship related to this topic. (Received September 25, 2018)

1145-E5-2519 **Matt DeLong*** (mdelong@marian.edu). *Comparing Ways of Knowing Across Disciplines.*
We live in an increasingly polarized culture that has become skeptical of facts and the notion of truth. In that context, a liberal arts education plays a vital role. At its best, it can help students simultaneously develop and understand their own convictions while engendering in them a humility that is essential to listening and dialogue. In this talk, I will describe a math-listed, sophomore-level, honors course that used the mathematical (axiomatic) method as a touchstone for comparing ways of knowing in the sciences, history, literature, theology, the performing arts, and other disciplines. I will discuss the history, rationale, content, and pedagogy of this course. I will also report on documented outcomes, including how the course played a role in both strengthening students' worldviews and in making them more aware of, and comfortable with, the uncertainty resulting from their own epistemological limitations. (Received September 25, 2018)

Inequalities and Their Applications

1145-F1-108 **Mohammad K. Azarian*** (azarian@evansville.edu), Department of Mathematics, University of Evansville, 1800 Lincoln Avenue, Evansville, IN 47722. *Unpublished Solutions of Some Problem Proposals in General Mathematics Journals Involving Inequalities.* Preliminary report.
Over the span of 1987 to 2015 the author published 76 problem proposals in general mathematics journals, and provided a solution to each one of these problems. Out of these 76 problems, 16 involved inequalities. In 8 of these 16 problems, the solutions that were provided by the readers were published, rather than the author's solutions. In this presentation we will discuss the author's solutions that were not published by the journals. The talk will be accessible to undergraduate mathematics students. (Received July 31, 2018)

1145-F1-320 **Eric Stachura*** (estachur@kennesaw.edu) and **Andrew K Hunter**. *A Quantitative method for choosing optimal Daubechies wavelets.*
I will discuss an undergraduate senior thesis project on the analysis of wavelets. In particular, I will discuss work with a previous student of mine (A. K. Hunter) on the development of new inequalities useful for choosing wavelets for applications. Such applications include the numerical analysis of partial differential equations and the visualization of signals. For functions of various smoothness (differentiability), we prove a new inequality which shows how well such a function can be approximated by its wavelet transform. (Received August 31, 2018)

1145-F1-342 **Fariba Khoshnasib-Zeinabad*** (khoshfa@earlham.edu), Richmond, IN 47374. *On some Integral means.*
Harmonic, Geometric, Arithmetic, Heronian and Contraharmonic means have been studied by many mathematicians. In 2003, H. Evens studied these means from geometrical point of view and established some of the inequalities between them in using a circle and its radius. In 1961, E. Beckenback and R. Bellman introduced several inequalities corresponding to means. In this paper, we will introduce the concept of mean functions and integral means and give bounds on some of these mean functions and integral means. (Received September 02, 2018)

1145-F1-351 **Eze R Nwaeze*** (enwaeze@tuskegee.edu), Department of Mathematics, Tuskegee University, Tuskegee, AL 36088. *Generalized weighted trapezoid and Grüss type inequalities on time scales.*
In this talk, some new generalized weighted trapezoid and Grüss type inequalities on time scales, with a parameter function $\psi : [0,1] \to [0,1]$, are presented. Our results give a broader generalization of some theorems in the literature. In addition, we discuss the cases when the time scale is $\mathbb{R}$ and $\mathbb{Z}$. (Received September 03, 2018)

1145-F1-554 **Joshua Michael Siktar***, jsiktar@andrew.cmu.edu. *Recasting the Proof of Parseval's Equation.* Preliminary report.
We generalize aspects of Fourier Analysis from intervals on $\mathbb{R}$ to bounded and measurable subsets of $\mathbb{R}$. In doing so, we obtain two interesting results. The first is a new proof of the famous Integral Cauchy-Schwarz Inequality. The second is a restatement of Parseval's Equation that doubles as a representation of integrating bounded and measurable functions over bounded and measurable subsets of $\mathbb{R}$. (Received September 09, 2018)

1145-F1-645 **Andrew Simoson*** (ajsimoso@king.edu), King University, 1350 King College Road, Bristol, TN 37620. *Golden-Mean Sunflower Inequalities.*

It is well-known that the seeds in an ideal sunflower are arranged as a family consisting of the Fibonacci number f_n of spirals for each integer $n \geq 2$, where $f_0 = 0$, $f_1 = 1$, and $f_n = f_{n-1} + f_{n-2}$. Let ϕ be the golden mean, $\phi = \frac{1+\sqrt{5}}{2}$, and let $F_n = \frac{f_{n+1}}{f_n}$ for all $n \geq 1$. When n is even, $|F_n - \phi| < \frac{1}{\sqrt{5}f_n^2}$; and when n is odd, $\frac{1}{\sqrt{5}f_n^2} < |F_n - \phi| < \frac{1}{2f_n^2}$. These inequalities enable us to find the number of seeds lying along one rotation for any of the f_n spirals. As a partial spoiler alert: when n is even the number of seeds is $f_{n-1} + f_{n+1}$. (Received September 12, 2018)

1145-F1-2136 **Risto Atanasov*** (ratanasov@email.wcu.edu). *Convex Functions and Their Applications to Inequalities.* Preliminary report.

As convex functions are defined by a functional inequality, they lead to a number of important inequalities. We will focus on two: Jensen's and Karamata's inequalities. They can be used in proving other inequalities, particularly those appearing as problems in mathematical competitions, including International Mathematical Olympiads and William Lowell Putnam Mathematical Competition. (Received September 24, 2018)

1145-F1-2311 **Marius Munteanu*** (marius.munteanu@oneonta.edu). *Extending Hlawka's Inequality.* Preliminary report.

Although the naïve extension of Hlawka's inequality from three to four real numbers is not valid, in this presentation we investigate how to adjust the naïve extension in order to obtain several valid generalizations. (Received September 25, 2018)

Innovative and Effective Ways to Teach Linear Algebra

1145-F5-201 **Fang Chen*** (fchen2@emory.edu). *Two True/False Questions on Linear Independence and an Application to a Set Theory Problem.* Preliminary report.

The introductory linear algebra course that I teach covers general theories and structures as well as fundamental topics. My typical class consists of first and second year students who have almost no experience in writing proofs or solving real problems. The course lets them get a glimpse of what mathematics is and how it is done. It is important to pose questions, kindle curiosities, explore connections and inspire interests. Through the course, apart from acquiring a solid foundation of knowledge, students learn to think mathematically, to explore, investigate and solve problems.

Some portion of the evaluation are True/False questions which require the students to either prove a statement or disprove it with an argument or a counterexample. Students found them interesting and challenging while I deem them an effective tool. I would like to share the experience of using two True/False questions on linear independence and an application to a set theory problem. These questions not only strengthen the understanding of linear independence and its connection to existence/uniqueness, but also introduce some useful techniques. Furthermore the process gives the students a taste of how to approach a nontrivial problem and how to polish a proof after a rough argument is reached. (Received August 19, 2018)

1145-F5-317 **Jeff A Suzuki***, 2900 Bedford Ave., Brooklyn, NY 11210. *Flipping Linear Algebra: Teaching a Majors-Level Linear Algebra Course in a Flipped Learning Environment.*

In a traditional class, students go to a classroom to hear a lecture, then go home to do assignments. But this means that if they run into difficulties on an assignment, they can't get help until the next class, which impedes their learning. In a flipped class, students hear lectures elsewhere, usually through online videos, then go to class to work assignments. We will discuss how to use open resources like YouTube videos and innovative in-class assignments to promote student understanding of the concepts of linear algebra, and to set students on the path towards creating advanced mathematics. (Received August 31, 2018)

1145-F5-574 **Minah Oh*** (ohmx@jmu.edu). *Teaching Linear Algebra through its Applications.* Preliminary report.

When learning linear algebra for the first time as an undergraduate student, it may take some time to understand and appreciate the beauty and importance of the subject. In contrast, when students see an interesting real world application of mathematics, they immediately become passionate and interested in the subject. In this talk, I will present some applications of linear algebra that instantaneously grabbed my students interest in my undergraduate-level linear algebra class. Some of these applications are in image compression and biomedical engineering in the treatment of liver cancer. Furthermore, I will talk about how my motivated students learned the basics of the finite element methods by applying their knowledge in linear algebra. (Received September 10, 2018)

1145-F5-923 **Connor Thomas Ahlbach*** (ahlbach@uw.edu), 1901 NE 85th St., Apt. 311, Seattle, WA 98115. *Sum and Intersection of Subspaces in Introductory Linear Algebra.*

In most introductory linear algebra classes, subspaces are treated as static objects. This mistreatment can be avoided by studying how subspaces interact through sum and intersection. Through studying sum and intersection of subspaces, we can correct some of the misconceptions about subspaces, motivate the utility of relation form, define complements and projection maps, build geometric intuition, and better prepare students for higher-level math and science classes. It is especially important that we educate students properly in linear algebra to prepare the future leaders in industry, where linear algebra is essential. (Received September 17, 2018)

1145-F5-1020 **James Hamblin*** (jehamb@ship.edu). *Helping Students Master Linear Algebra Through Writing.*

One of the main struggles that undergraduate students have with learning linear algebra is the large amount of new vocabulary they need to learn, especially at the beginning of the course. When I teach linear algebra, I focus on mathematical language and writing, and use technology to de-emphasize row-reduction. I create videos where I walk through terminology, definitions, and proofs with lots of examples. Assignments focus on reasoning and simple proofs. In this talk, I will provide details for the methods that I use in my course, as well as data to show how effectively students are learning these concepts. (Received September 18, 2018)

1145-F5-1057 **Daniel E. Otero*** (otero@xavier.edu), Department of Mathematics, Hinkle 104, Xavier University, Cincinnati, OH 45207-4441, and **Colin McKinney** (mckinnec@wabash.edu), Dept. of Mathematics & Computer Science, Goodrich Hall 109, Wabash College, Crawfordsville, IN 47933. *Learning determinants from Cramer and Cauchy: a TRIUMPHS Primary Source Project.*

This talk, a follow-up to an address from one year ago in the same Themed Contributed Paper Session, will report on an implementation by the second presenter of a Primary Source Project designed by the first presenter. The project, *Determining the Determinant: learning in the footsteps of Cramer and Cauchy*, is one of many produced by the NSF-supported TRIUMPHS grant, for use in a standard linear algebra course to teach the determinant and its basic properties. It uses writings by Gabriel Cramer (his statement of his eponymous Rule) and extensive excerpts from the monumental 1815 treatise on determinants by Augustin-Louis Cauchy to drive active student learning through carefully crafted exercises. (Received September 18, 2018)

1145-F5-1261 **Gilbert Strang*** (gs@math.mit.edu). *Linear Algebra and Deep Learning.* Preliminary report.

Since teaching is best discussed using examples (and I don't have any theories about teaching, except to be active and enthusiastic and conscious of your audience), I would like to report on my experience with a new course and new book. The course builds to an analysis of neural nets and deep learning.

Machine learning is a very active topic, students and faculty want to learn about it ! The components are 1) Linear algebra 2) Statistics and probability 3) Optimization . (Received September 20, 2018)

1145-F5-1668 **Crista Arangala*** (ccoles@elon.edu), Campus Box 2320, Elon University, Elon, NC 27244. *Using Matlab Apps to Explore Linear Algebra.*

This presentation will focus on using Matlab Apps from the Matlab Central File Exchange, writing Matlab Apps for the File Exchange that are valuable in Linear Algebra, and engaging students in writing Matlab Apps to delve deeper into the understanding of Linear Algebra. (Received September 23, 2018)

1145-F5-1845 **Steven Schlicker***, Department of Mathematics, GVSU, Allendale, MI 49401. *Motivating Students with Applications.*

For many years I have searched for real applications that my students can explore in my classes in an attempt to help motivate them to learn the concepts as well as the applications. The linear algebra applications will be included in an open source linear algebra text that my colleague Feryal Alayont and I have written. Each section of our text begins with a short discussion of an application that uses the material from the section, and concludes with an extended project in which students can explore the application. In this presentation I will share some of the applications that are in the text and the projects in which the students engage. (Received September 24, 2018)

1145-F5-2089 **Katiuscia C. B. Teixeira*** (katiuscia.teixeira@ucf.edu), 2427 Teton Stone Run, Orlando, FL 32828. *Pedagogical Strategies to Enhance Learning in a Linear Algebra Course.*

The heart of this study is an innovative method to improve the teaching of linear algebra course. The use of peer instruction in conjunction with a seminar strategy and supported by didactic engineering is proposed as a means to facilitate the mastery of abstract concepts, the undertaking of innovative research in problem solving, and the practical application of educational concepts. To assess the method's effectiveness, the Students' Evaluation of Educational Quality questionnaire was administered and assessed. In addition, to determine whether this new teaching approach leads to better learning results than the traditional method, a comparison between control and experimental groups was conducted. In sum, the proposed method has been proven to enhance student motivation and reflection, which are critical to a productive, collaborative learning environment that directly impacts academic retention and performance. (Received September 24, 2018)

1145-F5-2422 **Ton Boerkoel*** (aboerkoel@digipen.edu), 2241 Prescott Ave SW, Seattle, WA 98126. *Advanced uses of the TI-Nspire in a Linear Algebra Course.*

In Linear Algebra we discuss vector spaces over general fields, not just the real or complex numbers. But when it comes to examples, homework problems and tests, the fields $\mathbb{R}$ and $\mathbb{C}$ are used almost exclusively. In this talk I will discuss a suite of programs I have written for the TI-Nspire calculator to do Linear Algebra over the finite fields $\mathbb{F}_2$, $\mathbb{F}_4$ and $\mathbb{F}_7$, the fields of 2, 4 and 7 elements. It allows us to work in vector spaces such as $\mathbb{F}_4^n$, $M_{n\times m}(\mathbb{F}_7)$ and the polynomial spaces $P_n(\mathbb{F}_4)$, to explore these spaces just as we do over $\mathbb{R}$ and $\mathbb{C}$, using row reduction, solving systems of equations, finding determinants, inverse matrices, change of basis matrices, eigenvectors, diagonalization and LU decomposition etc. I have provided these programs to my students in my Linear Algebra classes the last five years to give them the experience to work in vector spaces beyond $\mathbb{R}$ and $\mathbb{C}$, and see how they compare and differ, and to work homework problems and test problems over $\mathbb{F}_2$, $\mathbb{F}_4$, $\mathbb{F}_7$, as well as $\mathbb{R}$ and $\mathbb{C}$. (Received September 25, 2018)

1145-F5-2535 **J Donato Fortin*** (dfortin@jwu.edu), 801 West Trade Street, Charlotte, NC 28202. *Discovering Ill-Conditioned Systems Via Plane Deformations.*

Ill-conditioned linear systems Ax = b may result in surprisingly large perturbations of the solution from very small perturbations to the objective vector, b. With unexpected results as bait, Quantitative Analysis students examined 2 by 2 linear systems for potential ill-conditioning via deformations of circles in the plane. Matrix and vector operations were introduced for solutions via inverses and to explain matrix manipulations conducted by calculator. Students calculated the pre-image for a small circle of points (small perturbations) around the objective vector. Graphs were obtained for the pre-images, and from these, students inferred troublesome/favorable directions of change (eigenvectors) and the max/min distortions (singular values) for the system.

Ultimately, students were able to characterize the condition of a system based on the amount of distortion of the perturbation circle and became sensitive to potential pitfalls of rounding of the objective vector. Although course requirements limited technology to calculators, the exercise can be greatly improved with a programming platform. (Received September 25, 2018)

1145-F5-2645 **Winfried Just*** (mathjust@gmail.com), Winfried Just, Department of Mathematics, Ohio University, Athens, OH 45701. *Teaching linear algebra through dialogues.*

We all teach through dialogues. When a student comes to our office hours, we guide that student through the process of learning by trial, error, discussion, critique of prior attempts, corrections, and trying again. This method works. Can we use it in a large classroom?

Of course not. Imagine putting a group of students in front of the class and having them discuss their attempts at selected homework problems, giving each other feedback on their trials and misconceptions, while the entire class comments on their mistakes. Impossible. Don't even try to think of those angry phone calls from parents and from the Dean.

But how about putting imaginary students in front of the class, script their dialogues so that these characters make all the right mistakes, and have the real students join the discussion through an electronic feedback system? Still impossible?

The presenter developed and is teaching a linear algebra course in the format described above and will show samples of these dialogues. Does the method work? Come to the talk and judge yourself! (Received September 25, 2018)

1145-F5-2694 **Sepideh Stewart***, 601 Elm Ave., Norman, OK 73019. *Highlights from a workshop on teaching and learning Linear Algebra: Outcomes and future endeavors.* Preliminary report.
In 1990, the Linear Algebra Curriculum Study Group (LACSG) suggested a set of recommendations for the first-year course in Linear Algebra (Carlson, Johnson, Lay, & Porter, 1997). In Fall 2018, a workshop was held to revise these recommendations. The goals of this 2-day workshop included:

(a) Working toward writing research based recommendations for teaching and learning of Linear Algebra; (b) Generating new research questions and ideas that encourage collaboration between research mathematicians and mathematics educators.

In this talk, I will give a brief overview of the workshop as well as share some of its outcomes and future initiatives. (Received September 25, 2018)

1145-F5-2877 **Kayla K. Blyman*** (kayla.blyman@usma.edu), United States Military Academy, Department of Mathematical Sciences, 646 Swift Road, West Point, NY 10996. *Exploring Applications of Linear Algebra through Low-Stakes Discovery Learning Assessments.*
While it is one of the most foundational classes in the undergraduate mathematics curriculum, linear algebra can be prohibitively abstract at times. But there are applications of linear algebra all around us! However, those applications are often complicated enough that it is beyond the possible scope of a single class to do justice to the richness of the example. By scheduling several class days throughout the semester for low-stakes Discovery Learning Assessments we can have students work with an application more deeply. For these days, students are expected to familiarize themselves with the context of the application before coming to class through a night before read ahead. Once they get to class they will individually take a brief computational quiz on some recent material related to the application. Next they will work in teams of 3-4 students to dive into the application. Since teams can be asked deeper, more complicated questions, they can explore the application more meaningfully than they could as individuals. Finally, to make sure that everyone was engaged in the teamwork, a very brief reflection problem is completed individually. Discovery Learning Assessment topics related to linear algebra will be discussed and sample assessments will be provided. (Received September 25, 2018)

Introducing Mathematical Modeling through Competitions

1145-G1-104 **Brian Winkel*** (brianwinkel@simiode.org), SIMIODE, 26 Broadway, Cornwall, NY 12518. *Student Competition Using Differential Equation Modeling - SCUDEM for Students and Faculty.*
Student Competition Using Differential Equation Modeling – SCUDEM is an opportunity for teams of three students from high school and undergraduate programs to select one of three modeling scenarios and over the course of a week build a mathematical model with differential equations to address the scenario. Problem areas for selection are (1) physical sciences and engineering, (2) life sciences and chemistry, and (3) social sciences. Students assemble on Competition Saturday at regional local sites in the United States and beyond where they submit an Executive Summary for faculty judging; address a new feature added to their model; participate with their faculty coach in collegial development program; make a presentation of their model for immediate feedback and judging; and participate in a fun individual MathBowl. SCUDEM is held in late October each year and is about the chance to model using differential equations with immediate feedback in a supportive day of meeting other students of like interest and working with faculty to develop ideas on how to incorporate modeling into differential equations courses. Complete details with all past questions and student submissions are available at www.simiode.org/scudem. (Received July 29, 2018)

1145-G1-339 **Jennifer A Czocher***, 601 University Dr, San Marcos, TX 78666, and **Kathleen Melhuish**, Texas State University. *Can mathematical modeling competitions help participants build confidence? If so, so what?*
We often hear about the benefits of mathematical modeling for students' learning of mathematics, development of modeling skills, and in the case of participating in competitions, for fostering "soft skills." In this talk I'll frame a systematic study of the impact of SIMIODE's mathematical modeling competition (SCUDEM) on participants' confidence to do mathematical modeling in terms of recent educational research about persistence in mathematics. I use the results to argue that modeling competitions are positioned to play an important supporting role in STEM students' ultimate success in their careers. (Received September 02, 2018)

1145-G1-458 **Eddy Kwessi*** (ekwessi@trinity.edu), San Antonio, TX 78212, **Sidoine Raoul Youtcha Nyandjou** (raoulyoutcha@yahoo.fr), Dauala, Cameroon, and **Rose Sandrine Mougoue Faguen**, Douala, Cameroon. *Mathematical Modeling Competition: A Trinity University approach to preparation.* Preliminary report.

Trinity University has been sending teams for Mathematical Competition (MCM) since 1989, with various degrees of success. Overall, the MCM has been a worthwhile experience for both students and advisors. Advisors at Trinity have had different approaches to the selection and preparation of students for MCM. In this talk, we will discuss the various approaches, the lessons learnt and the improvement we think may be needed. Trinity has established various exchange partnerships with academic institutions in Africa. We will also discuss how Trinity approach may be used to help interested students in Africa, especially in Cameroon to participate and thrive in the competition. (Received September 06, 2018)

1145-G1-597 **Jessica M. Libertini*** (libertinijm@vmi.edu) and **Amanda Beecher**. *Judging the ICM, A View from Within.*

COMAP's ICM is the premiere international undergraduate contest in interdisciplinary modeling. It has continued to grow since its inception in 1999 and last year, nearly 10,000 teams submitted solutions. The interdisciplinary team of judges works each year to fairly judge the papers within the context of the problem selected and the team's use of the structures and processes of modeling. In this talk, we will pull back the curtain and discuss the two-step judging system, triage judging and final judging, that the ICM uses to help whittle the growing number of entries down to the handful who earn the rank of "Outstanding". (Received September 11, 2018)

1145-G1-692 **Maria-Veronica Ciocanel***, ciocanel.1@mbi.osu.edu. *Insights and strategies for starting local Mathematical Contest for Modeling contests.*

As an undergraduate student, I had the opportunity to participate in the Math Contest for Modeling (MCM) and to receive a Finalist award. The weekend spent with my team was intense but made me realize that I enjoy solving applied problems and contributed to my decision to pursue a PhD in Applied Mathematics. In this presentation, I will discuss my experience with founding local MCM competitions at Brown University and at The Ohio State University that introduce undergraduate students to smaller scale versions of the contest. I will particularly focus on strategies for building strong student teams, for establishing the contest as a recurring event, and for taking advantage of the institution's resources (such as SIAM student chapters). The local contests offer ample opportunities for feedback and student training and can be framed as competitions where the top teams are sponsored to participate in the international contests. Students report enjoying the intensive contest experience and teams that won Outstanding Winner awards in the ICM were excited to present their problem solutions to undergraduate and graduate students. In addition, I have found that students who participate in the MCM/ICM contests are more likely to seek research experiences during their college years. (Received September 12, 2018)

1145-G1-1423 **Wai Wah Lau*** (lauw@spu.edu), 3307 Third Ave W, Department of Mathematics, Seattle Pacific University, Seattle, WA 98119, and **Tara Kats**. *MCM strategies for smaller colleges.*

Our presentation aims at faculty from smaller schools who want to start a MCM program or who have recently started a program. We will share the strategies we use for student motivation, recruitment, and contest preparations. One of my advisees, who is a 3-time meritorious winner, will share her contest experience via video. (Received September 21, 2018)

1145-G1-1995 **Courtney L Davis*** (courtney.davis2@pepperdine.edu). *A Beginner's Guide to Building a Science Modeling Club.*

I created our Science Modeling Club two years ago to provide a venue to introduce mathematical modeling beyond our curriculum. In weekly one-hour meetings, students work in teams to learn modeling ideas and techniques in hands-on ways while building toward COMAP's MCM and ICM contests. We had two teams compete in the COMAP contests in 2017, and six teams competed in 2018. From a beginner's perspective, I will discuss our evolving general strategies and lessons learned both in conducting the club and in preparing for these contests. This includes touching on club start-up, recruitment, how we find modeling questions, practice with mathematical software, team formation, contest planning, ongoing club involvement, and student feedback. I will describe some of the surprises as well as the most helpful takeaways so far, with a goal to lend insight to others in the early stages of launching contest-centered clubs or teams. (Received September 24, 2018)

1145-G1-2263 **Ruth G. Favro*** (rfavro@ltu.edu). *Thirty years of using the MCM for teaching Math Modeling.*

Lawrence Tech started competing in the Mathematical Contest in Modeling (MCM) in 1989. At that time we had no Math Modeling class. But the contest was a good fit for us—interdisciplinary student learning in a team, with a time deadline, and clear exposition required. The Math Modeling class, started in 1996, was based on the competition problems. We continue to recruit students for the competition from outside the class, and have started participation in SCUDEM. We will discuss our students learning, success, and include student comments. (Received September 25, 2018)

1145-G1-2327 **Peter R Kramer*** (kramep@rpi.edu), Department of Mathematical Sciences, RPI, 110 8th Street, Troy, NY 12180. *Complementing Applied Mathematics Education with Modeling Contests at Rensselaer.*

I will describe how we use practices for the Mathematical and Interdisciplinary Contest in Modeling at Rensselaer to prepare students to perform well in the contest, practice the mathematical modeling process, and learn some broadly useful techniques not typically taught in the classroom. We integrate graduate students and postdocs as coaches into our training of the undergraduates. Participation by women has been increasing (from originally low levels) over the years, and teams with both male and female students have had extraordinarily better success rates than our all-male teams. I'll also discuss some challenges regarding the training of our students and the evolving nature of the contest. Our institute's MCM/ICM training program is one of several activities supported by our mathematical sciences department's NSF Research Training Grant. (Received September 25, 2018)

1145-G1-2350 **William C Bauldry*** (bauldrywc@appstate.edu). *Judging the Mathematical Contest in Modeling (MCM): Process and Insights.*

The Mathematical Contest in Modeling (MCM), sponsored by COMAP (http://www.comap.com), began in February, 1985, with 90 papers; the contest has grown to 10,670 teams from around the world participating in 2018. Judging this vast collection of papers in 8 weeks is a feat. We will outline the judging process highlighting what judges look for in a student paper to provide insight for student teams and advisors. Our goal is to make it even more difficult for the judges to identify the papers awarded "Finalist." (Received September 25, 2018)

1145-G1-2658 **Patrice G Tiffany*** (patrice.tiffany@manhattan.edu) and **Emma Regenauer** (eregenauer01@manhattan.edu). *Modeling Competitions: Perspectives of Student and Faculty.*

Our school took part in the inaugural SCUDEM competition in the fall semester of 2017. Since then we had a team compete in the second competition in spring of 2018. This paper reports on the experiences of host, coach and student participants. The presentation will be given by a faculty member who hosted and coached and by a student who took part in both competitions. The student will speak on the competition from the student perspective. We will share mistakes made, suggestions for future contests, stories of how we responded to the modeling challenges and our particular successes in the events. (Received September 25, 2018)

1145-G1-2866 **Csilla Szabo***, 815 N Broadway, Saratoga Springs, NY 12866, and **Lucy Spardy Oremland**. *A 2-Credit Course Series for Applied Problem Solving and MCM/ICM Preparation.* Preliminary report.

In this talk we present the development, implementation, and reflections of a series of 1-credit applied problem solving courses for undergraduates at a liberal arts institution. The goal of these courses was to prepare students for the Mathematical Contest in Modeling (MCM) and Interdisciplinary Contest in Modeling (ICM). In Part I of the course series, we simulated the contest experience over a 15-week semester. During the course, we outlined general problem solving strategies as teams of 2-3 students worked through past contest problems. We provided feedback and guidance at each step of the modeling process, but the students were ultimately responsible for all modeling choices. As in the contest, students wrote a 20-page report detailing their problem solutions for the course. The teams were also required to present their work in presentations to the class in order to enhance their mathematical communication skills. In the follow-on course, students participated in the actual contest and then shared their problem solutions at a local conference or on campus at Skidmore's Academic Festival. In this talk, we will provide details of the course structure and share student feedback, positive outcomes (including a winning team!), and plans for future iterations of the course. (Received September 25, 2018)

1145-G1-2878 **Benjamin Galluzzo*** (bgalluzz@clarkson.edu), Institute for STEM Education, Clarkson University, 8 Clarkson Avenue, Potsdam, NY 13699, and **Karen M Bliss** (blisskm@vmi.edu), Virginia Military Institute, 404 Mallory Hall, Lexington, VA 24450. *The 24-hour Mathematical Modeling Challenge.*

In this talk, we describe the 24-hour Mathematical Modeling Challenge (24MMC), an extracurricular mathematical modeling event that exposes undergraduate students to mathematics as it can be applied to real-world problem solving over the course of a weekend. We give an outline of the rules, structure, and outcomes from over ten years of 24MMCs, with particular focus on how one might adopt this contest for use at their institution. (Received September 25, 2018)

Mathematics and the Life Sciences: Initiatives, Programs, Curricula

1145-G5-352 **Majid Masso*** (mmasso@gmu.edu), 8068 Stonewall Brigade Ct. #201, Manassas, VA 20109. *Active participation in current faculty research inspires student achievement.* Preliminary report.

Recent years have seen an explosion of cutting-edge published research in the field of quantitative biology, work often leading to practical wet-lab and clinical applications. This backdrop serves to powerfully motivate students. For the past 11 summers, George Mason University has hosted an intensive 8-week Aspiring Students Summer Internship Program (ASSIP) for high-school students to participate in ongoing research projects with participating STEM faculty. Admission is highly competitive ($< 9\%$), and most projects yield publications in top journals, presentations at conferences, and patented products. In our department, mentored students receive training in computational mutagenesis of protein structure, cross-disciplinary work incorporating aspects of biology, biophysics, computational geometry, discrete math, statistics, programming, and AI. With an understanding of the consequential nature of the research, our students eagerly welcome this steep initial learning curve. Data generated are subsequently used for training machine learning models to predict potential impacts of protein mutations on stability, activity, drug resistance, or human disease. Students eagerly embrace the opportunity to showcase and communicate their discoveries at a final poster symposium. (Received September 03, 2018)

1145-G5-1152 **Jessica Oehrlein*** (jessica.oehrlein@columbia.edu). *Introducing Mathematical Modeling to High School Students through Population Dynamics.*

In 2018 I taught several instances of a one-hour population modeling class for advanced high school students. The main goal of the course was to introduce students to modeling processes and techniques in a life science context. In the class, students worked in groups to develop and interpret discrete and continuous models of population growth, predator-prey interactions, and competition. The course also included brief discussions of other modeling approaches and challenges. I will give a survey of the class and discuss what went well, what didn't, and what I plan to change in future iterations. (Received September 19, 2018)

1145-G5-1393 **Filippo Posta*** (filippo.posta@estrellamountain.edu), Phoenix, AZ , and **Galyna Kufryk**. *Integrating mathematics and microbiology: a case study to improve learning outcomes and foster faculty collaboration.*

Math remediation in STEM courses has profound effects on learning outcomes and student retention in STEM secondary education. These effects are amplified in institutions with a diverse student population and serving metropolitan areas. We created and integrated an asynchronous, just-in-time-remediation model that relies on cross-disciplinary institutional collaborations grounded in the principles of Scholarship of Teaching and Learning (SOTL). In this presentation, we will discuss the specific aim of integrating remediation of exponential and logarithm concepts in a microbiology course. Discuss our results that show a statistically meaningful improvement of learning outcomes when compared to learners who did not use the remediation module. We will also discuss student's attitudes toward this effort and highlight some recurring themes. Our findings suggest that instructor driven asynchronous remediation can be effective, scalable and inexpensive. We will discuss best practices for implementation, collaboration and fostering of a SOTL culture through the creation of just-in time remediation modules. (Received September 21, 2018)

1145-G5-1620 **Timothy D Comar*** (tcomar@ben.edu), Department of Mathematics, Be, 5700 College RD, Lisle, IL 60532. *Undergraduate Research in Mathematical Biology Using Impulsive Models.*

We present an avenue for undergraduate research in mathematical biology using impulsive differential equations. Impulsive differential equations provides a structure in which certain events occur at discrete instances in time. Often, these instances can be periodic. We show examples of student projects modeling integrated pest management systems and epidemic models with period vaccination strategies. We also show how students can be prepared with the basic mathematics, the ability to do basic programming, and the ability to read journal articles needed to pursue this research through either a second semester biocalculus or a differential equations course. (Received September 23, 2018)

1145-G5-1635 **Yanping Ma*** (yma@lmu.edu), 1 LMU Dr., University Hall STE 2700, Los Angeles, CA , and **Curtis Bennett** (curtis.bennett@csulb.edu). *Incorporating relevant life science projects into Calculus class: Michaelis - Menten Kinetics and more.*

To help the students understand the importance of Math, we designed several biology and chemistry related projects for our Calculus I for Life Science class. The problems include the derivation of the Michaelis - Menten Kinetics with actual experimental data, the analysis of the Mean Arterial Pressure, the use of Shock Index and Modified Shock index in triage measures, and more. In the talk, we will share some of these projects, and report on our findings from students' comments on the Michaelis-Menten Kinetics project. (Received September 23, 2018)

1145-G5-2033 **Meghan M. De Witt*** (mdewitt@stac.edu), Sparkill, NY. *X-Lab: interdisciplinary research combining math, biology, computer science, and business.*

We describe the inaugural year of X-Lab, an interdisciplinary undergraduate research group in the scrum style. This first year of the program investigated human's effect on climate change and the extreme weather that can result from this. The project combined the work of biology students (who provided the subject matter expertise), math students (who performed the mathematical modeling and prediction), marketing students (who helped steer the project to a final format), and computer science students (who created a virtual reality experience that allows the user to submit data that will be used as part of the research). The success of this year's endeavor will lead to future projects in many disciplines and steer the college towards a more project based model of student learning. (Received September 24, 2018)

1145-G5-2174 **Andrew M. Baxter** (amb69@psu.edu), **Eric Simring**, **Amine Benkiran** and **Andrew Belmonte*** (Andrew.Belmonte@gmail.com). *Better Calculus through Biology: The Biocalculus Sequence at Penn State University.* Preliminary report.

The first-year biocalculus sequence at Penn State University (University Park) teaches over 600 life-science majors each semester, and is poised for a major expansion to smaller Penn State campuses in the next three years. We have witnessed dramatic improvements in student achievement without compromising mathematical rigor or scalability. Curriculum changes enable meaningful discussions of matrix algebra, Markov chains, and systems of linear differential equations in the first year. Student-centered pedagogical methods build quantitative literacy instead of mere procedure-execution. Through this first-year experience life-science majors, who were often written off as not mathematically-minded, now consider a minor in Mathematics. Furthermore, the success of this sequence has resulted in the development of a third-semester expansion of the sequence as well as a new Mathematical Biology option for math majors at Penn State.

This is joint work with Amine Benkiran, Eric Simring, and Andrew Belmonte. (Received September 24, 2018)

1145-G5-2392 **Melissa A Stoner*** (mastoner@salisbury.edu), 1101 Camden Ave, Salisbury University, Salisbury, MD 21801. *Building Relevance and Connection: Using Medical Simulation to Enhance Students' Connections between Calculus and Biology.* Preliminary report.

Building connections between the mathematical concepts we want students to learn and their usefulness in the world around them enhances student mastery of concepts and increased student perception of mathematics. In our Calculus I for Biology and Medicine course, we do this by having students use calculus to model various properties of a set of lungs being mechanically ventilated, mainly the volume, flow, and pressure of air in the lungs. We then attach a mechanical ventilator to a test lung in our medical simulation center on campus. Students are able to compare their mathematical models to the data being generated by the test lung and discuss similarities, differences, and how assumptions made in modeling account for those differences. Data collection and results focus on students' perception of mathematics to the real world, and the impact on their outlook towards mathematics. We also mention development of additional student projects that can be simulated including arterial blood flow. (Received September 25, 2018)

1145-G5-2579 **Hannah Highlander*** (highland@up.edu) and **Olcay Akman** (oakman@ilstu.edu). *A model for cross-institutional collaboration: how the intercollegiate biomathematics alliance (IBA) is pioneering a new paradigm in response to diminishing resources in academia.*

We present an emerging model of shared academic, intellectual and infrastructure resources that addresses the need for institutions to sustain their educational and scholarship missions under ever-declining funding. The IBA was created in 2014 in Illinois, eventually growing to a state-recognized 'Center for Collaborative Studies' in 2017. As the impact of the IBA continues to expand, it is on its way to become a new education paradigm in response to diminishing resources, and it can serve as a model to foster collaboration for other fields of mathematics. Here we will share the benefits of being a part of this academic consortium. (Received September 25, 2018)

1145-G5-2845 **Raina S. Robeva*** (robeva@sbc.edu), Department of Mathematical Sciences, Sweet Briar College, 134 Chapel Road, Sweet Briar, VA 24595. *Algebraic mathematical biology for undergraduate studies and research in the life sciences.*

In the past few years, advances in mathematical biology have validated the power of algebraic and combinatorial methods to answer questions from a wide range of topics in modern biology related to neuroscience, molecular networks, phylogenetic, and the assembly, folding, and classification of biomolecular structures, to mention a few. Those methods however have not yet percolated down to the undergraduate level, even though many of them require only background that is fully accessible to advanced undergraduates. So what is causing the disconnect? The talk will examine this question and focus on recently published resources that could be used to bridge the existing gap. (Received September 25, 2018)

Formative and Summative Assessment of Mathematical Communication and Conceptual Understanding

1145-H1-691 **Malcah Effron*** (meffron@mit.edu), MIT, E18-228K, 77 Massachusetts Avenue, Cambridge, MA 02139. *Term Paper Two Ways: Assessing Communication and Comprehension with Multiple Audiences.*

The communication intensive courses in the majors at MIT are designed with two primary learning outcomes: students' ability to communicate mathematics and demonstrate conceptual understanding of the course topics. The final term paper assignment for 18.100P Real Analysis thus formatively and summatively assesses students' abilities to communicate both to mathematicians and to lay audiences. In a project scaffolded with activities and drafts, students select a problem and then write up their understanding of its solution in two ways: first, as a math article with formal proof and second, in a genre appropriate to a non-mathematics audience (e.g. computer documentation, high school classroom activity, or pop science magazine article). In writing the same mathematical content for two audiences of different backgrounds and reading goals, the students grapple with their full understanding of the analysis content as well as their ability to communicate the content. This paper illustrates how a "term paper two ways" allows the students to demonstrate and the instructors to assess, formatively and summatively, students' command of the subject and their ability to communicate it effectively. (Received September 12, 2018)

1145-H1-766 **Lisa O Coulter*** (lcoulter@steson.edu) and **William W Miles**. *Results from Assessment of Mathematics Majors at Stetson University involving Mathematical Communication and Conceptual Understanding.* Preliminary report.

The Department of Mathematics and Computer Science at Stetson University hosts majors in both Mathematics and Applied Mathematics. We have had an assessment program in place since 2010 for students in Mathematics; in the last year we have added program level outcomes (PLO's) for Applied Math as well. Among PLO's which relate to mathematical communication are the expectation that students can both write and give presentations regarding mathematical concepts. Conceptual understanding is assessed via students' abilities to solve complex problems and, at the formative stage, to use subject specific terminology and notation. Results from assessments of these areas will be presented and discussed, along with curricular changes that have been implemented in order to address issues that have been discovered. The math program at Stetson University requires all seniors to produce a research product in the last year of study. One of the curricular modifications that has been implemented consists of a structured submission/review/re-submission procedure designed to improve writing skills in the discipline. This also allows the senior project course to count as one of the required writing-enhanced courses at the university. Early results from this new curriculum will be presented. (Received September 14, 2018)

1145-H1-954 **Whitney George*** (wgeorge@uwlax.edu). *Student Applications of Logic to Everyday Life.* Preliminary report.

Logic is a topic often covered in liberal arts general education courses. Students will learn about truth tables with the ultimate goal of understanding when an argument is valid or invalid. It is natural to ask if students can take these formal ideas and apply them to everyday life. In this talk, we will see how the author used student feedback, group projects, and discussions to measure the effectiveness of different course designs, focusing on logic and its applications to everyday life. (Received September 17, 2018)

1145-H1-1116 **Jason R Elsinger***, jelsinger@flsouthern.edu. *Using mastery-based assessment in lower level mathematics courses.* Preliminary report.

In order to learn science and mathematics with a deep understanding, one needs to work problems and ask questions while receiving consistent feedback. We desire our students to experience this practice-feedback loop to improve their abilities and confidence. However, grading schemes which use a weighted average of numerical scores assigned to assessments have several features that are antithetical to this learning cycle.

Standards based grading is an innovative grading scheme which is based on a student's mastery of course learning outcomes or standards. Final grades are determined by the instructor's choice of specifications for each letter grade. One key feature is that students can initiate re-assessment opportunities which can replace earlier marks. In this talk, I will describe the standards based grading framework and how I have adopted it to several mathematics courses including statistics, linear algebra, and differential equations. I will also describe the many benefits observed, and efficient ways to implement the scheme including keeping a grade book and how to set up office hour re-assessments. (Received September 19, 2018)

1145-H1-1174 **Beste Gucler*** (bgucler@umassd.edu), University of Massachusetts Dartmouth, 285 Old Westport Rd (LARTS 396C), North Dartmouth, MA 02747. *A discursive approach to teaching introductory calculus to foster students' mathematical communication and assessment of conceptual understanding in university mathematics.*

This session will be based on issues around formative and summative assessment as well as assessments that promote student communication and conceptual understanding in relation to the MAA Instructional Practices (IP) guidelines on assessment. I will present a completed research report on a teaching experiment I designed that used a communicational (discursive) approach to teaching introductory calculus to foster student learning and mathematical communication in university mathematics education. I will talk about the features shaping the design of the course and how the design supported the assessment of student communication and conceptual understanding of calculus concepts through summative assessments as well as formative assessment strategies incorporated into every classroom session. I will share those strategies with the audience and bring sample tasks I developed and used during the study to engage mathematics educators and researchers in an active discussion about the affordances of using such tasks and strategies for the assessment of students' mathematical communication and conceptual understanding of fundamental calculus ideas. (Received September 19, 2018)

1145-H1-1392 **Christina Therkelsen** (christina.therkelsen@uc.edu), University of Cincinnati, Department of Mathematical Sciences, PO Box 210025, Cincinnati, OH 45244, and **Susan Gregson*** (gregsosn@ucmail.uc.edu). *Going Gradeless: Strategies for Promoting Conceptual Understanding in Pre-Service Teachers.* Preliminary report.

We are the instructors of two courses for the same group of undergraduate prospective middle school teachers: a course in mathematics content and a course in mathematics teaching methods. Our goal is to shift students' focus from grades towards conceptual understanding of the course learning goals. Together we developed an alternative approach to assessment for these students in which we do not give numerical or letter grades on assignments. In this talk we will share more on the research that supports this approach and our implementation of these techniques including the involvement of students in making decisions about this assessment framework. (Received September 21, 2018)

1145-H1-1433 **Cristina Runnalls*** (ccrunnalls@cpp.edu). *A Formative Assessment of Formative Assessment: Exit Slips Over the Years.*

Over the past several years teaching mathematics, I have used exit slips faithfully as a way of assessing students' understanding of a new topic, suggesting direction for the next session, and tracking individual student growth. While I have always found exit slips informative, the ways in which I design and use them has changed. In turn, the success with their use and the information they provide has changed as well. In this talk, I will describe how my exit slip questions have transformed to focus more on the conceptual (and less on the procedural), especially through the use of student writing, feedback loops with past slips, and follow-up discussions. Ways to design more challenging but manageable exit slips, as well as the ways student solutions may be leveraged for future instruction, are discussed as well. (Received September 21, 2018)

1145-H1-1765 **Monica VanDieren*** (vandieren@rmu.edu) and **Deborah Moore-Russo**. *Using Mindmaps to Uncover Conceptual Understanding of Vectors.*

We investigate students' communicated understanding of vectors by examining how their mindmaps change over time in a multivariable calculus class. A mindmap is a visual network of connected and related concepts typically with one image or topic centrally located. Mindmaps can be used both as formative and summative tools of assessment. Through this open-ended instrument, we conduct a qualitative analysis to explore the connections students make between different aspects and multiple representations of vectors. While mindmaps may not perfectly represent student understanding, they provide insight to a student's thoughts. Knowledge about the connections and representations that students communicate can inform pedagogical practices and the development of digital environments to help students coordinate their ideas and representations into a connected, coherent understanding of topics. (Received September 24, 2018)

1145-H1-2115 **Larissa B. Schroeder*** (schroeder@hartford.edu), 200 Bloomfield Ave, West Hartford, CT 06117. *Writing Prompts as Formative Assessment in Calculus II.* Preliminary report.

One learning goal in Calculus II is for students to improve their ability to communicate mathematically. To achieve this goal, oral and written communication are emphasized throughout the course. In particular, writing assignments are used as a means of formative assessment. During the first half of the semester, students complete 6 writing assignments where they compose a formal written solution to a problem or series of related problems focused on an aspect of Calculus II that is typically confusing or difficult. Students receive written feedback from the instructor addressing writing style as well as their mathematical understanding. In this talk, I will provide examples of the writing prompts, the writing rubric developed for these assignments, and take a more in depth look at case studies of students' writing. Finally, I will discuss the results of pre- and post- survey of students' perceptions of their confidence in their oral and written mathematical communication using items adapted from the Student Assessment of Learning Gains (SALG) instrument. (Received September 24, 2018)

1145-H1-2266 **Kayla K. Blyman** (kayla.blyman@usma.edu) and **Marie Meyer*** (mmeyer2@lewisu.edu), One University Parkway, Department of Computer and, Mathematical Sciences #298, Romeoville, IL 60446. *Gaming Formative Assessment: Telestrations in the Mathematics Classroom.*

When students understand a mathematical concept, they are able to represent and communicate it in multiple ways. Learning to transition back and forth between those representations develops mathematical fluency. Telestrations is a game which involves communicating an idea in multiple ways, making it a perfect tool for developing and assessing students' conceptual knowledge as well as their communication skills. Over the course of several semesters we have used this game as a method of reinforcing mathematics concepts in courses such as Pre-Calculus level Mathematical Modelling, Linear Algebra, Mathematics for Preservice Elementary School Teachers, and College Algebra. It has always been an effective teaching tool and at times even seems to be tricking students into learning because they are having so much fun playing the game. By watching how much students struggle at different steps throughout the game and looking through the game decks after students are done, we gain a great understanding of the strengths and weaknesses in our students' conceptual understanding of the current topic and communication skills related to that topic. (Received September 25, 2018)

1145-H1-2430 **Emma Smith Zbarsky*** (smithzbarskye@wit.edu), Department of Applied Mathematics, 550 Huntington Ave, Boston, MA 02115. *Developing Mathematics Professionals.* Preliminary report.

I teach an upper level undergraduate course for applied mathematics majors and minors in partial differential equations. For the past two years I have taught the course with a fully mastery-based grading format including extensive use of writing and oral examinations. I will discuss the successes and failures of the past two years in working on developing my students' skills for future careers, as well as their competencies in the area of partial differential equations, and how I plan to incorporate the lessons I've learning into my other courses. (Received September 25, 2018)

1145-H1-2476 **Jonathan E Beagley*** (jon.beagley@valpo.edu), 1900 Chapel Drive, Department of Mathematics and Statistics, Valparaiso, IN 46383, and **Mindy Capaldi** (mindy.capaldi@valpo.edu), 1900 Chapel Drive, Department of Mathematics and Statistics, Valparaiso, IN 46383. *Cumulative Assignments.*

We discuss two studies using cumulative assignments in college mathematics courses. The first study using cumulative exam problems on midterm exams to see how this influences final exam scores. The second study using cumulative homework problems. Additionally, students were split into the categories of low-scorers and high-scorers based on their first test score, prior to the intervention. Low-scoring students saw more benefits than the high-scoring students. (Received September 25, 2018)

1145-H1-2496 **Girija Sarada Nair-Hart*** (nairhaga@uc.edu), 4200, Clermont College Drive, Batavia, OH 45103. *Exploration of Precalculus Concepts using Project-based Assessment Techniques.*

Project-based learning and assessment practices in mathematics classrooms facilitate increased conceptual understanding and support transfer-ability of knowledge into real life situations (Boaler, 1998; Boaler & Selling, 2017). Exponential functions have many real life applications, some of them are especially relevant to the growth and decay phenomena in everyday life. While solving a typical textbook problem with multiple parts on the application of these functions students often perform the computational parts that summons procedure knowledge easily. However, many students seem unable to answer the parts of the problem that require explanation of the answers in a meaningful manner. During this presentation I will discuss how assessment on exponential modeling using hands-on data exploration resulted in more fluent communication of the concept within the problem context and beyond in Precalculus students. (Received September 25, 2018)

1145-H1-2766 **Amit A Savkar*** (amit.savkar@uconn.edu), 341 Mansfield Road, Department of Mathematics, Storrs, CT 06269, and **Briana Hennessy**. *A psychometric approach to transitioning assessments from the open response to multiple choice in differential and integral calculus.* Preliminary report.

The need to efficiently and fairly grade midterm and final exams for differential and integral calculus has always been the focal point of discussions in various mathematics departments. When designing tests, faculty need to balance easy-to-grade multiple choice questions and open response formats which provide more information about student understanding. Open response questions also take time to grade and can have significant inter-rater reliability issues. Over the last three semesters, a project to understand how much information on students' understanding is lost in converting the open response questions to multiple choice question has been undertaken at the department of mathematics at University of Connecticut. We will present the design of this experiment, preliminary results that compare the performance of students on these questions and analysis for classifying students using both forms of exams. (Received September 25, 2018)

1145-H1-2853 **Jessie A Hamm*** (hammj@winthrop.edu), Rock Hill, SC 29732. *Formative and Summative Assessments in an Intro to Proof course.*

In this talk I will describe several types of formative assessments given in my Intro to Proofs course throughout the semester. These assessments include two types of written homeworks, oral presentations, and tests. I will also describe a summative assessment I have just used for the first time, a proof portfolio, along with pros and cons of this assessment tool. (Received September 25, 2018)

1145-H1-2872 **Amanda J Mangum*** (amangum@niagara.edu). *Pre-Planning and Modifications for Implementing Mastery Based Testing in Calculus.*

Mastery Based Testing (MBT) is a testing method designed to promote full learning while reinforcing important material in a way that allows students multiple opportunities to receive full credit. To place the emphasis on fully learning the course material, I have made several specific adaptations to the standard method for a Calculus I course to better serve my students. For example, I adapted my office hours to accommodate more retake opportunities, required effort between in-class testing periods, and facilitated the process of making connections between course material by providing a table relating the various concepts. The past two semesters I have taught the course, I have also experimented with allowing students to choose their testing method. The rationale and implementation of these adaptations will be discussed and recommendations for introducing MBT for introductory level courses will be given. (Received September 25, 2018)

1145-H1-2973 **Phillip Andreae*** (pvandreae@meredith.edu). *Assessment and transparency in a partially flipped intro to proofs classroom.* Preliminary report.

I have twice taught an introduction to proofs course in which students first encounter course content in pre-class reading assignments and spend the majority of class time on collaborative proof-writing activities. I will describe the design of the course and the changes I made to it based on student feedback and my own observations. The most significant changes were in assessment, including a redesign of the in-class activities and their assessment to provide more formative assessment opportunities and early feedback. I also attempted to make more transparent the course goals and my expectations of student behavior and student work. I will share quantitative and qualitative data from student course evaluations and departmental evaluation of student work. (Received September 25, 2018)

Integrated STEM Instruction in Undergraduate Mathematics

1145-H5-1288 **Jacob Duncan***, 751 E. Howard St, Winona, MN 55987. *Mathematics for Sustainability.*
Some of the biggest challenges facing humanity today stem from issues surrounding environmental degradation and social injustice, and the need to address the ramifications of these issues from a STEM perspective is greater than ever. This talk centers around the course Mathematics for Sustainability I recently developed at St. Mary's College, Notre Dame and currently teach at Winona State University. This course develops and applies mathematical concepts and tools to quantitatively explore real-world, topical problems pertaining to environmental and social sustainability. Topics are motivated by exciting hands-on experiences – experiments, demonstrations, outdoor data collection excursions – from relevant STEM fields. (Received September 20, 2018)

1145-H5-1411 **Ryan Nivens*** (nivens@etsu.edu), East Tennessee State University, Department of Curriculum and Instruction, Box 70684, Johnson City,, TN 37614-1709, **Ariel Cintron-Arias** (cintronarias@etsu.edu), East Tennessee State University, Department of Mathematics and Statistics, Box 70663, Johnson City, TN 37614-0663, and **Calvin B Purvis**, East Tennessee State University, University Career Services, Box 70718, Johnson City, TN 37614. *Capacity Building in STEM Careers with Emphasis on Mathematical Modeling.* Preliminary report.
Mathematicians have traditionally been a select group of academics that produce high-impact ideas allowing substantial results in several fields of science. Throughout the past 100 years, undergraduates enrolling in mathematics or statistics have represented a nearly constant rate of approximately 1% of bachelor degrees awarded in the United States. Even within STEM majors, mathematics or statistics only constitute about 4% of degrees awarded nationally. However, the need for STEM professionals continues to grow and the list of needed occupational skills rests heavily in foundational concepts of mathematical modeling curricula, where the interplay of measurements, computer simulation and underlying theoretical frameworks takes center stage. We cannot expect a majority of these undergraduates to pursue a double-major that includes mathematics. Similarly, we cannot assume that the number of degrees in mathematics will increase, or that those with such a mathematics degree would be capable of professional work in a STEM field that they have not studied. Given that increasing double-majors with mathematics is not viable, we present our solution, some early results of implementation, and a plan for nationwide adoption. (Received September 21, 2018)

1145-H5-2386 **Patricia Vela*** (pvela@agnesscott.edu). *Making the "M" in STEM salient through a robotics activity.*
Why do some students stare at a problem hopelessly while other students have fun with that same problem? George Polya proposed that experienced problem solvers employed heuristics to stimulate their mathematical thinking processes. That is, although experienced problem solvers might not know initially how to solve a problem, heuristics enable them to engage with the problem. Similarly, Papert (1980) reported observing problem solvers engaged with Turtle Geometry, an animal-like robot, using heuristics identified by Polya when attempting to solve problems – even though they were not taught or asked to use Polya's heuristics. In this talk, I will discuss whether students indeed resort to Polya's identified heuristics when engaged with a robotics-based task which requires the use of concepts from Algebra 2, Trigonometry, and Pre-Calculus. Furthermore, I will present student's affective reactions to mathematics in this technological setting. (Received September 25, 2018)

1145-H5-2512 **Jody Sorensen*** (sorensj1@augsburg.edu). *A Renovated Calculus Class: Active and Applied.*
Augsburg University is part of the SUMMIT-P (Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships) NSF IUSE grant, for which we are renovating our Calculus sequence in collaboration with partner disciplines to better suit the needs of our students. Our calculus courses include students from all majors, including the STEM disciplines of Biology, Chemistry, Computer Science, Mathematics, and Physics. The changes enacted in Calculus I in Fall 2018 include:

- the mathematical content: more differential equations, some multivariable ideas, less on limits
- the pedagogy: a structure that embraces two types of active learning in class every day
- applications: every day includes a minimum of one problem done in an applied context, including STEM disciplines and Business/Economics

As an example of the changes we've made I'll discuss a typical day of class which begins with an activity discussing derivatives in contexts from both Biology/Medicine and Physics. (Received September 25, 2018)

1145-H5-2537 **Enes Akbuga*** (akbuga@umich.edu), School of Education, University of Michigan, 610 East University Ave. #2400, Ann Arbor, MI 48109. *Motivation intervention through calculus tasks with science and engineering applications.*

Calculus students often ask: "why are we learning this?" If students are not given the opportunity to see this connection, they might become disengaged and unmotivated (Harackiewicz, Tibbetts, Canning, & Hyde, 2014). This study was based on Expectancy-value model (Eccles et al. 1983) that include utility-value as an essential component. The aim of this study is to examine the impact of an interdisciplinary approach to student motivational aspects: utility-value, interest, and performance expectations. Participants were enrolled in an introductory calculus course and approximately 81 students (from six sections) were involved. The study followed a quasi-experimental research design. The intervention sections were given the application tasks twice during the semester. The intervention was comprised of three calculus tasks with applications to science, technology, and engineering disciplines. However, the data only came from a survey (twelve Likert items). The results showed that the intervention wasn't significant on student motivation. However, a unique aspect of this study was the idea of implementing applied calculus tasks that were explicitly developed by potential future instructors of students in computer science, physics, and engineering fields. (Received September 25, 2018)

1145-H5-2589 **John H Wilson*** (john.wilson@centre.edu), 600 W. Walnut St, Danville, KY 40422, and **Sarah Murray** (sarah.murray@centre.edu). *Incorporating Science Modules into a Basic Skills Math Course.*

This presentation will describe modifications made to an introductory math course for students who did not meet our basic skills mathematics requirement before entering Centre College. Successful completion of this course is a graduation requirement and a prerequisite before students may enroll in any science course at the college. Several lectures in the course are now dedicated to presenting material from the introductory biology and chemistry courses. An example from population genetics will be described in the talk. Evidence for changes in student attitude towards STEM subjects will be given based on end of course evaluations. (Received September 25, 2018)

1145-H5-2783 **Theresa A. Jorgensen*** (jorgensen@uta.edu), **W. Ashley Griffith**, **Elizabeth M. Griffith**, **Rebekah Aududdell**, **Christopher Conwell** and **Ji-Eun Kim**. *iGEM^2: Integrating geoscience contexts into first year mathematics courses – creating new pathways to success.*

Math courses leading to Calculus are a major obstruction to success for alarming numbers of STEM-intended majors. Our project goals are to (1) improve success of intended STEM majors in mathematics courses that lead to Calculus and (2) introduce first year students to the geosciences, increasing the number and diversity of students who choose a geoscience major. We are modifying the curriculum of College Algebra by integrating the geoscience research of our faculty. Weekly lab meetings in College Algebra incorporate a video presentation by geoscience faculty describing how the mathematical skill the students are learning is essential for his/her scientific research. Student exercises are being cast in the context of that research, followed by problem-solving activities that synthesize and apply mathematical concepts with problems related to geoscience content. Pre- and post-course surveys assess student interest and self-efficacy in science and math as well as career perceptions of geoscience and related sciences. We present baseline survey data and initial results of a pilot study in which we recast exercises on logarithmic and exponential functions in the context of atmospheric carbon dioxide concentrations and ocean acidification. (Received September 25, 2018)

1145-H5-2874 **Jeneva Clark*** (dr.jenevaclark@utk.edu). *Learning How Our World Works: STEM Activities in a Mathematical Reasoning Course.* Preliminary report.

For a Mathematical Reasoning course re-design, I created activities motivated by science and engineering. Students found the radius of a golf ball using water displacement. They found the indices of refraction for jello, water, and oil. The eclipse and the Hubble telescope were used for problem solving tasks. Students used Newton's Laws of Motion and the continuity principle to design PVC Marshmallow shooters. Photos of autopsied cochlea were examined by students to investigate Golden Ratio patterns, and students engineered their own hearing aids from recycled materials such as party-hats and paper cups. For this general-education course for non-STEM majors, students' majors are often political science, sociology, speech pathology, and the arts. STEM-related anchor problems provided a shared relevance for this student population, relating mathematics to how our world works. In this session, the activities will be briefly shared, and course evaluation results that pertain to the STEM-mification of this course will be shared. (Received September 25, 2018)

1145-H5-2917 **Candice M. Quinn** (cmq2b@mtmail.mtsu.edu), **Joshua Reid*** (jwr4k@mtmail.mtsu.edu), **Jeremy Strayer** (jeremy.strayer@mtsu.eduj) and **Grant Gardner** (grant.gardner@mtsu.edu). *Exploring Integration through a BioCalculus Task: Implications for STEM Education.*

In this session we present a task implemented in Calculus I for STEM majors that integrates the biological concept of variation with exponential functions. The context of the task is regarding students' personal amount of caffeine they consume each day and the rate of decay of caffeine in their system depending on different CYP1A2 gene variants. Sample student work and instructor feedback will show how the instructor was able to analyze students understanding of how mathematics can be applied to and help them understand biological concepts. The insights gained from teaching with this activity highlight the need for the field to better understand what is an integrated STEM curriculum. Because STEM is still loosely defined (NSB, 2015), we note that a consensus view of STEM through the integrated lens of each discipline is needed. Do STEM domains have integrated epistemological characteristics or do they tend to be combined in less integrated ways? We end with a discussion of a theoretical model of the integrated nature of STEM that we propose, which was built from a broad literature review. In particular, we discuss how this model should be used to inform how we develop integrated or interdisciplinary STEM tasks for first-year and/or second-year mathematics courses. (Received September 25, 2018)

The EDGE (Enhancing Diversity in Graduate Education) program: Pure and Applied talks by Women Math Warriors

1145-I1-229 **Biji Wong*** (biji.wong@cirget.ca), Office PK-5211, President Kennedy Pavilion, 201 President Kennedy Avenue, Montreal, Quebec H2X 3Y7, Canada. *A Floer homology invariant for 3-orbifolds via bordered Floer theory.*

Using bordered Floer theory, we construct an invariant $\widehat{HF}^{\text{orb}}(Y^{\text{orb}})$ for 3-orbifolds Y^{orb} with singular set a knot that generalizes the hat flavor $\widehat{HF}(Y)$ of Heegaard Floer homology for closed 3-manifolds Y. We show that for a large class of 3-orbifolds $\widehat{HF}^{\text{orb}}$ behaves like $\widehat{HF}$ in that $\widehat{HF}^{\text{orb}}$, together with a relative $\mathbb{Z}_2$-grading, categorifies the order of H_1^{orb}. When Y^{orb} arises as Dehn surgery on an integer-framed knot in S^3, we use the $\{-1, 0, 1\}$-valued knot invariant ε to determine the relationship between $\widehat{HF}^{\text{orb}}(Y^{\text{orb}})$ and $\widehat{HF}(Y)$ of the 3-manifold Y underlying Y^{orb}. (Received August 22, 2018)

1145-I1-667 **Sherilyn Tamagawa***, Department of Mathematics, South Hall, Room 6607, University of California, Santa Barbara, CA 93106. *Welded Knots and the Infinitesimal Alexander Module.* Preliminary report.

The Infinitesimal Alexander Module (IAM) is a module over the integers which is a welded knot diagram invariant. In this talk, I will describe knots, their generalization to welded knots, and the IAM. I will also show that the IAM is a welded knot invariant. (Received September 12, 2018)

1145-I1-774 **Susan D'Agostino***, sdagost2 (at) jhu (dot) edu, and **Sarah Bryant**, **Amy Buchmann**, **Michelle Guinn** and **Leona Harris**. *A Roundtable with the EDGE Book Editors – Part 1: How to Write a Successful Mathematics Book Proposal.*

Are you a mathematician who has considered editing or writing an academic or popular mathematics book? Are you interested in getting a contract before writing or editing your book? Do you know and understand the features of a winning book proposal? Are you wondering whether you should submit your book proposal directly to an acquisitions editor at a publisher or to a literary agent? (Spoiler: The answer may depend on the kind of mathematics book you intend to write.) In Part 1 of this two-part presentation, the editors of A Celebration of the EDGE Program's Impact on the Mathematics Community and Beyond (due out from Springer in 2019) will share their experiences that led to a successful contract for their edited volume. In the process, they will provide an overview of important book proposal components, including the author platform and the book's "30-second sell," market, vision, competition, production basics, and more. Be sure to attend Parts 1 and 2 for the most comprehensive understanding of what it takes to write or edit a mathematics book. (Received September 14, 2018)

1145-I1-775 **Susan D'Agostino***, sdagost2 -at- jhu (dot) edu, and **Sarah Bryant**, **Amy Buchmann**, **Michelle Guinn** and **Leona Harris**. *A Roundtable with the EDGE Book Editors, Part 2: How to Proceed After Your Successful Book Proposal Earns a Book Contract.*

Congratulations, your proposal to write or edit an academic or popular mathematics book has been accepted by an academic or trade publisher! You have an editor, publisher, book contract, and final deadline. Do you understand the work involved in what comes next? Are you interested in hearing helpful tips and lessons learned by writers and editors who have been in the trenches? In Part 2 of this two-part presentation, the editors of A Celebration of the EDGE Program's Impact on the Mathematics Community and Beyond (due out from Springer in 2019) will share their post-book contract experiences engaging with authors and their publisher. Along the way, you will gain a sneak preview of the book's first-person essays, pedagogical studies, and current mathematics research papers—all written by EDGE community members—that back up the American Mathematical Society's claim that EDGE is a "Program that Makes a Difference." Come prepared to learn about practical steps, to hear stories from the front lines of mathematics book publishing, and to ask questions that may help guide your own book publishing journey. Be sure to attend Parts 1 and 2 for the most comprehensive understanding of what it takes to write or edit a mathematics book. (Received September 14, 2018)

1145-I1-865 **Lara Ismert*** (lara.ismert@huskers.unl.edu). *Connections between commutators, derivations, and the Heisenberg Commutation Relation.*

In this talk, we consider a weakly-defined derivation on $B(H)$ that is implemented by commutation with an unbounded self-adjoint operator. We show that this derivation has a surprising property, called *kernel stabilization*. Consequently, a certain class of derivations on C^*-algebras, originally studied in a 1975 article by Bratteli and Robinson, also have kernel stabilization. As another interesting corollary, we provide what we believe are new sufficient conditions for when two self-adjoint operators satisfying the Heisenberg Commutation Relation must both be unbounded. (Received September 16, 2018)

1145-I1-1277 **Katharine Ahrens*** (kaahrens@ncsu.edu). *Beyond Cyclotomics: Exploring New Base Rings for Ideal Lattice Cryptography.* Preliminary report.

Hard problems arising from ideal lattices are a leading candidate for implementation in future public key cryptographic schemes due to their conjectured quantum resilience. The majority of post-quantum cryptosystems generate ideal lattices over rings of the form $\mathbb{Z}[x]/\phi_n(x)$ where $\phi_n(x)$ is the nth cyclotomic polynomial. However, the 2014 quantum attack of the ideal lattice-based cryptosystem Soliloquy, which exploits the unit group structure in cyclotomic integer rings, has motivated exploration of alternative polynomials which give rise to rings with less algebraic structure. In this talk, we consider alternative rings, including those of the form $\mathbb{Z}[x]/(x^n - p)$ and $\mathbb{Z}[x]/m_p(x)$ where $m_p(x)$ is the minimal polynomial for $\zeta_p + \bar{\zeta_p}$, ζ_p a primitive pth root of unity. We evaluate the security of these rings both experimentally and algebraically across a variety of a leading candidates for post-quantum cryptographic schemes, including NTRUEncrypt. We compare the resilience of these new rings against state-of-the-art lattice attacks on the shortest vector problem, such as BKZ and hybrid methods, to that of more traditional base rings. Finally, we consider questions of efficiency in implementation and storage costs. (Received September 20, 2018)

1145-I1-2097 **Laurel A Ohm*** (ohmxx039@umn.edu). *Theoretical justification and error analysis for slender body theory.*

Slender body theory facilitates computational simulations of thin fibers immersed in a viscous fluid by approximating each fiber as a one-dimensional curve of point forces. We develop a PDE framework for analyzing the error introduced by approximating a truly three-dimensional object in Stokes flow by a one-dimensional curve. In particular, given a 1D force specified along the fiber centerline, we define a notion of 'true' solution to the full 3D slender body problem and obtain an error estimate for the slender body approximation in terms of the fiber radius. In this talk, we will treat both closed filaments and free endpoints, with attention devoted to the additional difficulties that the free end case presents. (Received September 24, 2018)

1145-I1-2470 **Chassidy Bozeman*** (bozeman1@stolaf.edu). *The tree cover number and positive semidefinite maximum nullity of a graph.*

For a simple graph $G = (V, E)$, let $\mathcal{S}_+(G)$ denote the set of real positive semidefinite matrices $A = (a_{ij})$ such that $a_{ij} \neq 0$ if $\{i, j\} \in E$ and $a_{ij} = 0$ if $\{i, j\} \notin E$. The maximum positive semidefinite nullity of G, denoted $\mathrm{M}_+(G)$, is $\max\{\text{nullity}(A) | A \in \mathcal{S}_+(G)\}$. A tree cover of G is a collection of vertex-disjoint simple trees occurring as induced subgraphs of G that cover all the vertices of G. The tree cover number of G, denoted $T(G)$, is the cardinality of a minimum tree cover. It is known that the tree cover number of a graph and the maximum positive semidefinite nullity of a graph are equal for outerplanar graphs, and it was conjectured in 2011 that $T(G) \leq \mathrm{M}_+(G)$ for all graphs [Barioli et al., Minimum semidefinite rank of outerplanar graphs and the tree cover number, *Elec. J. Lin. Alg.,* 2011]. We show that the conjecture is true for certain graph families. Furthermore, we prove bounds on $T(G)$ to show that if G is a connected outerplanar graph on $n \geq 2$ vertices, then $\mathrm{M}_+(G) = T(G) \leq \lceil \frac{n}{2} \rceil$, and if G is a connected outerplanar graph on $n \geq 6$ vertices with no three or four cycle, then $\mathrm{M}_+(G) = T(G) \leq \frac{n}{3}$. (Received September 25, 2018)

1145-I1-2490 **Miriam Parnes*** (mparnes@wesleyan.edu). *Cops and Robbers: Beyond Graphs.*
There are a number of two player cops and robbers games which can be played on a graph. Seymour and Thomas showed that for one of these games, k cops can catch the robber on a graph G if and only if G has tree width less than k, where tree width is an important measure of the connectedness of a graph. In this talk, I'll introduce an equivalent version of this game for graphs and define the notion of tree width. I will then explain how we can extend both the game and the concept of tree width to other structures (specifically, to the elements of an algebraically trivial Fraïssé class with a particular kind of independence relation). (Received September 25, 2018)

1145-I1-2531 **Stefanie G. Wang***, stefanie.wang@trincoll.edu, and **Jonathan D.H. Smith**. *Free Quasigroup Conjugates and s-peri-Catalan Numbers.*
A quasigroup $(Q, \cdot, /, \backslash)$ is an algebra equipped with three binary nonassociative operations. The symmetric group S_3 naturally acts on the binary operations to yield conjugate quasigroups of a quasigroup $(Q, \cdot, /, \backslash)$. The n-th s-peri-Catalan numbers gives the number of reduced words in a free quasigroup on s generators. This talk will present results that connect the s-peri-Catalan numbers and conjugates of a free quasigroup on s generators. (Received September 25, 2018)

1145-I1-2637 **Catherine Buell**, **Vicky Klima** (carmen.m.wright@jsums.edu), **Jennifer Schaefer**, **Carmen Wright*** (carmen.m.wright@jsums.edu) and **Ellen Ziliak**. *Classifying the H-orbits of the Symmetric Space of $SL_2(\mathbb{F}_q)$ for char$(\mathbb{F}_q) \neq 2$.* Preliminary report.
Symmetric k-varieties were introduced in the late 1980s as generalizations of Riemannian symmetric spaces of Lie groups defined over $\mathbb{R}$ or $\mathbb{C}$ to linear algebraic groups defined over general fields. Recently the study of non-Riemannian symmetric spaces and generalizations of these spaces to other base fields has led to exciting applications in many areas including representation theory and singularity theory.

Let $G = \mathrm{SL}_2(\mathbb{F}_q)$, where q is odd, with involution θ. With the fixed-point group $G^\theta = H$, one can define the generalized symmetric space $Q = G/H$. We will discuss the classification of the orbits of the action of H on Q since these orbits play an important role in understanding the representation theory of the space. (Received September 25, 2018)

1145-I1-2841 **Marisa J Hughes*** (marisa.hughes@jhuapl.edu) and **Elizabeth P Reilly**. *Saving the World with Modeling Integration.* Preliminary report.
When will we run out of power, water, or food? How will population growth and climate change impact these interconnected systems? How do you quantify the impact of a new technology or policy?

To answer these questions, we must consider multiple domains simultaneously such as population, power, water, food, economy, transportation, etc. Experts are generating more and more models and data for each of these domains, but how do we link these products together? In particular, can it be done flexibly enough to easily accommodate new models and data?

We discuss the challenges of this problem and present preliminary results derived from our approach: a modular modeling framework called SIMoN (System Integration using Multiscale Networks). SIMoN combines mathematical and software tools to address the issue of data/models arriving at multiple levels of granularity, particularly in geography and time. These levels of granularity are captured by posets which must be navigated carefully. SIMoN leverages these posets to facilitate the communication of coupled models between timesteps. A real-world application will be shown including interacting low fidelity population, power, and water models for the United States. (Received September 25, 2018)

Revitalizing Complex Analysis

1145-I5-1235 **Kyle D Hansen*** (kylhansen@westmont.edu), Westmont College, 955 La Paz Road, MS# 1799, Santa Barbara, CA 93108, **Mike Brilleslyper** (mike.brilleslyper@usafa.edu), Department of Mathematical Sciences, United States Air Force Academy, 2354 Fairchild Drive, Colorado Springs, CO 80840, and **Russell W Howell** (howell@westmont.edu), Department of Mathematics, Westmont College, 955 La Paz Road, Santa Barbara, CA 93108. *When the Fundamental Theorem of Algebra goes Awry.*

In contrast to an n^{th} degree analytic polynomial, an n^{th} degree (complex) harmonic polynomial can have more than n zeros. In this talk we will explore the family of harmonic trinomials of the form $p(z) = z^n \pm c\bar{z}^k \pm 1$, where n and k are integers with $1 \leq k < n$, and c is a positive real number. We begin by sketching a proof that, for $c = 1$, the harmonic trinomial has n zeros like its analytic counterpart. But as c increases we obtain more zeros. We present a conjecture for the maximum number of zeros, and describe the distribution of these zeros in the complex plane. Finally, we present several partial results and open problems. (Received September 20, 2018)

1145-I5-1281 **Michael Dorff** and **Beth Schaubroeck***, beth.schaubroeck@usafa.edu. *Properties of complex-valued harmonic polynomials.* Preliminary report.

What holds true and what changes with respect to standard results of analytic functions when they are generalized to (complex-valued) harmonic functions? In answering this question we begin by presenting some basic properties of harmonic functions, with particular attention to harmonic polynomials (whose terms contain powers of z and $\bar{z}$). We then explore some conjectures about harmonic polynomials, and suggest some open problems that students and faculty could investigate. For example, for some values of n, c, and k, the polynomial $p(z) = z^n + c\bar{z}^k - 1$ may have up to $n + 2k$ zeros instead of just n zeros. (Received September 20, 2018)

1145-I5-1585 **William Johnston*** (bwjohnst@butler.edu). *Riemann Surfaces and Other Projects on Mathematica.*

This talk presents five easy and interesting CAS projects for students in an introductory complex analysis course. They include such projects as one on graphing Riemann surfaces, whose Mathematica set of commands can be applied to a host of interesting functions and that are meant to lead students into asking thought-provoking questions – ones that that can lead, for example, into independent student investigation. It also describes an associated novel complex analysis course outline designed to make the course topics better connected to single-variable calculus. Of course, the commands in Mathematica can easily be modified to work in, say, Maple or MatLab, but the presentation will use only Mathematica. A hard copy (and/or e-copy) of the five projects' set of Mathematica command lines will be available for any interested audience member. (Received September 23, 2018)

1145-I5-1616 **Robert L. Sachs*** (rsachs@gmu.edu), MSN 3F2, George Mason University, Fairfax, VA 22030. *A Transition / Proofs Course Based on the Complex Numbers.*

This talk will describe an alternative transition / proofs course offered for the first time last spring. The unifying theme is the complex number system. The basic algebra, analysis, and geometry that develops also includes some discrete math, number theory, and topology. Students were introduced to a connected body of mathematics that simultaneously stimulated interest in the further content of upper-level courses and provoked a need for proof, attention to definitions and notation, a variety of proof techniques, prior content in a new context, and some surprising results. Student feedback and some preliminary data about their performance in subsequent courses this past fall will be discussed. (Received September 23, 2018)

1145-I5-2600 **Paul Zorn*** (zorn@stolaf.edu), MSCS Department, Saint Olaf College, Northfield, MN 55057. *Getting real about truly complex theorems.*

Basic complex analysis is, at a first pass, essentially the calculus of complex functions. Tracing similarities and—more strikingly— differences between the real and complex versions of single-variable calculus can help students better understand both theories. Liouville's celebrated theorem on bounded entire functions is one good example. The theorem is "truly complex": nothing similar holds in the analogous real sense. The apparently innocuous replacement of z for x in familiar places changes the landscape completely and dramatically. I'll illustrate this thesis with pictures and examples. (Received September 25, 2018)

Touch it, Feel it, Learn it: Tactile Learning Activities in the Undergraduate Mathematics Classroom

1145-J1-328 **Erin R Moss*** (erin.moss@millersville.edu). *A Physical Number Line as a Support for Students' Work with Absolute Value Equations and Inequalities.*

Absolute value equations and inequalities pose significant challenges to college algebra instructors and students alike. Despite instructors' best efforts to help students make sense of these problems, reflection on assessment results reveals that students often manipulate symbols with no knowledge of their meaning. In this talk, I share a powerful representation of a physical number line that supports students' understanding of how the absolute value of an expression can be interpreted when it is part of an equation or inequality. The number line itself is a long piece of twine from which we can hang index cards representing numbers and variable expressions. Students place numerous cards on the number line to represent all the possible solutions to the given equations and inequalities once absolute value is interpreted as a distance from zero. The physical and visual representation students have created then allows them to make further progress towards algebraic and graphical solutions to these problems. (Received September 01, 2018)

1145-J1-363 **Nicole R. Kroeger*** (kroeger@gssm.k12.sc.us), 401 Railroad Ave, Hartsville, SC 29550. *Using Toy Cars to Teach Calculus Concepts.*

How can you make the first day of calculus engaging and interesting to students while introducing them to important calculus concepts? Use toy cars! We will discuss and activity for the first day of Calculus I that uses toy cars to help students to understand the connection between average velocity and instantaneous velocity. This activity provides the starting point for an initial classroom discussion of tangent and secant lines, limits, and derivatives. Furthermore, we will discuss other ways to use toy cars throughout a Calculus course to help students engage with the material and see the physical applications of calculus. (Received September 04, 2018)

1145-J1-476 **Anthony J Macula*** (macula@geneseo.edu), 36 Westview Cr, Geneseo, NY 14454. *Decimals, Dilutions, DivisionS, without Division.* Preliminary report.

The method of serial dilutions, a common molecular technique in biology, is used to visually demonstrate "blah-mals", i.e., base "blah" representations of real numbers. (Received September 07, 2018)

1145-J1-551 **Marina Skyers*** (mus61@psu.edu). *Flowcharts, Playing Cards, and Pulse Rates: Hypothesis Testing in an Introductory Statistics Course.*

In this this talk I will present ideas for engaging students with hypothesis testing in an introductory statistics course. I will explain how these activities physically involve students with the concepts, and how to implement these ideas in the classroom. (Received September 09, 2018)

1145-J1-583 **David Pengelley*** (davidp@nmsu.edu), Mathematics, Oregon State University, Corvallis, OR 97331. *Group theory via a rectangle tethered up to homotopy by strings or strip: from middle school to general education to abstract algebra.*

A two-person manipulative is created by a rectangle with movable strip or strings attached, and the richness of the resulting possible symmetry discoveries by students applies from pre-teens to upper division abstract algebra students: Low floor, high ceiling. Ultimately it's all about discovering the 8-element quaternion group, with its noncommutativity and connections to complex numbers. Hands on challenges and big surprises abound at every level with this wonderful elementary manipulative. (Received September 10, 2018)

1145-J1-903 **Jay A Malmstrom*** (jmalmstrom@occc.edu), Dept of Mathematics, Oklahoma City Community College, 7777 S May Ave, Oklahoma City, OK 73159. *Using Cuisenaire Rods to Develop Student Understanding of Statistical Distributions.*

Students often have difficulty understanding what it means for a population to be skewed right or skewed left. A pair of guided activities using Cuisenaire rods helps the students develop an understanding about how three measure of the middle; Mode, Median, and Mean; are related and how they help us determine if a population is skewed and which direction it is skewed in. (Received September 17, 2018)

1145-J1-908 **Jonathan Needleman***, 1419 Salt Spring rd, Syracuse, NY 13214. *Constructing with Zomes.*

The innovative building toy Zometool has existed since 1992. In this talk, I explain how I use these toys, in a modern geometries class, to have students explore construct-ability of numbers, using a system other than straight edge and compass. (Received September 17, 2018)

1145-J1-1015 **Sharon S. Emerson-Stonnell***, emersonstonnellss@longwood.edu. *Modeling the Unit Circle in Precalculus.*

The sine and cosine functions are defined based on the unit circle. Students can then use their understanding of the unit circle to build most of the material needed in trigonometry. In this activity students create a unit circle using patty paper or tracing paper, a ruler, and a compass. Using paper folding, students create the x and y axes. They then use the compass to create a circle centered at the origin. Knowing that the circle has radius one, they can index the axes. This is the first activity that continues as the students investigate different trigonometric topics. Each topic activity builds on the previous circle. Circle symmetry: Students use reflections across axes to determine relationship between points and the angles made with the x-axis. Special angles: Students study unit circle points of special angles using paper folding, protractors, and algebra. Graphs of sine and cosine: Students use unit circle to examine the periodic nature of the sine and cosine functions. Right triangles: Students use unit circle and inscribed right angles to demonstrate similar triangles and relationships with trigonometric functions. Identities: Students use unit circle to examine Pythagorean, even-odd, and cofunction identities. (Received September 18, 2018)

1145-J1-1341 **Heather Pierce*** (pierceh@emmanuel.edu). *Using Tactile Models for Non-Euclidean Geometry.*

It is common to use balloons in a Geometry course to demonstrate the properties of spherical geometries. However, it can also be useful for the students to build the spherical space themselves, rather than just blow up a balloon. This talk will consider a different tactile model for spherical geometry, as well as an equivalent for hyperbolic geometry. We will also discuss how you can incorporate building these models in class before the formal introduction of the non-Euclidean geometry, as well as what advantages the students get from this process. (Received September 21, 2018)

1145-J1-1523 **Teresa Deltz Magnus*** (tmagnus@rivier.edu), Department of Mathematics and Computer Sci, Rivier University, 420 S. Main Street, Nashua, NH 03060. *Delving Deeper into Geometry through Purposeful Play.*

Pentominos, Tangrams, Geoboards, Pythagorean puzzle pieces, Polydrons, and other geometrical tools come out of the closet to encourage students to explore geometry in a whole new way. The intuitive notions of conservation of area, the area of a rectangle, and the angle sum of a triangle lead to an understanding of other area formulas, why the Pythagorean Theorem holds, and which regular and semiregular polyhedral can be built. While this course full of exploration, experimentation, and justification was designed for Elementary Education majors, it is open as an elective to all students wanting to know the why behind the geometry they've studied and to experience some topics outside the typical curriculum. (Received September 22, 2018)

1145-J1-1570 **Olivia M. Carducci*** (ocarducci@esu.edu). *The Use of Card Tricks to Discover How to Read a Math Text.*

The activity described in this talk is based on the idea that reading an introductory undergraduate mathematics text is similar to reading instructions. To encourage students to think about how to read when the goal is to learn to complete a task, have them perform a card trick, in pairs, from written instructions. One student reads the instructions to the other who performs the trick. The subsequent discussion helps the students identify the reading strategies they used to complete the card trick; for example, reread the step to make sure you got it right. The instructor should point out the connections to reading their mathematics textbooks. Nearly every class includes a pair who failed to complete the trick correctly the first time, but whose second attempt was successful. Point out that this sometimes happens with math problems as well. (Received September 23, 2018)

1145-J1-1655 **Laura Taalman*** (laurataalman@gmail.com). *3D Printed Mathematics: Student-led design and creation of mathematical objects to discover fractals, polyhedra, and knots.*

How can you use 3D printing and design to support a college mathematics course? In this talk we'll discuss one example of a hands-on inquiry-based liberal arts mathematics course in JMU 3SPACE, a 3D printing classroom at James Madison University. In this course students directed their own explorations of fractals, mathematical cake cutting, knots, polyhedral graphs, infinite geometric series, and other mathematical topics while at the same time using 3D design programs like Tinkercad, OpenSCAD, Meshmixer, and Fusion 360 to construct and 3D print models to support those explorations. (Received September 23, 2018)

1145-J1-2113 **Sylvia Gutowska*** (sgutowska@ccbcmd.edu), 7201 Rossville Blvd, Baltimore, MD 21237, and **Clarence Baney** (cbaney@ccbcmd.edu), 7201 Rossiville Blvd, Baltimore, MD 21237.
Hands on Calculus: Manipulatives Integral to Integration.

Integration, in Calculus I, presents students with two non-trivial tasks: constructing the Riemann Sum and evaluating it. A very common misconception among students is that integration can be easily accomplished by finding an antiderivative. Difficulties arise as students encounter the Riemann Sum, and the idea that it connects to the integral obtained through antidifferentiation. Students' struggles are further compounded when they are required to calculate the sum, as the number of subintervals goes to infinity. Can they even imagine this? While several widely available computer simulations have made it easier for students to visualize the above process, they do not help students learn how to construct the sum. This becomes a stumbling block when students try to set up integrals for calculating area, volume, or distance traveled. This presentation will offer one way to bridge the gap between construction and evaluation of the sum, using manipulatives constructed from foam sheets. These easily made manipulatives can be used to teach setting up the Riemann Sum, finding the area under (between) the curve(s), the volume of solids using the disc or cross-section method, as well as determining the total distance traveled by an object. (Received September 24, 2018)

1145-J1-2169 **Adam Giambrone*** (agiambrone@elmira.edu). *Using Tangle Toys to Explore Ideas in Knot Theory.*

If a knot is tied using a piece of rope and the ends are fused together, then a knotted loop is created. We would like to allow ourselves to manipulate our knotted loops so that we consider two knotted loops equivalent if one knotted loop can be deformed to create the other. A key question in knot theory is whether or not two given knotted loops are equivalent. By working with Tangle toys, students can create and deform their own knotted loops, forming their own conjectures and increasing their visualization skills along the way. Additionally, after enough exploration, the need for a common language and a way to depict knotted loops becomes clear. This talk will give audience members the chance to experience the fun of hands-on exploration, with the hope that both students and educators leave with new ideas. (Received September 24, 2018)

1145-J1-2234 **Silvia Saccon*** (ssaccon@bard.edu). *A search and rescue activity to explore multivariable concepts.*

In multivariable calculus, students often encounter difficulties in visualizing functions of two variables and struggle to fully grasp the meaning of level sets. To help students explore concepts in space, we have built three-dimensional surface models, and we have designed mathematical tasks that allow students to engage with calculus ideas through tactile and visual learning experiences. In this talk, we will provide an overview of the project, describe the mathematical tasks and physical manipulatives used in the classroom, and share students' comments about their experiences. (Received September 25, 2018)

1145-J1-2325 **Rachel Schmitz*** (rschmi9@students.towson.edu), **Youyu Liu** and **Kristin M Frank**.
Teaching rigid motions through embodied activities: Making the jump from 2- to 3-dimensions.

While embodied activities can have many positive impacts on students' mathematical learning, the fact that embodied activities often occur in 3-dimensional space and involve elapsed time can introduce unexpected levels of complexity to the mathematics being studied. In this talk we describe an activity that uses dancing and figure skating to teach rigid motion transformations (task adapted from Leonard and Bannister, 2018). We describe how participants, at both the middle school and university level, enacted translations, rotations, and reflections in ways that caused them to experience difficulty differentiating between reflections and rotations. By enacting the reflection as a pre-image, a motion, and an image, they saw every reflection as entailing a rotation. We conclude that enacting rigid motion transformations introduced an additional level of complexity; students needed to learn to differentiate the process of the transformation which they saw as a 3-dimensional activity from the result of the transformation which can be imagined as a 2-dimensional mapping. (Received September 25, 2018)

1145-J1-2500 **Mercedes A. McGowen*** (mercmcgowen@sbcglobal.net), 601 Pleasant PL, Streamwood, IL 60107. *Developing more robust mathematical understanding utilizing manipulatives and variations of a single problem.*

Algebra for us is not only a list of topics or general aspects of mathematics. It is also an attitude to mathematical thinking, one that emphasizes connections and flexibility of interpretation. The express aims of this series of problems is to break up undergraduate students' notions of mathematics as consisting solely of applying formulas to get an answer, and to provide experiences for them that increase the flexibility of their thought and their ability to see and value connections. We assign students a series of problems, utilizing concrete manipulatives initially, with the focus on building connections between different representations of a single problem involving binary choice. The problems selected are unlikely to allow a solution by a remembered formula. This presentation will include discussion of how these related problems with a focus on building connections can be utilized for a more robust understanding of binomial expansion, difference equations, sequences, basic functions (linear, exponential, quadratic), generalizations and mathematical arguments. Ways in which the problems could be extended or utilized in various courses will also be discussed. (Received September 25, 2018)

1145-J1-2568 **Lee W. Singleton*** (lsingleton@whatcom.edu). *Tactile Trigonometry: Lessons Learned from a Tactile Active Learning Classroom.*

Students in elementary school often learn through tactile manipulatives and active learning, but students rarely "get their hands dirty" in college math classes. Several issues can present barriers to employing tactile learning techniques including content related manipulatives, pre-designed lessons using manipulatives, physical space or time constraints, and many other factors. Through an NSF grant (DRL-1623405) "EAGER: MAKER: Engaging Math Students with 3d Printing for STEM Success," Dr. Lee Singleton has developed several manipulatives and active learning lessons at the Precalculus II (trigonometry) level to help students employ their sense of touch while learning. Data gathered over the two-year grant shows student performance on exams in Singleton's tactile classes are generally higher than his lecture classes. This paper will not only report on the data, but will also offer some insight into resources, techniques, and challenges that arose while working to get students physically involved in their learning. Preliminary work on an active grant (DUE-1834425) "Collaborative Research: Improving Representational Competence by Engaging with Physical Modeling in Foundational STEM Courses" involving the creation of manipulatives and lessons for Calculus II will also be shared. (Received September 25, 2018)

1145-J1-2649 **Lisa Driskell*** (ldriskel@coloradomesa.edu). *Tactile Learning Activities: Keeping It Simple in Calculus.*

The concepts of motion and change in calculus lend themselves naturally to tactile learning activities. While the relationships among velocity, acceleration, speeding up, and slowing down can be difficult to recognize, tactile activities aid students in physically feeling those relationships. Tactile activities can also be used to highlight the various changing quantities in standard related rates problems. By taking typical calculus problems and adding simple props and movements, we can employ tactile learning activities to introduce and reinforce concepts. The featured in-class activities are of variable length and are straightforward to prepare and implement, making them suitable for easy integration throughout the calculus course. (Received September 25, 2018)

1145-J1-2733 **Sarah A. Nelson*** (sarah.nelson@lr.edu), LRU 7527, 625 7th Avenue NE, Hickory, NC 28601. *Embodied Venn Diagrams: Bringing Sets to Life.* Preliminary report.

At the 2016 MAA MathFest, Dr. Hortensia Soto (University of Northern Colorado) introduced me to using embodied activities in the classroom. By having students take on the role of the object(s) they are studying, embodied activities afford them the opportunity to experience those concepts and challenge them to develop a deeper understanding of the related definitions. My experiences have shown that these assignments promote student engagement, allow students to struggle productively within a safe environment, and support student success.

In this talk, I will share how I created my own embodied activities for studying Venn Diagrams. In two different courses (one aimed at majors and the other aimed at non-majors), I have had students take on the role of elements as they explore and develop their understanding of Venn Diagrams. We will discuss these activities and different materials used. I will also share how student feedback was utilized to make improvements on new activities and some important lessons learned. (Received September 25, 2018)

1145-J1-2747 **Lindsey Fox*** (lfox7@vols.utk.edu), Ayres Hall 208, 1403 Circle Drive, Knoxville, TN 37996. *A G.U.E.S.T. Course in Statistics.*

It is essential that a university provide an exceptional learning experience in their introductory Statistics course that is approachable by students of any major. At the University of Tennessee, we have been improving our Statistical Reasoning course by having students collect and analyze their own data from a variety of "Portable Populations". These populations include Scrabble tiles, Uno cards, standard dice, and dice from the craps table of the Stratosphere Casino, and provide a variety of active learning experiences working with quantitative and categorical data. Knowing the make-up of the population allows students to make connections between their individual sample statistics and the population parameters that are sometimes difficult to grasp from computer-generated data. As a result, students gain a deeper understanding of the Central Limit Theorem and Hypothesis Testing. (Received September 25, 2018)

1145-J1-2781 **Melanie A Pivarski*** (mpivarski@roosevelt.edu), Mailstop AUD 402, 430 S. Michigan Ave, Chicago, IL 60605. *Using the campus to connect accessibility to precalculus.* Preliminary report.

Roosevelt University is located in two connected buildings: the historic Auditorium Theater building and the very modern Wabash building. These facilities lead to some interesting accessibility issues where floors aren't aligned with one another. In our precalculus class students work in groups to connect solving right triangles, measurements and errors, and the Americans with Disabilities Act in a class project. (Received September 25, 2018)

1145-J1-2856 **Brian Hollenbeck*** (bhollenb@emporia.edu), Dept. of Mathematics and Economics, Emporia State University, Emporia, KS 66801. *The SIR Game: Modeling an Epidemic.*

The Susceptible-Infected-Recovered (SIR) model is a well-known approach for modeling the spread of a disease. It is often analyzed using data from past epidemics. The SIR game is an activity that allows students to track the spread of a "disease" within their own classroom. Initially students are assigned a color that corresponds to being either susceptible or infected. Then based on the rules of the game and the interactions of the students, the infection will spread. Eventually all students will be "recovered" and the game ends. The data from the game is collected and analyzed using the discrete version of the SIR model. The nature of the game allows the infection rate, recovery rate, and initial populations to be modified as desired. This activity is generally used to introduce the SIR model and motivate its formulas. (Received September 25, 2018)

1145-J1-2890 **Stephen M. Walk*** (smwalk@stcloudstate.edu), Department of Mathematics and Statistics, ECC 139, St. Cloud State University, 720 4th Ave. S., St. Cloud, MN 56301-4498. *A block-headed approach to binomial expansions.*

Claims of the form "$(x+y)^n = x^n + y^n$" are high on every mathematics educator's list of common, egregious algebra errors. A simple classroom activity involving manipulatives can connect the algebraic symbols to their underlying geometric meanings and pave the way for a look at Pascal's triangle, combinations, and the binomial theorem. (Received September 25, 2018)

Research in Undergraduate Mathematics Education (RUME)

1145-J5-118 **Qingxia Li*** (qli@fisk.edu), 411 Annex Ave, Apt B4, Nashville, TN, and **Thomas Gross** and **Patricia McCarroll**. *Integration of Introductory Mathematics into General Biology by Reciprocal Course Content Exchange.*

The overall goal of this project is to increase academic performance, prepare students to pursue education and careers in STEM, and to develop an assessment and STEM educational intervention. A recent academic experience survey revealed that the major reasons Fisk STEM majors switch to non-STEM disciplines are: (1) poor "faculty teaching" due to instructor's failing to link concepts to applications, (2) student performance in mathematics courses, and (3) low-perceived self-efficacy. This project addresses these three issues via Intrusive Learning, achieved by creating a Learning Community. To connect math concepts with other STEM disciplines, reduce math anxiety, and increase student self-efficacy, intrusive learning communities for College Algebra and General Biology I was created, involving weekly sessions led by trained Peer Partnership Learning leaders to reinforce class content and work on mathematics projects related to Biology. A Performance Pyramid model, evaluated in collaboration with social science colleague, tested why the proposed intervention was effective and examined the extent to which each intervention reflected the influences of Performance Pyramid support systems. Data collected from both control groups and experimental groups will be discussed. (Received August 03, 2018)

1145-J5-239 **Blain Patterson*** (bapatte3@ncsu.edu). *Real Analysis Mathematical Knowledge for Teaching: An Investigation.* Preliminary report.

In this talk, I discuss the preliminary results from my dissertation, which investigates the relationship between teacher knowledge of real analysis and classroom teaching practices. Using the Mathematical Understanding of Secondary Teachers (MUST) framework, I analyzed this relationship in terms of teachers' mathematical understanding, mathematical proficiency, and mathematical context. Preliminary results from analyzing interviews and observations are discussed and future directions of this work are considered. (Received August 23, 2018)

1145-J5-343 **Younggon Bae*** (baeyoun3@msu.edu), 354 Farm Lane NK223, East Lansing, MI 48824. *Dynamic Geometry Tasks for Inquiry-Oriented Axiomatic Geometry.*

In this talk, I will present dynamic geometry tasks and student work from an inquiry-oriented axiomatic geometry course offered at a large public university in Spring 2018. The course aimed at guiding students to re-invent the axiomatic system of Euclidean geometry, the independence of parallel postulate, and non-Euclidean geometries including hyperbolic and elliptic geometries. Dynamic geometry tasks were designed for students' mathematical inquiry that involves defining geometric concepts, generating conjectures from examples, explaining and proving geometric statements. Student work from the tasks was collected in the form of screencast presentations, which include video recordings of their manipulations on DGE screen and audio recordings of their verbal explanation responding to the questions given in the tasks. A qualitative analysis of the data revealed how the students' mathematical reasoning related their uses of DGE in certain ways in which they interacted with dynamic constructions in DGE to support their arguments as well as develop mathematical concepts in non-Euclidean geometry. Different patterns of this relationships provide a glimpse of the students' different views of geometric model and mathematical proofs. (Received September 02, 2018)

1145-J5-376 **Sean P Yee** (yee@math.sc.edu), University of South Carolina, LeConte College, 317K, 1523 Greene Street, Columbia, SC 29208, **Kimberly Cervello Rogers*** (kcroger@bgsu.edu), Department of Mathematics and Statistics, Bowling Green State University, Bowling Green, OH 43403, **Jessica Deshler** (jmdeshler@mail.wvu.edu), West Virginia University, PO Box 6310, Department of Mathematics, Morgantown, WV 26506, and **Robert Petrulis** (robert.petrulis@epreconsulting.com), **Christopher D. Potvin** and **James Sweeney**. *Making Graduate Student Instructor Observation Protocols Actionable via Post-Observation Feedback.*

In this study, two universities created and implemented a student-centered graduate student instructor observation protocol (GSIOP) and a post-observational Red-Yellow-Green feedback structure (RYG feedback). The GSIOP and RYG feedback was used with novice graduate student instructors (GSIs) by experienced GSIs through a peer-mentorship program. Ten trained mentor GSIs completed 50 sets of three observations of novice GSIs. Analyzing 151 GSIOPs and 151 RYG feedback meetings longitudinally provided insight to identify what types of feedback informed and influenced GSIOP scores. After qualitatively coding feedback along multiple dimensions, we found certain forms of feedback were more influential for GSI development than others with respect to change in GSIOP score. Our results indicate contextually-specific feedback leads to more observed changes and improvement across multiple observations than decontextualized feedback. (Received September 04, 2018)

1145-J5-384 **Aubrey Kemp*** (akemp2@csub.edu), 8225 Hastings St, Bakersfield, CA 93311, and **Draga Vidakovic**. *Ways in which students transfer and apply definitions from Euclidean to Taxicab geometry: 2nd Cycle of Data Collection and Analysis.* Preliminary report.

This ongoing study seeks to improve student understanding of the content of mathematical definitions as well as their application in logic, since definitions are often not used correctly by students in proof or logic courses. Research also shows students can better develop their understanding of concepts in Euclidean geometry by observing properties and making conjectures in other geometries. As part of an ongoing project, an initial cycle of this study was conducted in a undergraduate geometry course at a university to identify and analyze ways students transfer and apply definitions from Euclidean to Taxicab geometry. APOS Theory was used as the framework in the analysis of students' use of definitions in course work and semi-structured interviews. In particular, the ways in which students applied definitions in a new context (Taxicab geometry) and how these methods influenced their overall understanding of these concepts were reported. Results from the initial study were implemented at another university, and data was collected as a second cycle of this study. These students demonstrated a variety of ways in which they transfer and apply definitions in new contexts. Here, we discuss the preliminary findings from the second cycle of data analysis as a part of the larger study. (Received September 04, 2018)

1145-J5-501 **Kelly P Findley*** (kfindley@fsu.edu), 2400 Fred Smith Rd., Apt 205, Tallahassee, FL 32303. *Is Statistics Just Math? The Developing Epistemological Views of Graduate Teaching Assistants.*

In recent decades, research has shown that teachers and instructors' views about the discipline they teach inform their instructional approaches. As a foundation for investigating this relationship in statistics, we explore how (or whether) beginning graduate students in statistics perceive statistics as distinct from mathematics. Using the lens of epistemology, we share findings from interviews with four, first-year graduate students who served as graduate teaching assistants (GTAs) in a statistics department. Using data collected from interviews across their first year, we constructed three models that explain how the GTAs conceived of the nature of statistics in relation to mathematics. Additionally, we identified two continua that reveal how participants came to understand the

nature of doing statistics. We discuss how these models and continua form the basis of a unified statistical epistemology that has implications on their views for statistics education. (Received September 07, 2018)

1145-J5-588 **Betsy McNeal** and **Sayonita Ghosh Hajra*** (sayonita.ghoshhajra@csus.edu), California State University Sacramento, Department of Mathematics and Statistics, Sacramento, CA 95819, and **Yajenny Patricia Pacheco Enamorado**. *Pre-service teachers' conceptions of area of a rectangle.*

In this talk, we will share the data contrasting responses of ten pre-service teachers (PTs) to problems that were part of an ongoing study of PTs' conceptions of area of a rectangle at a public university in the United States. PTs were asked to respond to the following tasks- a) find the area of a rectangle in terms of a non-square rectangular unit and relate that to multiplication, and b) interpret a fictional child's attempt to connect the area formula with counting square units. We witnessed a pattern among some PTs in task (a) who could identify groups and number of objects in each group describing how many rectangular units can fit in a bigger rectangle but failed in task (b) to find the relationship between the area formula with counting square units and identifying the groups (and number of objects in each group). We found some PTs struggle to describe abstract groups, for example, struggle to distinguish between counting length units on an edge and counting "rows" as groups. Finally, we will tie the data back to the existing literature and present our future plans on continuing this study. (Received September 13, 2018)

1145-J5-739 **Rachel Rupnow*** (rachr15@vt.edu). *Abstract Algebra Students' Use of Metaphors While Problem Solving.*

In an effort to understand ways students visualize isomorphisms and homomorphisms between groups, eight undergraduates from two introductory abstract algebra courses were interviewed. Students in one class had been instructed using the Inquiry-oriented Abstract Algebra materials while students in the other class were taught with lecture two days each week and lab activities on the third day. During these interviews, students were given various groups and asked to ascertain whether an isomorphism existed or a homomorphism existed between the groups. Some groups had the same cardinality and some had different cardinalities. Students' statements while solving were analyzed from a conceptual metaphor lens (Lakoff, G. & Johnson, M. (1980). Metaphors we live by. Chicago: The University of Chicago Press.). Conceptual metaphors are a construct for thinking about one thing as if it were another. Students' metaphors grouped into clusters such as around traveling (e.g. an element from group G sent to group H). The students experienced varied success in creating isomorphisms and homomorphisms and utilized a variety of conceptual metaphors for isomorphism and homomorphism while solving. Patterns in success and struggles while solving are examined in light of the metaphors students used. (Received September 13, 2018)

1145-J5-783 **Steve Bennoun*** (s.bennoun@cornell.edu) and **Matthew Thomas**. *Putting Students on the Right Track: Predicting Final Grades in Calculus using Early-Semester Data.* Preliminary report.

It is well-known that many students abandon a STEM major because they are not able to complete their calculus requirement. It is therefore important to be able to identify early on which students may be at risk of failing in order to guide them to appropriate support. In this paper we look at how one can predict the final exam grade of students in calculus using two instruments called the Pre-calculus Concept Assessment (PCA) and the Mathematics Attitudes and Perceptions Survey (MAPS). We first look at these two instruments individually and find that for the MAPS, the confidence and persistence sub-scores have the highest correlations with the final exam grade. We then combine the data from these two instruments and build a model for predicting final exam grades. In addition, we also investigate to what extent the PCA, which was developed for pre-calculus, can be used to measure change in pre-calculus concept during a calculus course. Finding no significant difference between pre- and post-scores, we infer that this instrument is not well-suited for this purpose. (Received September 14, 2018)

1145-J5-962 **Ralph E. Chikhany***, Department of Mathematics and Statistics, Washington State University, Pullman, WA 99164-3113, and **William L Hall**, Department of Mathematics and Statistics, Washington State University, 99164-3113. *Business Calculus Students' Understanding of Marginal Functions.* Preliminary report.

Business majors represent a significant proportion of the population of students enrolled in calculus at the college level. However, there is a lack in research literature that tackles the teaching and learning of business applications at this level. This pilot study represents the beginning phases of a project that aims to investigate business students' reasoning through tasks pertaining to marginal analysis (derivatives in a business context), accumulation functions and Riemann sums. A preliminary analysis of interviews with two pairs of students is presented, with an emphasis on their thought process while answering questions related to cost, revenue and profit functions as well as their marginal counterparts. The context-based activities were designed with a realistic mathematics education perspective, motivated by guided reinvention. (Received September 17, 2018)

1145-J5-1031 **Jungeun Park*** (jungeun@udel.edu), 501 Ewing hall, Univ. of Delaware, Newark, DE 19716. *Calculus TAs' teaching practice and reflections.*

In this study, we investigated the characteristics of the first time single variable Calculus TAs' teaching practice and reflections on their teaching. In our analysis we focused on how TAs addressed quantitative reasoning in their discussions of functions and the derivatives in the derivative unit using three views of function - correspondence, variation, and covariation. We also examined TAs' reflections on their own teaching using video-stimulated recall during two interviews before and after the professional development (PD) focusing on different quantities and their relationships involved in the definition of the derivative. Our analysis showed that most of TAs' classroom discussions and reflections on both the derivative at a point and the derivative of a function matched with the correspondence view of function with algebraic representations. TAs used correspondence dominantly even when they used graphs or solved related-rate problems, which are often used to emphasize variational and covariational nature of the quantities involved. There was some transition towards variation and covariation in reflections occurred after the PD, but their descriptions were still limited. The TAs mainly acknowledged that quantities change without describing how they vary or covary. (Received September 18, 2018)

1145-J5-1066 **Claire Gibbons*** (gibbonsc@oregonstate.edu). *Mathematics Graduate Teaching Assistants and Their Growth as Teachers.*

Mathematics Graduate Teaching Assistants (MGTAs) interact and work with college students through their roles as instructors, laboratory or discussion leaders, tutors, and graders. Thus, efforts to improve undergraduate mathematics instruction should include MGTAs, but there is currently limited research about how MGTAs grow as teachers. This study investigates how seven MGTAs at a doctoral-granting university developed as teachers over an academic year. Group interview, individual interview, and survey data were collected and analyzed using complexity science as a theoretical framework. Results will be presented about what factors influence changes in MGTAs teaching practices. (Received September 18, 2018)

1145-J5-1070 **Yi-Yin Ko*** (winnie.ko@indstate.edu), **Dalton Edgecomb** and **Nathan Kooi**. *Making Proof Accessible to Undergraduate Students through Communal Engagement.* Preliminary report.

Although proof is a critical element for deepening individuals' mathematical understanding and ability to communicate mathematical ideas (Stylianides, 2007), undergraduate students' difficulties with proof are well documented. One of the primary challenges undergraduate students face in constructing proofs is that their experiences with proof have often been limited to passively observing an instructor's completed and polished proof (Stylianou, Blanton, & Knuth, 2009). Under teacher-centered instruction, undergraduate students have little opportunity to make sense of why a particular proof method (proof by contrapositive or proof by contradiction) is appropriate and when a mathematical argument can be considered a proof. In this presentation, we will share a three-component instructional sequence (Ko, Yee, Bleiler-Baxter, & Boyle, 2016) used in a proof course. We will also share how the sequence increased undergraduate students' involvement in proving and enhanced their ability to construct and critique mathematical arguments by developing and revising their initial list of proof characteristics throughout the semester. Implications for how using the three-component instructional sequence can make proof accessible to undergraduate students will be discussed. (Received September 18, 2018)

1145-J5-1081 **Kristen Vroom*** (vroom@pdx.edu), 2220 SW 184th Ter, Beaverton, OR 97003, and **Naneh Apkarian**, **Jessica Gehrtz**, **Jessica Ellis Hagman**, **Matthew Voigt** and **Antonio Martinez**. *Students' reports of precalculus and calculus course experiences.* Preliminary report.

Improving students' experiences in their introductory courses is one of the common goals of researchers and practitioners of undergraduate mathematics education. As part of a larger study of university precalculus/calculus, we surveyed 4,969 Precalculus, Calculus 1, and Calculus 2 students at 12 institutions about their experience in and perceptions of their class. We present student data on their changing attitudes toward themselves and mathematics, reports of classroom climate, reports of instructional practices, and their perceptions of the helpfulness of those instructional practices. Most students reported a lack of interest, confidence, enjoyment, or ability to learn mathematics with minimal changes in these across the term. Students report that their regular class meetings are characterized by traditional lecture practices, which they believe is helpful for their learning.

We discuss the importance of these findings for further understanding and improving students' entire experience of their courses and consider their impact on interpreting student evaluations in active learning classrooms.
(Received September 18, 2018)

1145-J5-1210 **Halil I. Tasova*** (halil.tasova25@uga.edu), 110 Carlton Street, 105 Aderhold Hall, Athens, GA 30602, and **Biyao Liang**, **Irma E. Stevens** and **Kevin C. Moore**.
Characterizing Two Undergraduate Students' Quantitative Comparisons of Covarying Quantities' Magnitudes.

In this presentation, we characterize two undergraduate students' (Lydia and Caleb) quantitative operations during a teaching experiment as they reasoned about the relationship between the distance a rider has traveled (i.e., arc length) around a Ferris wheel and the rider's distance above the wheel's horizontal diameter (i.e., height). Both Lydia and Caleb constructed *differences* in height magnitudes for variations of arc length magnitudes; however, the way they operated on those differences differed. Lydia operated on differences in height magnitudes in successive states and additively compared these differences, whereas Caleb operated on both differences in height magnitudes and the corresponding differences in arc length magnitudes in order to multiplicatively compare them. We conjecture that although Lydia's differences reasoning is useful for drawing inferences about the rate of change between two quantities (e.g., height is increasing at a decreasing rate with respect to arc length in the first quarter rotation), Caleb's comparison is likely more productive in constructing rates of change as his comparisons afforded constructing and comparing *ratios* of differences in height to differences in arc length.
(Received September 20, 2018)

1145-J5-1514 **Razieh Shahriari*** (rshahria@uark.edu), 850 Dickson st. room 341, Fayetteville, AR 72701, and **Bernard Madison**. *The effect of technology on students understanding of college algebra.*

This mixed-methods study reports on the effectiveness of using technology such as hand-held and online graphing calculators on the college algebra students' understanding. This study was aimed to investigate i) what areas of college algebra are affected more by technology ii) how technology affects the organization of written work and, iii) the effect of technology on the attitude of the students toward mathematics. The study was conducted on 315 students of college algebra in 2016 at the University of Arkansas. Data were collected from different sources such as pre and post surveys, scores of three written tests, and student' interviews. The results of the study revealed that college algebra students who used technology had a better understanding of x and y-intercept, domain of a function, end behavior, vertical and horizontal asymptote. However, the performance of students in composite function and world problems was similar. In addition, college algebra students who used smartphone application in their class activities were able to make a better connection between logarithms and exponential functions. The results of the qualitative analysis show that students written work is more organized when they use technology in their tests. (Received September 22, 2018)

1145-J5-1564 **Kevin C. Moore*** (kvcmoore@uga.edu), 105 Aderhold Hall, Department of Mathematics & Science Education, Athens, GA 30602, and **Irma E. Stevens**, **Biyao Liang** and **Halil I. Tasova**. *Concept Construction and Abstracted Quantitative Structures.*

A critical aspect of mathematics education is supporting students in constructing sophisticated mathematical concepts. Accordingly, mathematics educators have described various framings of "sophisticated mathematical concepts." In this presentation, we draw on Piagetian ideas of abstraction, Carlson's covariational reasoning framework, Thompson's notion of quantitative reasoning, and related constructs including Steffe's units coordination to describe a construct—abstracted quantitative structures—that defines one form of "sophisticated mathematical concepts." An abstracted quantitative structure is a network of related quantities a student has come to understand as if it is independent of specific figurative material (i.e., representation free). Furthermore, this understanding entails that a student can accommodate (or assimilate) novel figurative material by re-presenting the abstracted quantitative structure, assuming the material and situation permits the associated quantitative operations. Using data collected during clinical interviews and teaching experiments with undergraduate students, we illustrate the introduced construct and we include its research and instructional implications in the context of secondary and undergraduate algebraic and calculus ideas. (Received September 23, 2018)

1145-J5-1565 **Ileana Vasu*** (ivasu@hcc.edu), PO Box 33, North Hatfield, MA 01066. *Multiple Representations of the Enacted Fundamental Theorem of Calculus, Student Understanding, and Gender.*

Multiple representations of the Fundamental Theorem of Calculus (FTC) are deemed essential to creating mathematical habits of mind, but not all classroom instruction includes them. This study articulates the relationship between college students' experience with multiple representations of the FTC in the curriculum and their use of multiple representations, with a particular attention to gender. The effect of gender on the relationship between the use of multiple representations in the FTC curriculum and student understanding is examined. Results suggest that meaningful use of multiple representations in an active learning environment helps support a fuller understanding of the FTC. The relationship is stronger for female students. A mixed methods design is used, which includes lesson observations at three colleges, classroom assessments, and semi-structured think-aloud interviews with nine students – three from each college – as they problem-solve around the FTC. The study contributes to the existing literature on Calculus education by providing a more complete picture of the ways in which an enacted college curriculum that includes multiple representations of the FTC supports deeper learning and understanding of Calculus for all students. (Received September 23, 2018)

1145-J5-1574 **Kedar M Nepal*** (nepal_k@mercer.edu), 1501 Mercer University Drive, Department of Mathematics, Mercer University, Macon, GA 31207, and **Khyam Paneru**. *Are They Doing the Homework or Only Finding the Answers?*

We will present results of a pilot and an actual study on Calculus students' use of web-based homework. We collected student answers to problems on web-based homework, the number of attempts they used, the total time they spent to complete the homework, and their grades on the homework. Weekly in-class quizzes were given the day after the homework had been submitted, which included problems identical to those on the most recent homework. Our results showed that overwhelming majority of students received very high grades on the homework, but half of them received a low D or F on the quizzes. About 70% of the students used at most two attempts to solve the problems. Those who received D or F on the quizzes had spent the least amount of time on the homework, but their homework grades were no different from those receiving high grades on the quizzes. Our results indicated that many students might complete their homework with a great deal of external assistance. We will present how a minor intervention can make sizable impact on their performance on in-class quizzes and exams. Control group scored significantly higher on the web-based homework than the treatment group, but the treatment group outperformed the control group on the in-class quizzes and exams. (Received September 23, 2018)

1145-J5-1866 **David Miller**, West Virginia University, Morgantown, WV , and **Joshua Case*** (jpcase@mix.wvu.edu), West Virginia University, Morgantown, WV. *Mathematics Students' Views of Proof and How They Change During an Introductory Proof Course.* Preliminary report.

Research related to undergraduate understanding of proof has produced two views concerning students' preferences regarding empirical and deductive approaches to argumentation. The first suggests that mathematics students who have been exposed to introductory proof instruction may still prefer empirical approaches. The second view posits that, while these students may engage in empirical strategies, they do not actually believe they are convincing. We contribute to this discussion by investigating how mathematics students' views of deductive and empirical arguments change during an introductory proof course. A survey was given at the beginning and the end of the course consisting of four claims and corresponding empirical and deductive proofs that they could choose from. They were also asked to evaluate the validity of each corresponding proof. In terms of proof preference, results suggest that students had improved in their deductive proof choices, supporting the view that these students indeed do not find empirical proofs convincing. In this talk, we discuss our study design, results, and conclusions and end with some teaching implications and future research directions. (Received September 24, 2018)

1145-J5-1887 **Matthew Voigt** (mkvoigt@gmail.com), **Antonio Martinez*** (aemartinez@sdsu.edu) and **Chris Rasmussen**. *Calculus variations as figured worlds for math identity development.*

Calculus is often an essential milestone during a students' time in college and can be especially impactful for students wishing to major in in a math or science field. Given its relative importance, the ways in which calculus courses are delivered can have a lasting impact on a student's trajectory and relationship with mathematics. Most notably, with how students perceive themselves as learners and doers of mathematics. In this study we document the ways in which three calculus course variations at the same university operate to promote different mathematics identities for students. In addition to the standard calculus, this university has a coordinated

calculus-physics course for advanced students and a life science course, which includes a focus on biology. We conducted focus groups with 3-5 students from each course variation. Drawing on the Holland et. al.'s (1998) framework of figured worlds, we showcase the ways in which these course variations act as if they are different calculus worlds that constitute socially organized and produced realms of being. We highlight the ways in which these figured worlds position or fail to position students with the opportunity to refigure themselves and others in relation to mathematics. (Received September 24, 2018)

1145-J5-1972 **Jeremy F. Strayer*** (jeremy.strayer@mtsu.edu), Department of Mathematical Sciences, Box 34, Middle Tennessee State University, Murfreesboro, TN 37132, **Yvonne X. Lai** (yvonnexlai@gmail.com), 306 Avery Hall, PO BOX 880130, Lincoln, NE 68588-0130, **Alyson E. Lischka** (alyson.lischka@mtsu.edu), Department of Mathematical Sciences, Box 34, Middle Tennessee State University, Murfreesboro, TN 37132, **Candice M. Quinn** (cmq2b@mtmail.mtsu.edu), Department of Mathematical Sciences, Box 34, Middle Tennessee State University, Murfreesboro, TN 37132, and **Cynthia O. Anhalt** (canhalt@math.arizona.edu), Department of Mathematics, 617 N. Santa Rita Ave., Tucson, AZ 85721. *A Working Framework for Observing and Interpreting Preservice Secondary Teachers' Development of MKT in Undergraduate Mathematics Courses.*

We present our work on developing mathematical knowledge for teaching (MKT) in preservice secondary mathematics teachers. Based on the analysis of 59 teachers' responses to tasks that approximate the practice of teaching mathematics in 2 content courses across 3 institutions during 3 different semesters, we propose a framework for observing and interpreting teachers' MKT. Our framework integrates (1) Silverman and Thompson's (2008) framework for examining the development of MKT; (2) Rowland's (2014) dimensions of MKT and categorization of teaching practices that elicit these dimensions; (3) and Ader and Carlson's (2017) framework for observing teaching actions that result from levels of decentering. Our data suggest that MKT may develop somewhat independently along different dimensions; and articulating key developmental understandings (Simon, 2006) is essential to describing the development of MKT. Our work is an important initial step toward a framework for helping mathematics instructors notice and cultivate the development of MKT in the preservice secondary teachers they teach in mathematics content courses. (Received September 24, 2018)

1145-J5-2155 **Anna Marie Bergman*** (a.bergman@pdx.edu). *What is a rotation? Mapping student's evolving descriptions of 3-dimensional symmetries.* Preliminary report.

In this presentation I will explore the various ways in which a pair of students described 3-dimensional rotational symmetries while investigating symmetry groups in the context of chemistry. During a series of teaching experiments, a pair of mathematics education graduate students were asked to develop an algorithm for classifying chemically important point groups beginning with an investigation of a few ball and stick models of molecules. The student's description of rotational symmetry evolved from highly contextualized and dependent on the location of particular atoms to a much more generalized description equivalent to a conventional definition. The progress the students made through the use of each definition of rotation is framed with the Realistic Mathematics Education design heuristic of emergent models. (Received September 24, 2018)

1145-J5-2367 **Jayleen L. Wangle***, wanglej@oneonta.edu. *An APOS Analysis of Calculus Student Comprehension of Continuity and Related Topics.*

In this study quantitative and qualitative methods were used to investigate Calculus I students' comprehension of the concepts of function, limit, and continuity. This talk will center on results from participant interviews. Items were designed to inquire about participant understanding of function, limit, and continuity. Participant responses were viewed through the lens of the constructs depicted by Dubinsky's (1991) Action-Process-Object-Schema theory. A prominent finding was that participants who demonstrated a stronger conception of function displayed a more in-depth understanding of continuity. (Received September 25, 2018)

1145-J5-2462 **Jeffrey Slye*** (jeffrey.slye@uky.edu), University of Kentucky, Department of Mathematics, 715 Patterson Office Tower, Lexington, KY 40506. *Mapping Mappings: Students' Reasoning on Morphisms in Both Linear and Abstract Algebra.*

It is well documented that students have difficulty with the more formal aspects of linear algebra, such as the abstract notions of linear transformations and vector spaces. From the point of view of abstract algebra, a linear transformation is a more restricted group homomorphism, and a vector space is a special case of a group. Many associated concepts such as images and kernels are also revisited in an abstract algebra class. It is then interesting to ask: Do students who continue on to see group theory make any connections between group theory and vector space theory?

In this talk I will present part of my dissertation study on students' ability or inability to make these connections. The data for this talk will mainly draw from semi-structured interviews and card sort activities conducted with ten undergraduate students who had encountered both linear algebra and abstract algebra. I will discuss some of the highlights of these interviews, and the interesting ways in which students use (or do not use) analogical reasoning to align concepts and make inferences. (Received September 25, 2018)

1145-J5-2473 **Paul Regier*** (paulregier@gmail.com) and **Milos Savic** (savic@ou.edu). *How Can Instructors Fostering Mathematical Creativity Build Student Self-efficacy for Proving?*

Mathematical creativity has been emphasized as an essential part of mathematics, yet little research has been done to study the effects of fostering creativity in the undergraduate mathematics classroom. In this talk, we explore how fostering mathematical creativity impacts student self-efficacy for proving. For this, we examined classroom observations, online surveys, and student interviews for evidence of Sriraman's (2005) five principles for fostering mathematical creativity and changes in students via Bandura's (1997) four sources of self- efficacy. This revealed connections between four of the five principles and changes in student self-efficacy for proving, along with two instances where the combined use of principles may have provided students greater opportunities for building self-efficacy for proving. Several implications of these connections and suggestions for future research will be discussed. (Received September 25, 2018)

1145-J5-2495 **William L Hall*** (w.hall@wsu.edu) and **Karen A Keene** (kakeene@ncsu.edu). *Contextual Reasoning in Calculus: A Qualitative Study of How Students from the Biological and Life Sciences Solve Calculus Accumulation Tasks.*

The contexts we select for mathematical tasks play an important role in how students reason through those tasks. Educators can leverage students' contextual reasoning in mathematics, provided we have a sense of how that contextual reasoning intertwines with and influences their mathematical understanding. We conducted task-based interviews with students from the biological and life sciences where students completed two calculus tasks that differed only by context. Results indicate students were more likely to interpret a graph representing the rate of change of a quantity incorrectly as the accumulated quantity if in a plant growth task compared with a kinematics task. Additionally, students solved the two tasks rather differently regardless of how they interpreted the graphs. In this session, we share details of this study as well as how these results have influenced a novel approach to teaching accumulation using differential equations and authentic contexts in the biological and life sciences. (Received September 25, 2018)

1145-J5-2556 **Amanda M Milewski*** (amilewsk@umich.edu), University of Michigan, 610 E. University Drive, Room 2405, Ann Arbor, MI 48109-1259, **Patricio Herbst**, MI, and **Claudine Margolis** and **Enes Abugka**. *What do we know about courses in Geometry for Secondary Teachers?*

While most teacher preparation programs rely on courses taught in mathematics departments to support the development of the novices' mathematical knowledge for teaching (CBMS, 2012), many have questioned whether the content of such courses is sufficiently connected to the work of a secondary teacher (Wu, 2011; Zazkis & Leikin, 2010). In the context of a five-year project that leverages the improvement science approach (Bryk, Gomez, Grunow, & LeMahieu, 2015) to develop an inter-institutional system of support the improvement of the undergraduate college geometry course for secondary teachers, we sought to better define the problem and the systems that contribute to it, as well as identifying possible improvement levers. We examine 20 college geometry courses (using syllabi, interviews, and course descriptions) across the U.S to document the variation across these courses. Using that data, we ask: (1) What is the variation in the mathematical content and methods being covered in GeT courses across the United States? (2) How might considerations of the nature of the work of instruction in college help us understand that variability and its probable relationships with the problem of developing capacity for teaching the high school geometry course? (Received September 25, 2018)

1145-J5-2570 **Melissa Newell***, Department of Mathematics, University of Connecticut, 341 Mansfield Road U1009, Storrs, CT 06269-1009, and **Fabiana Cardetti**. *Investigating Students' Mathematical Challenges and Corresponding Successful Support Strategies at a Quantitative Learning Center.*

At institutions of higher education many students make use of quantitative learning centers (QLCs) that support them in mathematics courses and other quantitative courses. Students that visit QLCs span across disciplines and backgrounds and have varied interest in mathematics. Often the support at a QLC is supplied through peer tutoring and these tutors' experiences provide them with insights into the students' needs that others may not have. Thus, through studying the practices and events within these centers we can garner valuable knowledge about students' mathematical challenges and corresponding successful support strategies. This presentation will discuss findings from a study addressing the questions: (1) What are the mathematical needs of the students who visit a QLC, and (2) What tutor strategies help students understand the mathematical topics they seek help with? The findings are based on analysis of two surveys distributed at a large, public research university, one to students who visited the university's QLC and one that was distributed to all students enrolled in calculus I, II, and two business math courses. Findings are also based on qualitative analysis of tutoring observations and interviews with students and tutors. (Received September 25, 2018)

1145-J5-2578 **Younhee Lee*** (yul182@psu.edu), 420 McAllister, State College, PA 16803. *Developing an advanced viewpoint on school mathematics in the learning of collegiate mathematics: Through the lens of a transformative transition framework.*

This report will present the result of a study investigating the question of "how might university students come to see school mathematics from an advanced viewpoint in their learning of collegiate mathematics?" The research design involved developing a categorical framework of transformative transition, which includes four categories of growth in one's mathematical understandings—namely, extending, deepening, unifying, and strengthening. The framework built on Piaget and Garcia's triad and the APOS theory. A set of teaching interviews was designed to provide a setting for participants' building on what they had previously known about factorization and polynomial equations in order to construct the unique factorization theorem for polynomials. Data collection included conducting a total of 40 interviews with six mathematics-intensive majors. This report will focus on an empirical elaboration of the categorical framework and discuss how participants enriched their prior understandings of factorization and polynomial equations by reexamining their previous assumptions and norms that seemingly had been exercised and established in their school mathematics. (Received September 25, 2018)

1145-J5-2613 **Erika J. David*** (ejdavid@asu.edu). *Undergraduate Students' Interpretations of Graphs of Real-Valued Functions with Statements from Calculus.*

In commonly-used Calculus curricula, graphs of functions accompany key definitions and theorems. Students' interpretations of the graphs they encounter may support or hinder their understanding of concepts in Calculus. This presentation describes an investigation of undergraduate students' interpretations of graphs of real-valued functions and their effects on their interpretations of Calculus statements. I conducted clinical interviews in which students were asked to evaluate propositional statements related to Calculus concepts using graphs of various functions. The related concepts were: (1) the Intermediate Value Theorem, (2) injective functions, (3) increasing functions, (4) continuity at a point, (5) the difference quotient, and (6) the Mean Value Theorem. Analysis of these interviews indicates that students' interpretations of graphs may differ from convention, that the same student's interpretations may differ across contexts, and that their interpretations may impact their interpretations of statements from Calculus. I describe the ways in which my analysis expands the constructs of value-thinking and location-thinking (David, Roh, & Sellers, 2017). I also discuss the implications of these findings for curriculum and instruction, as well as further research in this area. (Received September 25, 2018)

1145-J5-2675 **Shanah K. Grant*** (ssharpe5@student.gsu.edu) and **Draga D. Vidakovic**. *An In-Depth Investigation of How an Undergraduate Mathematics Student Learns the Concept of Proof.*

Mathematical proof is of high importance in the advanced proof-based courses which mathematics majors must take in order to graduate. Investigating how a competent student learns the concept of proof may be very beneficial in the curriculum development of proof courses. In this study, the Action-Process-Object-Schema (APOS) theoretical framework and the Self-Regulated Learning (SRL) theory were employed. A competent student in mathematics from an Introduction to Proof course was observed during the entire semester. The observational data was triangulated through follow up discussions after class observations and a final interview at the end of the semester. The results of data analysis indicate that the participating student was successful in writing valid proofs. Based on APOS theory, his conception of a proof was at least at the process level. The student's responses to a SRL questionnaire were used to develop a generalized linear regression model to predict student's grades based on his/her level of self-regulation and motivation. Suggestions on how to incorporate self-regulated learning in the classroom that is beneficial to students learning the concept of proof will be discussed. (Received September 25, 2018)

1145-J5-2678 **Kayla K. Blyman** (kayla.blyman@usma.edu), United States Military Academy, Department of Mathematical Sciences, 646 Swift Road, West Point, NY 10996, and **Bryan Adams** (bryan.adams@usma.edu), **Kristin M. Arney** (kristin.arney@usma.edu), **Lisa Bromberg*** (lisa.bromberg@usma.edu) and **David A. del Cuadro-Zimmerman** (david.delcuadro-zimmerman@usma.edu). *Positive Impacts of Discovery Learning Assessments.*

In an attempt to find ways to develop creative and critical problem solvers, we implemented a novel Discovery Learning Assessment technique in Mathematical Modeling and Introduction to Calculus during the Fall 2017 semester. This technique entailed weekly assessments in place of major exams. The assessments consisted of three parts: a night before read-ahead focused on a new application, an in-class individual portion where students responded to short answer questions, and an in-class group portion where groups of 3-4 students provided team responses to similar questions after discussion, learning, and consensus.

After assessing the impacts of the Discovery Learning Assessments on students' performance in the subsequent course – Single Variable Calculus – it was determined that the Discovery Learning Assessments had a statistically significant positive impact on first-time calculus students' performance. Additionally, across the population analyzed, the Discovery Learning Assessments did not hinder any subgroup's performance.

These results and other observations will be discussed. (Received September 25, 2018)

1145-J5-2710 **Brady A. Tyburski*** (tyburski@math.colostate.edu), **Andrew Darling**, **Cameron Byerley**, **Steven Boyce** and **Jeffrey Grabhorn**. *The Role of Improper Fraction Schemes in STEM Students' Conception of Measurement.*

Measurement plays a critical role in STEM fields. However, there is evidence that mathematics, chemistry, and medical students at the college level struggle to convert between units and decide if their answers are reasonable. This is despite the fact that these measurement concepts are elementary school standards. Steffe proposed that students must be able to coordinate three levels of units in order to conceptualize the relative sizes of units of measurement. He also stated that many students are not developmentally ready to learn measurement meaningfully at the age it is taught in the United States. This could have a long-term impact on those pursuing STEM majors in college. To model college students' understanding of measurement, we conducted task-based interviews with students taking a calculus I class for biological scientists. In these interviews, we diagnosed students' unit coordination and fraction schemes using validated items from prior research and then presented students with tasks involving unit conversion and ruler drawing. In this talk, we report on the factors that constrain or afford students from successfully completing such tasks. Special attention will be given to the role that students' improper fraction schemes play in accomplishing these tasks. (Received September 25, 2018)

1145-J5-2927 **Sandra L. Laursen***, 580 UCB, Boulder, CO 80309-0580, and **Charles N. Hayward** and **Tim Archie**. *Taking the long view: The influence of professional development workshops on instructors' teaching practice, ten years out.*

Professional development workshops on teaching are widely thought to be an important influence on instructors' teaching practices, especially in encouraging instructors to take up teaching approaches that emphasize active and collaborative learning. Yet relatively few studies document whether and how what instructors apply what they learn in a workshop, how long it takes for them to make regular use of new practices, or how long they persist with those practices. In 2016 we conducted a study of 90 instructors who attended a multi-day intensive workshop on inquiry-based learning (IBL) in 2006-2010. We will report results from a survey of these instructors (51 usable responses) and interviews with a subset of seven. Using evidence about the timing and nature of their engagement with IBL teaching methods, we discuss common trajectories of uptake for eager adopters, deliberate adopters, de-adopters, and non-adopters of IBL teaching methods. Spanning a longer time scale than is feasible in typical workshop evaluation efforts, this study examines instructors' sustained use and development of IBL teaching expertise, slow or latent uptake of IBL methods, and non-uptake, thus providing a rare opportunity to look back further in time. (Received September 25, 2018)

1145-J5-2933 **Luis A Leyva** (luis.a.leyva@vanderbilt.edu) and **Alexandria Cervantes*** (alecervantes@csumb.edu). *Detailing shifts in relational dimensions of Latinx students' mathematics classroom experiences between high school and college.*

Supportive relational spaces of K-12 mathematics classrooms have been documented as affirming the social backgrounds of underrepresented students in STEM. Relational dimensions of undergraduate mathematics classrooms, however, remain underexplored. This report, based on an interview study of 19 first-year college students, characterizes shifts in relational dimensions of students' mathematics classroom experiences between high school and college. To detail variation at a single intersection of racial and gender identities, we focused on the experiences of two Latinx women and one Latinx man pursuing mathematics-intensive majors. Three analytical themes were revealed. First, the students' reflections captured variation in the extent to which their mathematics teachers balanced developing mathematical content and providing relational support in high school and college. Second, the Latinx students described a contrast in high school and college mathematics instructors' sense of care about students' mathematical learning and future in STEM. Lastly, relational spaces of undergraduate classrooms influenced Latinx students' attributions of their successes and struggles in mathematics. These findings inform implications for relationally supportive instruction in college mathematics. (Received September 25, 2018)

1145-J5-2966 **Jessica R Gehrtz*** (gehrtz@math.colostate.edu), 1874 Campus Delivery, Department of Mathematics, Fort Collins, CO 80523. *Responsiveness: An underlying and enacted disposition.* Preliminary report.

There is evidence that instructors who are responsive to students' thinking tend to provide more positive learning experiences for students. Additionally, instructor dispositions towards student thinking influences what they attend to and how they respond to students, impacting learning. In order to investigate the construct of instructor responsiveness, eight college calculus instructors were interviewed three times over the course of one academic year. A preliminary thematic analysis of the task-based interviews highlights that instructors demonstrate responsiveness to student thinking during multiple phases of instruction (e.g. planning, in-the-moment teaching, grading or looking at student work), and that responsiveness takes the form of both an underlying disposition influencing instructors' pedagogical decisions and of an enactment of this disposition in the form of eliciting, reflecting, and responding to students' thinking. (Received September 25, 2018)

1145-J5-2969 **Andrew J Krause*** (krausea3@msu.edu), **Willie W Wong**, **Mark Iwen** and **Ryan Maccombs**. *Examining Student Engagement with Student-Driven Activities.* Preliminary report.

A wide range of teaching innovations have been implemented to promote active learning in college mathematics, such as course projects, in-class lab explorations, and even online homework. Research aimed at understanding the impact of these innovations has primarily focused on measuring student achievement–for example, Freeman and colleagues (2014) found that moving from traditional lecture to active learning substantially improved student achievement across a wide range of contexts. These achievement studies support the shift towards more student-centered teaching–this is good. However, achievement studies provide limited information about what college mathematics students are doing while they learn, how they feel about their coursework, and what motivates their learning strategies. I will present a qualitative examination of student engagement with calculus labs that has informed curriculum development, improved teaching, and helped us understand some of the complexity of students' learning experiences (especially with more student-driven activities). I will explain how this case study is an example of a research approach that can generate local data that compliments achievement studies to provide a more complete understanding of students' learning experiences. (Received September 25, 2018)

Ethnomathematics: Ideas and Innovations in the Classroom

1145-K1-143 **Henry Musisi*** (hmuusi@gmail.com), St. Mary's College Kisubi, P.O. Box: 26 Kisubi, Uganda(East Africa), Entebbe, Uganda. *Designing Sustainable Information And Communications Technology (ICT) Educational Tools For The Teaching And Learning Of Ethnomathematics In The 21st Century.*

As the world becomes more of a global village, it is incumbent upon us to realize and equip ourselves with a sustainable master plan of how we should handle and plan for a much more diverse community in terms of culture, ideology, and pedagogy without distorting the idea of belongingness. One key element in every society is that it aims at equipping its inhabitants with a basic level of mathematics—and this is achieved in very many ways—This paper therefore seeks to: explicate the ideologies of ethnomathematics across four major continents; Africa, Asia, America, and Europe, isolate all the unifying elements across the contents in question, review, suggest modifications, and creation of new sustainable ICT educational technological tools that can be used in the teaching and learning of ethnomathematics basing on all the unifying elements of the different cultures. In conclusion, the writer argues that the designing of sustainable ICT educational technological tools for the teaching and learning of ethnomathematics in the 21st century should not be based individual group beliefs, but on shared ideologies of basic ethnomathematics. (Received August 08, 2018)

1145-K1-255 **Satish C Bhatnagar***, Mathematical Sciences, 4505 Maryland Parkway, University of Nevada Las Vegas, Las Vegas, NV 89154. *Ethnomathematics of India.*

The Vedic Mathematics is the ethnomathematics of India. It is unique in its format. Ved/Veda, a Sanskrit word, also means knowledge, and Vedic means knowledge drawn from the Vedas, the most ancient scriptures of the Hindus.

For a number of reasons, the Hindus became the doormats for hundreds of invaders from Central Asia, Middle East and Europe. Subsequently, they lost all their treasures - including grandiose temples and institutions. In particular, the Vedic Mathematics disappeared from the cultural horizon of India for a few centuries.

The Vedic Mathematics got international traction and renaissance in 1964, when Bharati Krsna Tirthaji delivered a series of lectures on Vedic Mathematics in the US. In 1965, he published the most popular book, Vedic Mathematics, which is a set of eighteen sutras (aphorisms), for solving arithmetics problems encountered anywhere.

In 1980s, Vedic Mathematics got a boost from Maharishi Mahesh of the Transcendental Meditation fame, who supported its propagation. In the late 1990s, the Government of India implemented its introduction in schools.

This paper presents all the eighteen sutras and demonstrates the applications of one or two of them. Playing with these sutras is a mental calisthenics too. (Received August 25, 2018)

1145-K1-269 **Cynthia J. Huffman*** (cjhuffman@pittstate.edu), Mathematics Department, Pittsburg State University, 1701 S. Broadway, Pittsburg, KS 66762. *Maya Mathematics in a Geometry Classroom.*

Ethnomathematics shows students how dynamic mathematics is and how the development of mathematics is a function of culture and time. This talk presents ideas of how mathematics of the classical Maya culture can be incorporated in a geometry class. In particular, we will discuss activities that the presenter has been using in an informal geometry class for pre-service middle school mathematics instructors for several years based on using a rope as a tool to construct certain ratios and right angles. The right angle construction is especially interesting since it is based on equilateral triangles unlike the ancient Egyptian method of using the converse of the Pythagorean Theorem. (Received August 27, 2018)

1145-K1-634 **Amy Shell-Gellasch*** (ashellge@emich.edu), 4279 Lilac Lane, Ann Arbor, MI 48197. *Ancient Indian Verse and the Powers of 2.*

Ancient Indian culture regarded the writing of verse as a high art. In fact, even their mathematics was written in verse. An important component of writing verse was Prosody, determining which and how many syllables are stressed in each line of poetry. Ancient Indian's used an ingenious mathematical algorithm to determine how many syllables could be stressed. Given that they did not have exponential notation, their method is more efficient than straight multiplication. (Received September 11, 2018)

1145-K1-1372 **Rochy Flint*** (crf51@tc.columbia.edu). *Math Chavrusa: A Partnership Learning Model.* Preliminary report.

We introduce a new learning modality called Math Chavrusa. Inspired by the ancient rabbinic approach to Talmudic study, the chavrusa model pairs students in a partnership of deep text-based analysis, discussion, and debate. Over centuries the model has proved its ability to generate thorough understanding, build skills, develop the courage to question, and demonstrate to students the value of both independent thinking and collaboration. We propose that the Math Chavrusa model begin in Grade 7, with increased time spent in chavrusa as student maturity grows. Math Chavrusa is a complementary model to other accepted modalities for generating student understanding. It is particularly effective when employed after a lecture class. In teaching about the model, we will discuss its origins, how it facilitates deep learning and understanding in mathematics, and techniques for implementation. We have begun to utilize the model in our classes, and are gathering data about its real-world effectiveness. (Received September 21, 2018)

1145-K1-2971 **Elizabeth (Betty) C. Rogers*** (brogers@piedmont.edu), Piedmont College, Central Avenue, Demorest, GA 30535. *Multicultural Mathematics for Teachers: Making Mathematics Relevant for a Diverse Student Population.*

A large proportion, and in many cases, the majority of students in Atlanta area and Northeast Georgia schools are immigrants from many different countries and have no frame of reference to Eurocentric mathematics. Over the past eight years, the author has developed a course in Multicultural Mathematics for Mathematics Teachers. The course begins with the indigenous peoples of the Americas. It focuses on the pre-Columbian peoples of the areas from which many students came. This includes the Mayans, Aztec, and Incas. However, it goes back to

the civilizations that predated them such as the Moche, Chimu, and others in Peru. The course then crosses the Atlantic Ocean to Africa. In recent years, more research has been available on the cultural mathematics of this continent. From there, it continues through Thailand and the Middle East into Southeast Asia with Laos, Cambodia, and Vietnam. Less emphasis is placed on traditional countries such a Japan, China and Korea because they are not a prominently represented in the schools. In its journey around the world, the course focuses on Ethnomathematics as including pottery, weaving, architecture, numerical symbols, and even a comparison of pyramid construction. (Received September 25, 2018)

1145-K1-2972 **Darrah Chavey*** (chavey@beloit.edu), Beloit College, 700 College St., Beloit, WI 53511. *What Graphs Support Good Blockade Games?* Preliminary report.

Blockade games are played on a graph by moving pieces along the edges trying to block your opponent so they are unable to move their pieces. Such games are played on at least 5 different graphs, in at least 8 countries and 4 continents. To determine which graphs generated good games, we constructed a variety of criteria for "good games" based on standard approaches to gaming, and using thresholds of measures of quality determined by the games that exist in various cultures. Such criteria include ideas of fairness, complexity, and the presumption that improved skill and practice should result in more wins. The analysis of what graphs generate good blockade games showed, for example, that such graphs must be 2-connected. Analyzing all 2-connected graphs with at most 9 vertices (the maximum for all but 1 of the existing blockade games), including simulations of play on those graphs, we showed that game players across cultures had discovered essentially of the possible best games. In the classroom, our students play these games, discover aspects of this analysis on their own, and study other aspects of the analysis to help understand how we analyze games, and how we can compare the complexities of traditional games. (Received September 25, 2018)

Mathematical Experiences and Projects in Business, Industry, and Government (BIG)

1145-K5-57 **Aaron Luttman*** (luttmaab@nv.doe.gov). *Mathematics and Nuclear Nonproliferation: Big Data, Hard Problems, and Real Impacts.*

The US Department of Energy's National Nuclear Security Administration has the science of nuclear nonproliferation as one of its core missions. This involves the development of technologies for detecting nuclear proliferation, detecting detonations, international nuclear safeguards, and treaty verification. Whereas this has traditionally focused on the invention and design of physical systems, like radiation detectors or seismic arrays, there has been a redirection towards big data analytics and mathematical and statistical approaches to extracting actionable information from diverse sources of data. The idea is to develop analysis methods to enhance our ability to see smaller and more subtle signatures indicative of illicit nuclear proliferation in the data we already have. Data from experiments being performed at the Nevada National Security Site for the design and development of mathematical and statistical approaches to detecting "patterns of life" associated with nuclear experimentation will be demonstrated. The sensor systems are compact and mobile, with multiple sensing modalities but very low-quality data, and we will present some of the computational methods designed to find signatures in this data, along with some projects for student internships or graduate theses. (Received July 11, 2018)

1145-K5-92 **Darren Narayan*** (dansma@rit.edu), School of Mathematical Sciences, 85 Lomb Memorial Drive, Rochester Institute of Technology, Rochester, NY 14623-5604. *Trash Talking: Making Connections with the Waste / Recycling Industry.*

We will present applications of graph theory and a modified traveling salesman approach to optimizing route pickups by a local waste / recycling company in Rochester, NY. We will discuss the surprising number of intricacies involved in solving these problems. In addition, we will talk about how to start communication and build a successful relationship with this industry. (Received July 27, 2018)

1145-K5-561 **James H Fife*** (jfife@ets.org). *The automated scoring of mathematics responses containing text and equations.*

The immediate automated scoring of digitally-captured constructed responses is an important and necessary feature of large-scale summative assessments, where efficient and cost-effective scoring is required, and of smaller-scale formative assessments, where immediate feedback is part of the learning process. For computer-delivered mathematics tests, constructed-response questions often ask students to explain their answer to a problem. When these explanations involve only next, natural language processing (NLP) techniques can frequently be used to reliably score the responses automatically. But most of these explanations will also involve equations, and NLP techniques cannot analyze equations. In this talk, I will describe a project that combines NLP techniques with a computer algebra system (CAS) to score responses consisting of text and equations. Preliminary results indicate that the combination NLP+CAS produces scores that more closely agree with human scores than NLP alone. (Received September 10, 2018)

1145-K5-1237 **Tung T Thai***, Wentworth Institute of Technology, 550 Huntington Ave, BOSTON, MA 02115. *A Cost-Benefit Analysis of Cyber Defense Improvements.*

In the past few years, several major cybersecurity attacks on supervisory control and data acquisition (SCADA) devices have been reported. Such attacks can result in damages to the economy and have an impact on society. In 2010, Ten et al. presented an attack tree mode of impact analysis. We have implemented the attack tree structure developed by Ten, in concert with typical financial loss data to implement Monte Carlo techniques to generate a new cost-benefit analysis of various security improvement scenarios. Time to attack is modeled as an exponentially distributed random variable obtained via maximum likelihood analysis; financial losses are modeled using regression to generalized logistic functions via gradient descent. Under these conditions, hypothetical future losses are simulated for a variety of intrusion scenarios and improvement schemes. Our model incorporates budgetary constraints in an effort to advise the prioritization of system improvements, and we compare the results of genetic and differential evolution algorithms in determining an optimal budget allocation. (Received September 20, 2018)

1145-K5-2215 **Jeffrey Yeh*** (jeffreyyeh@cpp.edu), **Skyler Seto**, **Takahiro Noguchi**, **Sakura Hoshi** and **Yuya Ota**. *Optimal Vehicle Fleet Size and Fleet Management Control.*

In this talk, we discuss economic and operational policies for controlling Autonomous Mobility-on-Demand (AMOD) systems, wherein fleets of self-driving vehicles transport passengers in an environment. We start by describing the Model Predictive Control-Perfect (MPC-Perfect) model introduced in "Data-Driven Model Predictive Control of Autonomous Mobility-on-Demand Systems" by R. Iglesias et al. which proposes a time-expanded network, preemptive re-balancing strategy, and minimum feasible fleet size to satisfy all travel demand immediately. We then propose extensions to the model incorporating charging station visits, multiple passenger pickups, and other self-driving, electric vehicle attributes. The model is evaluated on New York city taxi demand data, and Sendai city person-trip data. In both cases, we demonstrate substantial profit over traditional services, while maintaining similar fleet sizes and guaranteeing immediate (or near immediate) passenger service.

This work was performed while part of the Graduate-Level Research in Industrial Projects for Students program with support from the Institute for Pure and Applied Mathematics, Toyota Motor Corporation, and Tohoku University. Sendai city data was provided by the Miyagi prefecture government. (Received September 25, 2018)

1145-K5-2571 **Tom Cuchta*** (tcuchta@fairmontstate.edu), Fairmont State University, 1201 Locust Avenue, Fairmont, WV 26554, and **Robert J. Niichel** (rniichel@fairmontstate.edu), Fairmont State University, 1201 Locust Avenue, Fairmont, WV 26554. *Machine learning and Monte Carlo at NASA.*

During the summer of 2017, our department was approached with a research opportunity for our students with a local NASA IV&V contractor, TMC^2 Technologies of West Virginia. We will discuss how the partnership was made, how we ran the internship/class, the expectations NASA had for us and the students, what we felt worked well (and what didn't) and how we plan to improve with future undergraduate projects. (Received September 25, 2018)

1145-K5-2839 **Mihhail Berezovski*** (mihhail.berezovski@erau.edu), Department of Mathematics, Embry-Riddle Aeronautical University, 600 S. Clyde Morris Boulevard, Daytona Beach, FL 32114. *Mentoring Undergraduate Research Projects in Industrial Mathematics.*

In this talk, we will discuss the challenges of mentoring undergraduate students in research projects on problems provided by business and industry. We highlight several different undergraduate research opportunities and student training in computational mathematics at ERAU, including the PIC Math program (Preparing Students for Industrial Careers in Mathematics) projects and ERAU Industrial Math projects. We will discuss getting students involved in these projects and share ideas for successfully designing and mentoring such projects. The outcomes of the projects and lessons learned from these research experiences will be presented. (Received September 25, 2018)

1145-K5-2905 **Abdul-Nasser El-Kassar*** (abdulnasser.kassar@lau.edu.lb), P.O. Box 13-5053 Chouran, Beirut, 1102 2801, Lebanon. *An Economic Production Quantity Model for a Multi-Stage Production Process with Raw Material and Quality.*

A multi-stage production process that takes into account the various costs of raw material/components required at each stage. The raw material /components acquired from different suppliers are assumed to contain imperfect quality items. In this multi-stage process with N stages of production, all stages are assumed to start simultaneously at the beginning of the production cycle. The stages may be machines, production processes, or departments (assembly, finishing,...). The production rates at the various stages $P_1, P_2, \ldots, P_N$ are assumed to satisfy the condition $P_1 > P_2 > \ldots > P_N > D$, where D is the demand rate of the finished product. This condition prevents the stages from being idle and allows inventory of semi-processed items to built-up between subsequent stages. A mathematical model is developed and a closed form formula for the optimal production quantity is derived. The costs of ordering, purchasing, screening, and holding the raw material/components as well as the cost of disposing of the imperfect quality items are incorporated into the model. Numerical examples are provided to illustrate the calculation of the optimal solution. (Received September 25, 2018)

Open Educational Resources: Combining Technological Tools and Innovative Practices to Improve Student Learning

1145-L1-73 **John Diamantopoulos*** (diamantj@nsuok.edu), 14854 N. Trent St., Tahlequah, OK 74464. *From Animated GIFs to GeoGebra: Using GeoGebra to Create Some "Proofs Without Words".*

I'm going to explain the process of how one could use GeoGebra to create "proofs without words". I'll then compare what I was able to create using just animated GIFs vs what I am able to do now using GeoGebra as my creation tool. (Received July 18, 2018)

1145-L1-272 **Bryan Adams*** (bryan.adams@usma.edu), United States Military Academy, 646 Swift Road, West Point, NY 10996, and **Dusty Turner** and **Andrew Plucker**. *Academic Apps: Teaching with Technology to Motivate Instantaneous Rates of Change.*

Fundamental to understanding differential calculus is understanding the derivative as an instantaneous rate of change. Despite rudimentary examples presented in textbooks, students often fail to see applications of a derivative to their daily lives. For first-time calculus students, this disconnect can severely limit their understanding of fundamental concepts and theorems presented in a calculus course. Thus, we offer a technique that allows students to collect personal activity data using a commercial application, RunKeeper, on a personal device. Once the data is collected, a ShinyApp created in RStudio transforms the data into a comma-delimited file that students can manipulate in order to investigate their own rates of change. The process of collecting and analyzing personal activity data serves two purposes in the classroom: it allows students to discover the necessity of the limit as they analyze their own rates of change and it allows students to see how calculus is used to describe the physical world. (Received August 30, 2018)

1145-L1-350 **Chung Y Wong*** (cwong@ccm.edu), 214 Center Grove Road, Sheffield Hall 307, County College of Morris, Randolph, NJ 07869. *Taking Advantage of Smartphones: Using Kahoot to Keep Students Engaged.* Preliminary report.

As technologies continue to advance every day, so does their effects on our students. It would not be a stretch to say that every student checks their phones at least once during class. Therefore, instructors have to adapt to the changing student behaviors in order to reach them effectively. In this presentation, I will discuss my experience on using Kahoot, a free online game-based platform, to engage students in my developmental courses. Preliminary observation on its impact for the class will be presented, and a demonstration on how to create a game on Kahoot and how a game is run will also be provided. (Received September 03, 2018)

1145-L1-440 **Ariel Cintron-Arias*** (cintronarias@etsu.edu), Department of Mathematics and Statistics, Box 70663, East Tennessee State University, Johnson City, TN 37614-0663, and **Michael Garrett** and **Ryan Nivens**. *Improving Distance Learning of Advanced Mathematics.* Preliminary report.

Learning mathematics above Calculus I with asynchronous online content is demanding for students. Their time management and self-discipline must leave almost no room for error. One of the key aspects in achieving proficiencies is for the distance-learning students to receive high-quality feedback about their academic progress. We devised a plan to improve the quality of the feedback provided to the distance-learning students that included:

(1) office hours by video conference technology; (2) supplemental instruction with live video streaming and archive of recordings; (3) automatically graded exercises with multiple but limited submissions; (4) portfolio exercises that were manually graded, and in selected cases could be resubmitted to earn recovery points; (5) proctored examinations using an electronic platform to display questions, while collecting hand-written answers in examination booklets; (6) Reports of online activity generated by the students while tracking completion of weekly expected tasks. We successfully implemented this plan during a 10-week summer session in three different courses: Calculus II; Linear Algebra; & Differential Equations. In this talk, we report some of our preliminary results in implementation. (Received September 06, 2018)

1145-L1-542 **Razieh Shahriari** (rshahria@uark.edu) and **Nama Namakshi*** (namakshi@uark.edu). *An investigation into college algebra students' learning logarithm concepts using smartphone apps.*

This mixed-methods study reports on the effectiveness of using apps in teaching logarithms to students in college algebra classes. In this study, two smartphone applications (apps) were used to investigate students' understanding of logarithm concepts. 150 students enrolled in four different college algebra sections in fall 2016 participated in this study. Students in two sections were asked to use two educational apps as class activities (treatment sections), and two sections (control sections) worked on worksheet. Written tests and interviews were used to discover students' understanding and misunderstanding. Written test questions were designed based on Bloom's six levels of learning. Data from students' written tests and interviews were collected and analyzed. Students understanding of logarithms concepts categorized in five levels. In addition, students' errors were identified and categorized. The result of the study indicates that students who used apps made accurate connections between logarithms and exponential functions and performed better in applying some logarithm properties. However, students performed equivalently on questions that require higher level of understanding and reasoning. (Received September 09, 2018)

1145-L1-707 **Jorge Florez*** (jflorez@bmcc.cuny.edu), 199 Chambers Street, New York, NY 10007, and **Jae K Lee**, 199 Chambers Street, New York, NY 10007. *Incorporating Open Educational Resources and Active Learning Strategies in the mathematics Gateways courses at an urban community college.*

In recent years there has been a fast increasing presence of Open Educational Resources (OER) and Student-Centered instructional strategies in college math classrooms across the country. This trend is the consequence of an effort to make college more affordable for economically disadvantaged students, as well as to enhance pedagogical effectiveness through intellectual engagement. The scope of our grant Opening Gateways to Completion has been to provide BMCC faculty with training and exposure to the latest educational developments in these areas of education. We carry this out by conducting a semester-long seminar where our main goal is to create an interactive environment for our faculty fellows to work collaboratively, with the guidance of leading experts, to design learning activities that incorporate these areas of education.These professional faculty seminars established a new community where the faculty members can share ideas and enhance instructional methods in their classroom. In this talk we will present some of these exciting learning activities developed by our fellows from ideas that were born in this seminar. (Received September 13, 2018)

1145-L1-765 **Christina M Ferrante** (christinaferrante2@mail.adelphi.edu) and **Lara M Klein*** (laraklein@mail.adelphi.edu). *Refining Mathematical Curriculum.*

In this research project, we will survey the topics typically covered in liberal arts colleges for the undergraduate mathematics curriculum. We will determine the most important concepts and write detailed proofs, including every logical step required. We will directly focus on informing undergraduate math majors on successful procedures in Calculus 1, Calculus 2, Methods of Proofs, and Geometry. The goal is to create a freely-available online resource for mathematics students to use as a guide as well as a reference in their courses. (Received September 14, 2018)

1145-L1-870 **Lina Wu*** (lwu@bmcc.cuny.edu), 529 West 42nd Street Apt. 5K, New York, NY 10036. *Discussion of Various Technical Strategies Used in College Math Teaching.* Preliminary report.

Educational technology has encouraged students' learning success by enriching teaching in an interesting way, doing exercises in an active way, and studying math in a real-life environment. The presenter would like to share her experience on the use of different educational technologies in college math courses, such as Algebra, Statistics, and Calculus. The following technical strategies will be discussed: 1. E-Blackboard and Video teaching materials used in Flipped Classroom Approach 2. WeBWork online homework system used as Open Educational

Resources 3. Digital games used in Game-based Learning Approach 4. Maple Software used in Project-based Learning Approach Technology used in math teaching has made students see the value in learning math and has encouraged students to merge math into their daily life. (Received September 16, 2018)

1145-L1-968 **Johannes C. Familton*** (jfamilton@bmcc.cuny.edu), Mathematics Department, 199 Chambers Street, New York, NY 10007, and **Ke Xin**. *Developing a OER/ZTC for quantitative reasoning.*

Quantitative Reasoning was first introduced to Borough of Manhattan Community College which is a part of the City University of New York in 2007 by Professors Teixeira and Reese. This is a one semester credited math course that was originated an alternative to Statistics or Foundation of mathematics for liberal arts students. Quantitative Reasoning focuses on helping students to think critically and solve problems in everyday life. It used the standard Quantitative Reasoning text book, at the time, by Bennett and Briggs, Using and Understanding Mathematics: A Quantitative Reasoning Approach, with a price tag now of almost 200, more than most liberal arts students want to pay for a one semester math course. Over the summer of 2018 Professors Familton and Ke have developed an OER version of this course that includes notes based on the lectures that act as the course textbook and on line homework program developed by Professor Xin that students can sign up for and access free of charge. In this talk we will talk about our experience developing an OER for Quantitative Reasoning and piloting the course for BMCC in the fall semester of 2018. (Received September 17, 2018)

1145-L1-1094 **Ariane Masuda*** (amasuda@citytech.cuny.edu), New York City College of Technology, Department of Mathematics, 300 Jay St., Brooklyn, NY 11201, and **Lucie Mingla** (lmingla@citytech.cuny.edu), New York City College of Technology, Department of Mathematics, 300 Jay St., Brooklyn, NY 11201. *Engaging College Algebra and Trigonometry students with OERs.* Preliminary report.

The Opening Gateways project is a five-year cross-campus collaboration between the mathematics departments of New York City College of Technology and the Borough of Manhattan Community College supported by the DOE. Focused on promoting student success in gateway mathematics courses, Opening Gateways engages faculty in an intensive seminar that introduces active learning strategies, open educational resources, and open digital pedagogies. In this talk, we will show the open educational resources that our team has developed and discuss how we made them available to the entire mathematics department. We will also showcase several DESMOS (a free online graphing calculator) activities we created for our own College Algebra and Trigonometry classes, and share classroom experiences and best practices for their implementation. (Received September 18, 2018)

1145-L1-1111 **Minsu Kim*** (minsu.kim@ung.edu), 1560 Gallant Fox LN, Suwanee, GA 30024. *Effectiveness of Adopting Open Educational Resources Platforms in Blended Learning: Undergraduate Mathematics Student Learning, Achievement, and Perspectives on an Innovative Pedagogical Approach.*

Adopting open educational resources (OER) with an organized educational frame has the potential to not only reduce student cost for learning materials but also improve student learning, instructional methods, and educational environments. The aims of this study are to explore student perspectives on the use of an OER platform in blended learning, and to examine student achievement, engagement, and opportunity for learning mathematics. As a mixed project, the data was collected from 423 students in 15 sections of Elementary Statistics during four semesters. The results of this study showed that the use of an OER learning platform in blended learning promoted student engagement and significantly increased student opportunity for learning. There were not significant differences in student achievement between adopting an OER learning platform in blended learning and adopting commercial resources in regular classes. This study will contribute to the knowledge of the open educational use of technology. (Received September 19, 2018)

1145-L1-1157 **Matt Boelkins*** (boelkinm@gvsu.edu). *Active Preparation for Calculus: a new free and open text.* Preliminary report.

This talk is a preliminary report on a new text that is expected to be publicly released in January 2019. *Active Preparation for Calculus* is a free and open source textbook written in Rob Beezer's PreTeXt (https://mathbook.pugetsound.edu/): as such, it will be freely available in HTML format with interactive Desmos graphics and anonymous WeBWorK exercises. The text is designed to engage the reader and instructor with active learning pedagogy in the spirit of the text *Active Calculus*; the text is organized as a preparatory course for students not yet ready for calculus, focusing on functions and models, average rate of change, and other concepts that are heavily used in calculus. In my presentation I'll share features of the text, information about free and open ancillary supporting materials, and perspective on both using and writing the text. (Received September 19, 2018)

1145-L1-1223 **Michael E Gage*** (gage@math.rochester.edu), Department of Mathematics, University of Rochester, Rochester, NY 14627. *Using WeBWorK with WebSim, SageMath and Geogebra to teach the simplex method, linear algebra and other aspects of a Linear Optimization course.* Preliminary report.

This talk will present recent innovations in using WeBWorK and other open source software to teach the simplex method and other aspects of linear algebra in a Linear Optimization course. In particular the javaScript program WebSim designed by Prof. Glenn Hurlbert (VCU) can now interoperate with WeBWorK reducing the tedium of entering and manipulating data by hand while still requiring students to understand the simplex procedure.

The "scaffold" question type creates a sectioned worksheet where students must complete the first segments before the next segment is presented. The sectioned worksheet forces a careful step-by-step analysis and explanation of two and higher dimensional examples and leads students to a deeper understanding of both the simplex method and procedures from their previous matrix algebra course.

Since this course was first taught 4 years ago the pool of WeBWorK questions has grown in size, quality and variety of topics. There are new tools for authoring questions incorporating tableaus.

Automatic grading allows this homework to be used in large classes or assigned as optional independent study.

The interoperability of the open source WeBWorK, WebSim, Geogebra, MathSage systems provides an excellent platform for further exploration. (Received September 20, 2018)

1145-L1-1255 **Carrie Diaz Eaton*** (cdeaton@bates.edu). *Opening the classroom: Adopting and Adapting Open Educational Resources and Open Source Software for a Discrete Computing Course.*

In our new Computational and Digital Studies program, we have decided to commit to the use of Open Educational Resources (OER) and Open Source Software (OSS) in the teaching of our courses. In this talk I discuss how I approached this challenge in the context of developing a Discrete Structures and Modeling course. I also discuss some of the OER platforms that I used, such as QUBES Hub, the challenges I had, and the professional development and personal support I received to help learn about and adapt my resources. I will also talk broadly about QUBES research into the challenges of OER ecosystems in the adopt, adapt, revise, reshare framework. (Received September 20, 2018)

1145-L1-1311 **D Scott Dillery*** (dillerys@lindsey.edu), 802 N Central Avenue, Campbellsville, KY 42718. *SageMathCell and Automated Interactivity.*

Embedded SageMathCells offer the ability to create a wide variety of activities that go beyond the standard problems of most mathematics problem software. Unfortunately, it has been challenging to more automated experiences for students that allow for interaction with the web page as well as the student and for recording results. I will report on combining php, html forms and SageMathCell to create interactive quizzes with multiple attempts. (Received September 20, 2018)

1145-L1-1494 **Sun Young Ban*** (sunyban8@gmail.com). *The Influence of Technology on Mathematics Anxiety in Developmental Mathematics Courses.* Preliminary report.

This study investigated the influence of technology on students' mathematics anxiety in the developmental mathematics classroom in an urban community college. The participating students (n=185) were recruited for this study: Half of whom were in lecture classrooms without using technology, and other half of whom were in inquiry-based learning classrooms with technology such as google classroom, online educational software, or other open educational resources over the academic 15-weeks. The overall findings were that there was a significant difference between two different instructions in measuring students' mathematics anxiety. This study concludes with a discussion how the use of technology including WeBWork, cloud-based apps and other open educational resources impacts students' mathematics anxiety, and demonstrates whether technology integration in an inquiry-based learning classroom supports students learning in developmental mathematics courses in an urban community college. (Received September 22, 2018)

1145-L1-1521 **Victor Sirelson*** (vsirelson@citytech.cuny.edu), 9 Dekay Road, Warwick, NY 10990. *Creative use of online tools to enhance teaching of Mathematics.*

The advent of new online programs provides vast opportunities for instructors for creative classroom teaching. Too often we rely on formal lectures and Power Point presentations and then find it awkward to encourage dialogue with students. Two tools that are both flexible and engaging for students are graphing and online homework programs. Using the homework program WebWork and the online graphing program Desmos, I will illustrate both prepared and improvised techniques for addressing topics in different levels of math classes. These approaches can be used for many subjects. Applications will include Shifting Parabolas and the Unit Circle for Algebra and Trigonometry, the Normal Distribution and applications for Statistics, analysis of domains for Pre-Calculus and introducing limits and the difference quotient for Calculus. (Received September 22, 2018)

1145-L1-1548 **Lee Stemkoski*** (stemkoski@adelphi.edu). *Virtual and Augmented Reality Applications for Math Education.*

In this talk, we will begin by describing some current applications in mathematics education that make use of virtual reality and augmented reality. We then present some new applications that use A-Frame, an open-source framework which can be used to develop both virtual reality and augmented reality applications. The A-Frame library greatly simplifies the content creation process by using an HTML-like tag system, and also simplifies dissemination by enabling applications to be shared as websites. Virtual reality applications can be experienced with inexpensive technologies such as Google Cardboard or Oculus Go, while augmented reality applications can be experienced with smartphones, tablets, or desktop computers with webcams. (Received September 23, 2018)

1145-L1-1751 **Marianna Bonanome*** (mbonanome@citytech.cuny.edu), 131 Fairfax Road, Massapequa, NY 11758. *Creating and using Open Educational Resources and STEM Applications for Algebra and Trigonometry Courses.*

Opening Gateways to Completion is a 5 year Title V collaborative grant between the New York City College of Technology and the Borough of Manhattan Community College, CUNY. As part of the grant's activities, cohorts of full-time and part-time faculty grant participants from both campuses take part in an intensive professional development seminar, where they are exposed to active learning strategies, open digital pedagogies, multiplayer and flipped classroom techniques, games in the classroom, WeBWorK, Desmos and much more. Join us as we present some of the exciting OERs, activities and STEM applications developed and utilized by our grant participants for their Algebra and Trigonometry classes. (Received September 24, 2018)

1145-L1-1801 **Axel Brandt*** (brandta2@nku.edu). *An OER Cycle in a Calculus Course.*

We discuss the structure of a Calculus 1 course in which students cycle through a variety of OER technological tools for each section of course material. The OER cycle begins with reading an open-source textbook on a collaborative reading platform (Perusall) prior to class. Then students process course material in part through an in-class voting/clicker system (Plickers) using questions from a repository of questions (Cornell Good Questions). Students complete homework online (Edfinity/WeBWorK) before restarting the cycle by reading the next section of the textbook. Although the emphasis of this talk is on the implementation and utilization of OER technologies, we will also discuss their impact on student learning. (Received September 24, 2018)

1145-L1-1952 **K. Andrew Parker*** (kparker@citytech.cuny.edu). *Open-Ended Exploration Problems: Using WeBWorK to Break the Textbook-Problem Mold.* Preliminary report.

Open-source online homework software, such as WeBWorK, enables instructors to craft just about any problem they can think of. So why do the majority of online homework problems still look like they came straight from a textbook?

This talk will showcase new instructional content, powered by WeBWorK and GeoGebra in tandem, designed to support student inquiry by circumventing the standard "here's a problem, now do something with it" homework paradigm. These new problems challenge students to create and solve their own problems; and for instructors, the underlying framework presents rich opportunities for further development and creativity.

This work is funded by Opening Gateways to Completion, a collaborative Title V grant between New York City College of Technology and Borough of Manhattan Community College. (Received September 24, 2018)

1145-L1-2102 **Anna Davis*** (davisa@ohiodominican.edu) and **Paul Zachlin** (pzachlin@lakelandcc.edu). *Creating and Using Multimedia OER Modules for a Linear Algebra Course.*

The Ohio Department of Higher Education funded a statewide initiative to create and adopt open educational resources for 20+ college courses, including a Linear Algebra course. A team of six faculty members representing a wide variety of public and private institutions worked as content writers and reviewers to create a set of multimedia modules that can be used as a primary content source or in conjunction with another OER text to teach an introductory course in Linear Algebra. The modules utilize the open Ximera platform to provide an interactive experience to users through machine-graded exercises, embedded demos, and videos. The modular structure of the content allows for greater flexibility. The multimedia aspect of the materials make them well-suited for use in a variety of instructional settings, including traditional, flipped, and online classrooms. In this presentation we will showcase the materials, discuss different approaches to using them in the classroom, and share information about using the product and opportunities to contribute to its further development. (Received September 24, 2018)

1145-L1-2137 **Debasmita Basu*** (basud2@montclair.edu), basud2@montclair.edu, and **Nicole Panorkou** (panorkoun@montclair.edu), panorkoun@montclair.edu. *Developing Students' consciousness about Greenhouse Effect through Dynamic Mathematical Activities.*

This study focuses on the role of critical mathematics literacy (Frankenstein, 1990) to help students examine the socio-political issues of the greenhouse effect by analyzing and identifying patterns in mathematical data and graphs. Although most of the essential information about the greenhouse effect in news media and weather reports is expressed in the form of graphs, the interpretation of such graphs is challenging for students. Students often focus on the shape of the graph, overlooking the covariational relationship between the concerned quantities (Monk & Nemirovsky, 1994). To address this issue, in this study I developed a set of mathematical dynamic modeling tasks in NetLogo (Wilensky, 1999) and implemented them in two middle school classrooms. The results of the study show that the dynamic nature of the tasks enabled students to identify the covariational relationships between the quantities that affect the greenhouse effect, such as identifying the covariational relationship between carbon-dioxide and air temperature, and carbon-dioxide and height of sea level. Identifying these mathematical relationships developed within students a critical consciousness about the causes and consequences of greenhouse effect. (Received September 24, 2018)

1145-L1-2138 **Sieben Nandor*** (nandor.sieben@nau.edu), AZ. *Administering and using WeBWorK across the curriculum.*

Our Department is an early adopter of the free online homework delivery system WeBWorK. We successfully use it on a wide spectrum of courses, from Quantitative Reasoning to graduate level Linear Algebra. In this talk I share our experiences. I also explain how our WeBWorK server is set up and what I do as the system administrator of the server. This includes training new faculty, creating student roster files, creating recommended problem sets for each course, creating daily backups of the classes, monitoring the server, using and editing the Open Problem Library, and writing new problems. (Received September 24, 2018)

1145-L1-2222 **Corey Irving*** (cfirving@scu.edu). *From WebWork to Edfinity, Making the Transition.* Preliminary report.

We share the experiences of the medium-sized Department of Mathematics and Computer Science at Santa Clara University (SCU) as we incorporate more online homework into our courses. We have used several commercial and open-source systems, but the long term goal is to move to an open-source system. Our first effort used WeBWorK, supported by the MAA and NSF. The system has many great features and worked well for the department at first, but we found it hard to get faculty onboard, mostly due to an onerous user interface. We are currently transitioning to another NSF-supported system, Edfinity, for which we are a beta-testing site. Edfinity is basically a nice front end for WeBWorK. It leverages the WeBWorK infrastructure, in particular the Open Problem Library, but has many additional features that are great for SCU, such as managed hosting, student analytics, and an intuitive product user interface. The transition to online homework and further to open-source online homework has not been trivial, but is really worth the struggle. The goal of the talk is to share our experience moving from WeBWorK to Edfinity. (Received September 25, 2018)

1145-L1-2335 **Davide P Cervone*** (dpvc@union.edu) and **Volker Sorge** (v.sorge@mathjax.org). *MathJax v3: Modern Mathematical Typesetting for the Web.*

MathJax is a javascript program that has been making it easy to typeset mathematics (in LaTeX, MathML, or AsciiMath formats) within web pages for ten years. Over that time, however, much has changed with the features available in web browsers, and with website design technologies. MathJax version 3 is a complete rewrite of MathJax from the ground up that takes advantage of modern web tools and programing paradigms. In this presentation, we discuss the new organization of MathJax v3, how it differs from version 2, and why some of the changes were made. We give examples of how version 3 can be used both in the browser and on a server, and describe some mechanisms for creating extensions and additions. (Received September 25, 2018)

1145-L1-2382 **Michael P Hitchman*** (mhitchm@linfield.edu). *An Open Access Conversion Experience in Geometry.*

This talk focuses on one author's experience in converting a previously published geometry text into an open access text using PreTeXt, and on the impact an open access text has had on student involvement in a non-Euclidean geometry course. (Received September 25, 2018)

1145-L1-2431 **Philip DeOrsey***, pdeorsey@westfield.ma.edu. *What is Precalculus?: My journey in developing active learning materials.*

What content should you cover in precalculus? This question is hard to answer by following traditional precalculus textbooks as they contain many topics that won't appear in a typical calculus course. To help myself answer this question I created a list of prerequisite topics I felt were necessary for calculus as I taught the course. From this list I created guided activities and turned them into a workbook titled "Guided Activities for Precalculus." I will talk about my choices for content, my creation of coordinated YouTube videos, my use of Desmos and WeBWorK, and introduce my workbook as a new open resource for precalculus. (Received September 25, 2018)

1145-L1-2454 **Bob Carmichael*** (bobc@edfinity.com) and **Davide P Cervone** (dpvc@union.edu). *Edfinity: Enhancing traditional high-school education materials.*

Edfinity is an online homework system that allows you to create and manage courses and assignments in mathematics. You can choose questions from a large library of existing problems, or you can create new problems using Edfinity's built-in problem editor, either through its own problem templates, or using WeBWorK's PG problem language. Edfinity has access to the complete WeBWorK Open Problem Library, but we have been developing a new corpus of problems and resources centered on the International Baccalaureate (IB) and International General Certificate of Secondary Education (ICGSE) standards. These were field tested in India in the fall of 2018. In this talk, we describe Edfinity, the new materials we have developed, the results of their use in India, and our future directions. (Received September 25, 2018)

1145-L1-2768 **Zephyrinus C. Okonkwo*** (zephyrinus.okonkwo@asurams.edu), 504 College Drive, Albany, GA 31705, and **Anilkumar Devarapu** and **Robert S. Owor**. *An Examination of the Impact of Affordable Learning Georgia Textbook Transformation Projects on Instruction, Learning, and Student Achievement at Albany State University.*

University System of Georgia (USG) encourages faculty members to apply and receive the Affordable Learning Textbook Transformation Grants which enable them to develop resources as well as utilize Open Education Resources (OER) for course instruction. In most cases, these courses are zero-cost textbook courses, whereby every student in the class has access to an ebook. The ebook is usually reposed on the course learning platform (GeorgiaView). This state-wide grant has saved students millions of Dollars. In this presentation, we discuss the data collected on such grant activities on three distinct courses which have led to positive outcomes. (Received September 25, 2018)

1145-L1-2775 **Yevgeniy Milman*** (ymilman@bmcc.cuny.edu). *Quick Adaptation and Effective Use of OER Homework Platform in Algebra, Precalculus and Quantitative Reasoning Courses.*

The use of online homework platforms had become a common place in developmental and gateway mathematics courses. There are various commercial products available that are usually attached to a specific textbook. However, many instructors have developed their own problem sets and/or have written manual for their students. As an alternative to commercial products, there are few OER online platforms available. There is a misconception that adapting OER platform is time consuming task and requires programming knowledge to write your own question. The presenter will demonstrate the ease of adaptation of MyOpenMath platform in elementary and intermediate algebra, quantitative reasoning as well as precalculus courses. This presentation will give an overview of creating your own questions, integrating them with the extensive database of the available questions and aligning . The overview of gradebook and analytics features of this platform will also be discussed. (Received September 25, 2018)

1145-L1-2782 **Zeynep Akcay*** (zakcay@qcc.cuny.edu), 222-05 56th Ave, Bayside, NY 11364. *How does using OERs and teaching online effect student success at a community college?* Preliminary report.

Queensborough Community College - CUNY (QCC) has been actively encouraging faculty for teaching of online or partial online courses by offering relevant workshops. Many of Mathematics faculty at QCC has taken advantage from these opportunities. On the other hand, there has been a CUNY-wide initiative for spreading the use of OERs and the Math department has been granted funding as part of this initiative. Courses ranging from Quantitative Reasoning to Precalculus has switched to OERs. We will first introduce overall efforts of the math faculty for switching to OERs and online courses by numbers. Moving from traditional textbooks to OERs and from teaching regular classes to online, are we able to maintain the quality the courses offered? The results from the assessment that has been done on Precalculus sections which use OERs will be shared and discussed. Finally, student success form regular sections of College Algebra will be compared with those from partial online sections. Relevant student feedback will also be provided. (Received September 25, 2018)

1145-L1-2843 **Michael D. Miner*** (michael.miner0@mycampus.apus.edu), 65 Edenbrook Dr., Hampton, VA 23666. *Open Educational Resources Adaptation for Mathematics Instructions in Online Mathematics Courses.* Preliminary report.

As a result of a study examining "the impact of open textbook adaption on the learning outcomes of post-secondary students", American Public University System, a prominent online university, tasked faculty to convert courses to adapt Open Educational Resources (OER) where applicable. In the initial phase of this initiative, several mathematics courses were targeted for conversion to OER. MATH200, Analytic Geometry, was one of those courses. This presentation will discuss the road-map to successful conversion and implementation of MATH200 to a textbook free course employing OER. (Received September 25, 2018)

1145-L1-2882 **Matt Sunderland*** (matthew.sunderland@csi.cuny.edu), Mathematics Department, 2800 Victory Blvd, Staten Island, NY 10314. *Challenges and Opportunities of Using WeBWork as a Free Homework System in Teaching Calculus.* Preliminary report.

Online homework can play an important role in mathematics learning and teaching. To support and advance students' learning processes, online math problems must be pedagogically well-formed and designed to engage understanding of mathematical concepts.

In this presentation, the author will share his experiences using WeBWork, an online homework system, in teaching Calculus courses. How does WeBWork provide opportunities to implement inquiry based learning pedagogy in teaching? How does WeBWork bring opportunities to students for enhanced engagement and access. Finally, what are the challenges of using WeBWork for professors and students? (Received September 25, 2018)

1145-L1-2967 **Ke Xin*** (kxin@bmcc.cuny.edu), 11055 72nd RD Unit 102, Forest Hills, NY 11355, and **Jean Richard**, **Bernard Beecher**, **Lucio Prado**, **Daniela Bardac-Vlada** and **Shahin Uddin**. *Open Educational Resources for a Co-requisite Course: Introductory Statistics with Algebra.*

The movement of Open Educational Resources (OER), with the objectives of inexpensive knowledge acquisition, constitutes a positive change in the production and distribution of textbooks, at the level of higher education. But there is a challenge. Most OER mathematics textbooks are being offered without a compatible online platform for homework assignments and support for students out of the classroom. In this presentation, we will introduce a new platform, with OER homework and video resources that we created. This platform was tailored for the Introductory Statistics with Algebra course, to reinforce mathematical concepts and techniques, and ultimately to enhance teaching and learning. This course integrates Introductory Statistics, with selected algebraic concepts, with the objective of helping non-STEM students gain exemption from remedial mathematics, while acquiring 4 credits in Introductory Statistics. We will present the challenges and successes of this online homework platform by demonstrating its capabilities. (Received September 25, 2018)

1145-L1-2982 **Jean Richard*** (jrichard@bmcc.cuny.edu), 552 Parkside av apt D4, Brooklyn, NY 11226, and **Ke Xin**, **Bernard Beecher**, **Luio Prado**, **Shahin Uddin** and **Daniela Bardac-Vlada**. *The evolution of an introductory Statistics course with Algebra for non-Stem majors.*

This presentation describes the challenges encountered in a Statistics course with Algebra created for non-STEM related fields and the methods used to face these challenges. In most community colleges across the United States, students must be exempt from remedial algebra before registering for an introductory statistics course. Since students cannot successfully complete the remedial algebra course, we proposed that concepts of elementary algebra be embedded in a traditional introductory statistics course, allowing students to fulfill the remedial course in the same semester and receive college credit for statistics. Due to the course's success, we had increased the number of sections and were faced with several challenges. Our talk will cover how we are experimenting with an Open Educational Resources textbook, and an online homework platform that we created. We will also describe the model workshops, used to train professors on how to teach the course, and the model of Supplemental Instruction (SI) leaders in the classrooms. (Received September 26, 2018)

Philosophy of Mathematics

1145-L5-228 **Thomas D Morley*** (calcprof@gmail.com), School of Mathematics // Georgia Tech, 686 Cherry St // Skiles Building, Atlanta, GA 30332. *Feynman's Funny Pictures.* Preliminary report.

"They were funny-looking pictures. And I did think consciously: Wouldn't it be funny if this turns out to be useful and the Physical Review would be all full of those funny looking pictures. It would be very amusing." – Richard Feynman In this talk we cover briefly several ways of looking at one of the most important new notations of the twentieth century – the Feynman diagram. Feynman Diagrams were originally invented to keep track of terms in a perturbation series (Wick's expansion of a Dyson series) of the scattering matrix of a physical process with interaction(s). Yet they seem to say much more.

"The Feynman graphs and rules of calculation summarize quantum field theory in a form in close contact with the experimental numbers one wants to understand." - Bjorken, J. D.; Drell, S. D. (1965). "Relativistic Quantum Fields". New York: McGraw-Hill

We briefly look at the original use of Feynman diagrams, what they say seem to say mathematically and physically, and talk about some examples of how the notation has influenced physics and mathematics. (Received August 22, 2018)

1145-L5-740 **Sergiy Koshkin*** (koshkins@uhd.edu). *Mathematical Intuition and the Secret of Platonism.* Preliminary report.

We will look into the interplay between modern perceptions of mathematical objects, and of the roles of intuition and proof in mathematics, and the structural and notational changes in algebra and formal logic in 19th century. The received view, with its emphasis on formal proof, is arguably in tension with the traditional mathematical platonism, which perceives intuition as a primary means of interacting with mathematical objects. We will then discuss an alternative, diagrammatic, view of a mathematician's work developed by C.S Peirce, and supported by his diagrammatic notation for predicate calculus, and argue that it gives a plausible resolution to this tension. Namely, a theory of intuition that explains both the indispensability of formal proofs, and the secret of the continued appeal of platonism to mathematicians. (Received September 13, 2018)

1145-L5-1343 **Ilhan M. Izmirli*** (iizmirl2@gmu.edu), 4400 University Drive, Fairfax, VA 22030. *Wittgenstein and Social Constructivism.*

In this paper our main objective is to interpret the major concepts in Wittgenstein's philosophy of mathematics, in particular, language games and forms of life, from a social constructivist point of view in an attempt to show that this philosophy is still very relevant in the way mathematics is being taught and practiced today. In the first section we briefly introduce the social constructivist epistemology of mathematics – a perspective that reinstates mathematics, and rightfully so, as "... a branch of knowledge which is indissolubly connected with other knowledge, through the web of language" (Ernest 1999), and portrays mathematical knowledge as a process that should be considered in conjunction with its historical origins and within a social context. In section two, we give a telegraphic overview of the main points expounded in Wittgenstein's two books, Tractatus Logico-Philosophicus and Philosophical Investigations, as well as in his "middle period" that is characterized by such works as Philosophical Remarks, Philosophical Grammar, and Remarks on the Foundations of Mathematics. In the third and last section, we highlight the connections between social constructivism and Wittgenstein's philosophy of mathematics. (Received September 21, 2018)

1145-L5-1466 **Daniel C. Sloughter*** (dan.sloughter@furman.edu), Department of Mathematics, Furman University, Greenville, SC 29613. *What is a measure?* Preliminary report.

Most mathematicians first see measures as functions defined on sets: given a sigma algebra Σ of subsets of $\mathbb{R}$, a measure is a function $\mu : \Sigma \to \mathbb{R}$ satisfying certain conditions. On the other hand, a functional analyst may find it more useful to think of a measure as a linear functional on the space $C_c(\mathbb{R})$, the set of all continuous functions on $\mathbb{R}$ with compact support. The notation changes accordingly: $\int f d\mu$ becomes $\langle \mu, f \rangle$. With the change of notation comes a change in view: for example, the latter motivates generalizations to linear functionals on related function spaces, such as distributions, or "generalized functions", as linear functionals on $C_c^\infty(\mathbb{R})$. What, then, is a measure? Poincaré wrote that "mathématique est l'art de donner le même nom à des choses différentes." But the other side of this: sometimes it's advantageous to give a different name to one thing. Or is there only one thing? How would we know? (Received September 22, 2018)

1145-L5-1642 **Donald G Palmer*** (dgpalmer@null.com), Ossining, NY. *Boundary Conditions: Numeric Representation and the Boundary of Pure and Applied Mathematics.*

Being so basic to mathematics, numeric representational systems touch many areas of the discipline. Numeric systems could be said to lie on the boundary of pure and applied mathematics, providing the means to apply mathematics to the real world and to define how we manipulate numbers. The numeric system we use today is the decimal numeric system, which is a key system underlying current science and technology. This system is over one thousand years old, predating much of our science and technology. It can be argued that this mathematical tool, missing for the ancients, prevented them from attaining technology close to ours. In an analogous manner, discovering an expanded, more powerful numeric system would affect both sides of the pure/applied boundary. Being so basic to measurements, expanding the power of our numeric system could expand what we are able to measure, and hence provide a quantum leap in many areas of science. Being so basic to the concept of number, the expansion could provide new areas for theoretic mathematical investigation, potentially expanding what we think of as a number. This talk will consider characteristics of numeric representation and the potential for expanding our current systems, considering directions to work on and where this might lead. (Received September 23, 2018)

1145-L5-1687 **Kevin Iga*** (kiga@pepperdine.edu), Pepperdine University, 24255 Pacific Coast Hwy., Natural Science Division, Malibu, CA 90263. *What does mathematical terminology say about linguistic determinism?*

The question of whether our notation determines our understanding of mathematical concepts is part of a more general controversy in the study of linguistics: that of linguistic determinism, sometimes called the Sapir-Whorf hypothesis, which posits that features of language can have an effect on what kinds of thoughts are possible, or which are more easily accepted or understood. I will survey the history of this hypothesis and summarize a range of current views. Then I will look at a few cases in the history of development of mathematical notation, and explore how these examples can contribute to our understanding of the Sapir-Whorf hypothesis. (Received September 23, 2018)

1145-L5-1790 **James R. Henderson*** (jrh66@psu.edu), 402 W Main Street, Titusville, PA 16354. *Multiplicity of Logical Symbols: Why Is That a Thing?*

It is not surprising that, over the years, different authors have suggested different symbols to stand in for different logical connectives and quantifiers. After all, different languages have various sounds for the same concept or object, and, perhaps more closely related, mathematicians sometimes have different ways of symbolizing the same operation or transformation. (Easy example: Newton and Leibniz famously used different notations for the derivative.) It is one thing, however, for two mathematicians to independently develop a rather sophisticated idea and use dissimilar notation, and quite another to have multiple symbols for very simple connectives like negation or disjunction, even after the development of a decades-old literature concerning truth tables. It seems a bit excessive. Why hasn't there developed, for instance, one canonical way to join two propositions into a conjunction rather than the use of the ampersand, the dot, the inverted wedge, or simply placing characters adjacent to each other? It is as if authors of elementary arithmetic books had half a dozen ways to express the notion of "two plus four." This talk concerns the motivations of authors to affect the way logical concepts are envisioned by readers, which may lie at the root of this phenomenon. (Received September 24, 2018)

1145-L5-1961 **Jeff Buechner*** (buechner@rci.rutgers.edu). *What makes a notation for the natural numbers a good notation?* Preliminary report.

Decimal notation is just one among many distinct notations for the natural numbers. Binary and stroke notation are well-known alternatives. Those who use decimal notation experience a feeling that there is no additional computation to make when, say, they add the positive integers 14 and 17, and obtain the result 31. But that result in binary would require, for someone not versed in binary, an additional computation—into decimal—in order to see that the result is correct. One view is that this experience is relative to one's culture. In a culture in which binary notation is used, the experience would be that no additional calculation is required when the result in binary is obtained. In the early 1990s, in his Princeton seminar, Saul Kripke argued that the cultural relativism view cannot be wholly correct. He conjectured that decimal notation mirrors the "logical structure" of the natural numbers—as presented in the analyses of Russell and Frege—better than other notations. I will discuss Kripke's conjecture, and some problems that it raises. (Received September 24, 2018)

It's Circular: Conjecture, Compute, Iterate

1145-M5-333 **Rebin Abdulkader Muhammad*** (rm775311@ohio.edu), 24 home street apt 104, athens, OH 45701. *Equidistant Dot on Grid.* Preliminary report.

Assume that we have a grid of n row and m column. We want to know what is the maximum number of dots we can place (in each cell only one point can be placed) with the condition that we do not have equidistant (list of all distances between placed dots may not repeat). We start by exploring a simple case like 1 by 1, 1 by 2, or 1 by 3 and then we make a conjecture about 1 by n. Later we will go further and ask a question about the case of a 2 dimensional array, for example 3 by 4. In addition to the question: What is the highest number of dots that can be placed in that array? we will also ask the question: Is the answer is unique? And in case we find more than one answer, we will ask: Are they are similar? (symmetry). In the Dots in Box activity students need to compute set of possible distance, make conjectures, and then test them. After this, the students have the possibility to go further and try to answer questions related to 3 dimensional arrays. Geogebra app can be used as a company to this activity. (Received September 01, 2018)

1145-M5-720 **Matthew G Jones*** (mjones@csudh.edu). *What I Learned About Sharing Long After Kindergarten.*

Have you ever tried sharing a dessert, like a birthday cake, with someone, and wondered how to share it fairly? What happens when you have a batch of cookies to share, some with nuts and some without–how can you share them fairly? What if you are dividing up a number of items between two people, say a jewelry collection, where the items cannot be broken apart? What does it mean to share fairly?

This Math Teacher Circle session develops ideas of what it means to share fairly, allows participants to conjecture (and in some cases, prove) properties of some approaches to fair sharing, and to compute iterations that lead to the adjusted winner in some examples. In this presentation, I will give the broad outline of the session and provide session resources. (Received September 13, 2018)

1145-M5-1295 **Philip B. Yasskin*** (yasskin@math.tamu.edu), Dept of Math, Texas A&M Univ, 3368 TAMU, College Station, TX 77843-3368. *Minimum Volume between a Surface and its Tangent Plane.*

Sometimes you need to present a Math Circle activity to older participants who already know calculus, such as high school students; a college math club; or an IBL calculus class. Here is an activity stated for Calculus 3 but also has a simpler version for Calculus 2. "Minimum Volume between a Surface and its Tangent Plane": Pick a function $z = f(x, y)$ which is everywhere concave up (or down) on the rectangle $[0, 1] \times [0, 1]$. Construct the tangent plane at a point $(p, q) \in [0, 1] \times [0, 1]$. Compute the volume, $V(p, q)$, between the surface and its tangent plane above the rectangle. Finally, find the point (p, q) which minimizes this volume. Each student should pick their own function $f(x, y)$, not the polynomial $f(x, y) = x^2 + y^2$, some concave up, some concave down. After they complete this, they will observe they all got the same answer. Surprise! They make a conjecture and prove it. Notice how this single problem incorporates most of the majors points in differential and integral calculus. They find tangent planes. (Using a general point is hard for most students.) They find volume between two graphs. They do a max/min problem. They make a conjecture and prove it. A similar problem works in Calculus 2 using a curve and its tangent line. (Received September 20, 2018)

1145-M5-1414 **T. T. Craig***, 251 Vesta Drive, Myrtle Beach, SC 29579. *The Coastal Paradox.*

Teaching in a coastal community, we had the unique opportunity to take our K-12 Coastal Carolina University Math Teachers' Circle to the beach and challenge our teachers to measure our coast to introduce them to fractal geometry. During this session, teachers make conjectures on how measurement of complex shapes changes as we use different measurement tools. This activity was interactive and provided our teachers with an opportunity to get their hands sandy while exploring the Coastline Paradox. The participants first measure hula-hoops with multiple methods and discover an infinite series that is convergent, which is intuitive to most. Next teachers are given a variety of materials and challenged to compute the length of the South Carolina coastline. The session closes with teachers learning how the coastline connects to fractals like the Koch snowflake. (Received September 21, 2018)

1145-M5-1530 **Paul Ellis**, **Sam Coskey** and **Japheth Wood*** (jwood@bard.edu). *Nim and Jim - Solving Combinatorial Games through Data Collection, Conjecture, and Proof.*

Solving a combinatorial game means deducing its winning strategy, and is equivalent to partitioning its game states into Winning and Losing positions. We present several significant and entertaining games, including

Nim and Jim, and show how students may be able to solve these games, guided by patterns gleaned from data collection. (Received September 23, 2018)

1145-M5-1769 **Thomas J Clark*** (tom.clark@dordt.edu), 498 4th Ave. NE, Sioux Center, IA 51250.
The Number Machine.

The number machine is a function that takes in two numbers, combines them in various ways (depending on its settings), and outputs a new value. This simple premise can lead to a variety of directions of inquiry from trying to guess the pattern based on testing various values, figuring out what properties the machine possesses, and determining how to make the machine output the largest possible value by starting with a fixed number of inputs. Exploration of the number machine can be done by hand, but often naturally leads to investigation via calculators and even spreadsheets. We will also discuss ways in which the session topic can be modified for all audiences from elementary age children to teachers. Changing the settings on the number machine allows the whole session to reboot for another iteration of discovery, conjecture, and understanding. (Received September 24, 2018)

1145-M5-2297 **Samuel Coskey**, **Paul Ellis*** (paulellis@paulellis.org) and **Japheth Wood**.
Bulgarian Solitaire - Understanding combinatorial patterns through data collection, conjecture, and proof.

Bulgarian Solitaire is an automaton disguised as a solitaire card game. There are some lovely patterns that uncover some insightful mathematics, and these can be uncovered through good old data collection. Small cases can easily be done by hand, but it is natural to move to computer modeling for larger ones. (Received September 25, 2018)

1145-M5-2505 **Maya Schwartz*** (ms1795@bard.edu), 30 Campus Rd, Annandale-on-Hudson, NY 12504.
The Combinatorics of SET (the card game).

SET is a card game with 81 cards in which each card varies in 4 different characteristics: color (red, green, or purple), quantity (one, two, or three), shape (diamond, oval, or squiggle), and shading (solid, striped, or empty). Each card is unique, and the entire deck has every combination of these four characteristics. My peer Emma Bernstein and I developed a lesson plan on the mathematics of SET, which was aimed at a group of middle school girls, who are members of the Girls Math Club at Bard. As a group, we all came to the conclusion that there are 1,080 unique sets that can be made with the entire deck, given two cards, there is only one card that will complete the SET. (Received September 25, 2018)

1145-M5-2587 **Mel Currie*** (currie19@gmail.com). *A new book in the Mathematical Circles Library series - Mathematics: Rhyme and Reason.*

A little more than three years ago, while attending the Conference for African American Researchers in the Mathematical Sciences at ICERM, I spontaneously announced to another attendee that I thought I would write a book about the heart of mathematics. Then I went ahead and did it. What was I thinking?! Publishing Mathematics: Rhyme and Reason is akin to undressing publicly. So, what ends up being exposed? Well, among other things, I place in plain view relationships with people in my mathematical upbringing, some of whom popped into my life for better and, at least once, for worse. One will also see my life-long attachment to the simple truths of mathematics. The book is a message to the kid I was, with the assumption that such kids still exist. I present a large collection of theorems and call them nursery rhymes in the book, though I didn't stumble across a few of them until I was well beyond nursery-rhyme age. I also write about whether or not I have ever managed to scratch the surface of mathematics. I plan to spend the allotted time discussing these matters and more. (Received September 25, 2018)

1145-M5-2746 **Aris Winger*** (aris.winger@gmail.com), **Brianna Donaldson**, **Mark Saul**, **Tatiana Shubin** and **Diana White**. *The Community Alliance for Mathematics.*

The Community Alliance for Mathematics (CAM) is a new collaborative endeavor with a mission of fostering nationwide engagement of students, teachers, and community members with mathematics as an active, creative, and living discipline that belongs to all. Our goals include: 1) working with local and regional leaders to build Mathematical Communities that serve as sustainable local ecosystems of mathematical activity; 2) facilitating communication, collaboration, and connections among partner organizations, mathematics professionals, and communities; 3) providing resources and training that support the creation of equitable, accessible, and inviting out-of-school spaces for doing mathematics; 4) encouraging underrepresented students, teachers, and community members to participate in these spaces; and 5) partnering with K-12 teachers to bridge the excitement of out-of-school mathematics into classrooms. We will provide an overview of CAM, focusing on how mathematics professionals can become engaged in this initiative at the local and national levels. (Received September 25, 2018)

1145-M5-2807 **Gabriella A Pinter*** (gapinter@uwm.edu) and **Istvan G Lauko** (iglauko@uwm.edu).
Grids in the Circle.

In this talk we present a few problems from our Circle where computational experiments enhanced the problem solving process and led to some answers and motivated more questions. Some examples will be shown where the design of the computational experiment itself presented an interesting problem as well. (Received September 25, 2018)

1145-M5-2925 **Zvezdelina Entcheva Stankova*** (stankova@berkeley.edu), Department of Mathematics, 713 Evans Hall, University of California at Berkeley, Berkeley, CA 94720-3840. *"Math Taught the Right Way": Curriculum from Overseas, Adapted to the U.S. Educational Reality and Implemented Parallel to the Berkeley Math Circle.*

Two decades of BMC showed that even the most motivated U.S. math circlers may lack basic skills in what is standard school material abroad. Geometry is the Cinderella of U.S. math education: beautiful but neglected. Other math areas also severely lag behind. To compensate, every BMC session has to start low, fill in all gaps, and exponentiate in difficulty, in order to reach its goals in 2 hours. Parents keep asking for good textbooks in English, to prepare children for BMC and for a life of math ahead. "Math Taught the Right Way" (MTRW) was a working name for a program that started in 2016 at UCB and two nearby schools. It is based on the adaptation of a new middle/high school Bulgarian curriculum. Each MTRW group meets for 3 hrs a week for Algebra, Geometry, and Problem Solving/Proofs, taught twice as fast as in school. Each class has pre-tests, HWs, and final exams. It does sound like a math school! The temporary name "MTRW" stuck as true for its 130+ students in 4 groups (6-9 grades); if left unrestricted, it will quickly outgrow the BMC size of 500+ students. The 6-8 grades textbooks are published in English. This talk will discuss the necessity, structure, difficulties, and successes of MTRW as a satellite to math circles and a replacement of math school curriculum. (Received September 25, 2018)

Mathematical Themes in a First-Year Seminar

1145-N1-731 **Ricardo V Teixeira*** (teixeirar@uhv.edu), 3007 N. Ben Wilson Ave, Victoria, TX 77901. *A MatheMAGICAL First Year Seminar.*

Some universities require that all new first-year students take a First-Year Seminar in their first semester. The course is intended to teach students skills that are necessary for success in college. The course also engages students with their major (or potential major) and other resources on campus.

Some faculty create courses designed around a theme and adapt the activities based on it. By being intentional in the selection of a theme, students will explore a topic that interests them and meet other students who share that interest.

With some math faculty having strong interest in magic tricks, the University of Houston – Victoria is planning to launch a "Mathemagics" FYS in 2019. Our presentation will cover the development of material to be used, showing samples of activities. We will also show how to adapt current events in FYS to have the Mathemagics theme. (Received September 13, 2018)

1145-N1-801 **Katrina Palmer*** (palmerk@appstate.edu), 121 Bodenheimer Dr, Boone, NC 28608.
Mathematics & Sustainability as a First Year Seminar Course. Preliminary report.

For two years, I have taught a First Year Seminar course titled "Mathematics and Sustainability" at Appalachian State University. Many of the topic we learned about in the course came from DIMACS Mathematics of Planet Earth modules. In this presentation I will share the mathematical topics the students learned about and the activities they enjoyed most. I will also provide my thoughts on the successes and failures of the course. (Received September 15, 2018)

1145-N1-1745 **Matthew J Prudente*** (matthew.prudente@alvernia.edu), 400 St Bernardine St, Reading, PA 19607. *Precalculus Mathematics Through First Year Seminar.*

A first year seminar class at a small, liberal arts institution is a great way for students to build a sense of camaraderie with their fellow classmates. At my current and previous institutions, the goals with the first year seminar program are to focus on areas essential for success: academic responsibility, critical thinking and presentation of ideas. As a first-year seminar instructor in a precalculus class, I deliver the material in such a way that reflects how the mathematics they learn in precalculus will influence their lives through practical examples and small group projects. (Received September 24, 2018)

1145-N1-1808 **Debra L. Hydorn*** (dhydorn@umw.edu). *Infographics: A First Year Seminar on Visual Communication.*

In this first year seminar students build core skills for visual analysis and learn about the cognitive, communication and aesthetic principles of information design. By examining collections of example infographics students develop an understanding of the components of effective infographics and construct a definition of visual literacy. They learn that effective visual communication relies on the visual literacy skills of both the producer of the graphic and the intended audience. Class activities include "deconstructing" infographics to develop students' visual literacy skills. To demonstrate their mastery of reading and interpreting infographics students take turns presenting an "Infographic of the Day" to the class. To develop their skills in preparing infographics students learn to use a variety of infographics tools, such as Vidi, Many Eyes, Tableau, Infogram and R. Working in small groups, students prepare infographics for data from a variety of sources, including a survey of students in other first-year seminars across campus and class data of VARK (Visual, Aural, Reading/Writing and Kinesthetic) learning styles. In addition to providing examples of student work from throughout the course a collection of good resources will be provided. (Received September 24, 2018)

1145-N1-2426 **Marie P. Sheckels*** (msheckel@umw.edu), Department of Mathematics, University of Mary Washington, 1301 College Ave., Fredericksburg, VA 22401. *The Art of Mathematics.*

The Art of Mathematics is a one-semester First-Year Seminar in which students develop their skills in writing, speaking and research through exploring various mathematical topics and concepts that can be expressed artistically in a variety of different ways. Upon completion of this course, students should be able to identify and describe the mathematical components of various art works and create their own mathematical art. Topics include various forms of symmetry, types of patterns, tessellations, similarity transformations, iteration, fractals, depth and perspective, tilings, and computer-generated art. Assignments include a visit to an art gallery, written analysis of the mathematical aspects of art works, a group presentation and the development of an art portfolio with their own work. Students with differing artistic and mathematical talents and experience all found the material accessible. Most students were enthusiastic about discovering how the two areas of mathematics and art intersect and how the application of mathematical concepts can be used to help create works of art (Received September 25, 2018)

1145-N1-2508 **Lesley W. Wiglesworth*** (lesley.wiglesworth@centre.edu), 600 W. Walnut Street, Danville, KY 40422. *Exploring the Mathematics and Impacts of Gambling.*

Examples of glorified gambling fill popular culture and film, often causing a false perception of the gaming industry in first-year students' minds. In this talk, we reflect on a First-Year Seminar designed to analyze the probability and odds of casino games as well as the social and economic impact of the gaming industry. We will discuss the structure of the course and effective course assignments as well as detail examples of special learning opportunities and experiences such as field trips, readings, guest speakers, and occasions that allow first-year students to interact with people gambling. The evolution of the course and adjustments made to better meet student learning objectives and goals will also be discussed. (Received September 25, 2018)

1145-N1-2752 **Mark Kozek*** (mkozek@whittier.edu), Department of Mathematics, Whittier College, Whittier, CA 90608-0634. *Math in Pop Culture: A First-Year Writing Seminar on Mathematics.* Preliminary report.

In this first-year writing seminar, students explore mathematical topics through their appearances in popular media and culture. Students read pieces of narrative non-fiction about mathematics and watch the films these have inspired. Students learn about mathematics through history or story-telling and write about the issues mathematicians or mathematical characters had to overcome in order to to attain their goals. Also, I discuss how, as a mathematician, I approach teaching *writing* in a first-year seminar. (Received September 25, 2018)

1145-N1-2779 **P. P. Yu***, 501 Westminster Ave., Fulton, MO 65251. *Not so fearful symmetry – how "partition of unity" works for teaching First-Year Seminar.* Preliminary report.

Unlike regular mathematics classes, First-Year Seminar provides an ideal platform for the instructor to organize course material in a creative, flexible, yet coherent manner. The theme of my section of the Seminar is "Not so fearful symmetry". Guided by concrete examples arising from quantum computing, black hole geometry, topological insulators, etc., fundamental concepts in group theory and low-dimensional topology acquire flesh. Freshmen with minimum mathematical background gain tangible understanding through hands-on exercises in a collaborative learning environment. In turn, the unique style of this course enables me to use the topic as a vehicle for their scholarly as well as social developments.

In this talk, I will share my experience of running a section of First-Year Seminar for a primarily STEM-oriented audience. More specifically, I will go over the structure and logistics of the course, detail major learning goals and how I managed to lead the class towards achieving them. Along the way, I will highlight what I find to be effective pedagogical techniques and activities engaging students in mathematics, physics, and engineering. For assessment, I will present indicators of success and reflect on areas that deserve further improvement. (Received September 25, 2018)

1145-N1-2859 **Sarah Dumnich*** (sarah.dumnich@stvincent.edu), 300 Fraser Purchase Road, Latrobe, PA 15650. *Beyond Elementary Functions: Introducing students to college-level academic culture in a math-based first year seminar.*

The goals of many first year seminar programs are very different than those of a typical math course. Adjusting to those differences and creating a cohesive structure for a course of this type can be a challenge. On the other hand, these courses give us the opportunity to spend more time on skills that we wish we could build in our more standard classes: collaboration, growth mindset, communication, and information literacy. In this talk, I will discuss the specific goals of Saint Vincent College's first year seminar, and how I was able to connect these to mathematical themes with specific activities. I will also discuss the difficulties I encountered along the way with some ideas of how to address these issues in the future. (Received September 25, 2018)

1145-N1-2937 **Helmut Knaust*** (hknaust@utep.edu), The University of Texas at El Paso, Department of Mathematical Sciences, 500 W. University Ave, El Paso, TX 79968-0514. *Scientific Revolutions - A First Year Seminar Course Design.*

We present the design of a first-year seminar course for science students who also take a developmental mathematics course. The mathematical course objective is to improve the students' mathematical abilities while at the same time showing them examples of how mathematics was (and is) used in the physical and biological sciences. Examples include: Copernicus and Galilei: from linear to quadratic functions; Kepler: power functions; Fibonacci and Malthus: exponential growth models, Mendel and Darwin/Hardy-Weinberg: probability and difference equations. Spreadsheets are an important tool for the second part of the course. (Received September 25, 2018)

Technology and Resources in Statistics Education

1145-N5-179 **Brian R Powers*** (brpowers@asu.edu). *StatPowers - A Simple Web-Based Statistics Suite for Introductory Statistics.* Preliminary report.

It is increasingly important to teach statistics using technology. But in an introductory course, why should students need to download a software package designed for the most advanced analysis with a daunting learning curve. In an effort to provide a free, web-based solution, I have been developing StatPowers.com, an exceedingly easy to use platform to carry out any analysis a student in a typical Introductory Statistics course would have to perform. It comes equipped with probability calculators for the common distributions as well as custom discrete and continuous distributions. Students can carry out analysis on 1, 2 or N independent samples, paired samples, contingency tables and perform multiple regression. The interface is simple and compact, and it has been developed in HTML and JavaScript, allowing client-side processing. (Received August 16, 2018)

1145-N5-213 **Leon Kaganovskiy*** (leonkag@gmail.com). *Statistics teaching and research with R.*

In this talk, I will discuss using Mosaic R package and Intro to Statistical Learning (Gareth, Witten, Hastie, and Tibshirani) for an intermediate Applied Statistics course. I will also mention briefly contemporary textbooks and approaches, which I have used in teaching Applied Statistics courses using R software. In the remaining time, I will discuss the most recent joint projects with Ecologist Dr. Lowman and Psychologist Dr. Kidron, which were made possible by R. (Received August 20, 2018)

1145-N5-324 **Bernadette L. Lanciaux*** (bllsma@rit.edu), School of Mathematical Sciences, Rochester, NY 14623. *The View from the Trenches: Teaching Introductory Statistics in a Digital World.*

My introductory statistics course is both an introduction to statistics and data science. The new approach grew out of several factors. •NOT mentioning Data Science in introductory statistics is dishonest in a digital world. •Explaining to students how to use a t-table to find the p-value in a two tailed hypothesis test about the mean is like describing how to get into an advanced yoga pose. •TI technology is older than our students. •Simulation Based Inference doesn't help students do the analysis they need to do in their program of study.

Students need to know how to •deal with real data in all its beauty and complexity. •do extensive exploratory data analysis, including contemporary data visualization. •communicate the results of their analysis to a non-technical audience.

I will share course materials that demonstrate how to cover all this material in a single semester, show examples of student work and share student comments about their experience in the course. (Received August 31, 2018)

1145-N5-373 **William Adamczak** and **Joseph McCollum*** (jmccollum@siena.edu), 515 Loudon Road, Loudonville, NY 12211. *Using R Programming to Enhance Mathematical and Statistical Learning.* Preliminary report.

At Siena College we offer a variety of statistic classes ranging from introductory statistics to time series analysis. These courses are either offered in the Mathematics department or the Quantitative Business Analysis department. We have incorporated the R programming language across the curriculum in both departments. In the process of bringing the R language into these classes we have discovered a variety of ways that this can be done while reinforcing statistical and mathematical concepts. We have augmented our typical lectures with examples where students use basic R programming to better understand key concepts of statistics. We would like to share some of our success stories such as understanding the standard deviation through coding. Plus, we will discuss how R programming allows a student a framework for organizing student's thoughts about statistical tests. Finally, we would highlight that one should be careful of the "black box" called R and to always check your answer to ensure accuracy. We believe what we have learned will be of value to individuals teaching statistics courses whether they have a programming component or not and look forward to sharing these experiences. (Received September 04, 2018)

1145-N5-408 **Carl Clark*** (cclark@irsc.edu) and **Rita Lindsay**. *Using the Islands in an Introductory Statistics Course.*

This talk introduces the participants to the virtual world of the Islands, and how to integrate the platform into an Introductory Statistics course. Using the Islands exposes students to a cross-curricular experience, including writing and presenting, while using statistics to answer questions in STEM fields (e.g., medicine). The prevailing objectives for the students are based on workplace applicable skills (e.g., using Excel) merged with the Scientific Method and statistical applications, and include: proposal process, sampling, data collection, data organization, analysis (e.g., multiple regression), and reporting. The participants of the talk should leave with basic outline for implementing the Islands in their own courses. (Received September 05, 2018)

1145-N5-671 **Robin L Angotti*** (riderr@uw.edu), School of STEM, Campus Box 358538, 18115 Campus Way NE, Bothell, WA 98011, and **Johnny Arenas** (arenasj@uw.edu), **Bethany Leach** (bleach22@uw.edu) and **Dion Thompson** (diont2@uw.edu). *Democratizing Data: Expanding Opportunities for Students in Data Science.*

According to Glassdoor, data science was the hottest job in America the last three years. How can small colleges and universities with no data science program or even a statistics department give students experiences to explore further study or pursue employment in data science after graduation? At one small northwestern university, faculty are piloting an internship program in which an interdisciplinary team of undergraduate students learn how to help university faculty, staff and community partners analyze, visualize, and understand complex data. This allows students to have hands-on practice with software and data science concepts, learn how to communicate with clients, understand large complex data sets, and answer underlying questions the clients are grappling with. Students employ data analysis, visualization techniques, and use of appropriate software tools in an iterative design based cycle to give clients insight on what their data is saying. Students work as a team under the supervision of a faculty member but are responsible for end products and communication with clients. In this talk, undergraduate students involved in this program will present their perspectives and examples of use of common software in solving these real world problems. (Received September 12, 2018)

1145-N5-725 **Patti Frazer Lock*** (plock@stlawu.edu), Dept of Math, CS, and Stat, St. Lawrence University, Canton, NY 13647. *Teaching a Technology-Rich Intro Stat course in a Traditional Classroom.* Preliminary report.

All of the current Guidelines for teaching an excellent and modern Introductory Statistics course recommend that statistics software be an integral part of the course. Yet many of us teach in a traditional classroom rather than a computer lab, and many of us need to give our quizzes and exams in a traditional classroom. This talk offers ideas for these instructors on ways to effectively integrate technology into an Intro Stats course, and to ensure that all students have practice with statistical software, even in large classes. (Received September 13, 2018)

1145-N5-767 **William Corson** (william.corson@usma.edu), **David R. Galbreath*** (david.galbreath@usma.edu), **Bryan E. Adams** (bryan.adams@usma.edu) and **Kayla K. Blyman** (kayla.blyman@usma.edu). *Written Versus Digital Feedback; Which Improves Student Learning?*

It is understood that feedback is paramount to strengthening learning connections in students. It reinforces correctly understood knowledge and provides adjustment to misunderstandings. There are two competing requirements for providing feedback to students. The feedback needs to be quick but also detailed. Web-based homework provides instant feedback to students but does not provide feedback on the process they took to solve the problem. Paper-and-pencil based homework provides the instructor an opportunity to provide detailed feedback, but it is time consuming. This study is aimed to evaluate the effectiveness of these two means of providing feedback. Eight sections of a Probability and Statistics class at the United States Military Academy were randomly assigned to a control and treatment group. The control group is currently submitting homework through a common homework delivery system. The treatment group is currently submitting paper-and-pencil based homework. In addition to analyzing the impact of the homework methods on the students' performance in major graded events, we will also discuss the cost associated with grading the paper-based homework. (Received September 14, 2018)

1145-N5-1023 **Adam F Childers*** (childers@roanoke.edu), Adam Childers, 221 College Lane, Salem, VA 24014, and **David G Taylor** (taylor@roanoke.edu), David Taylor, 221 College Lane, Salem, VA 24014. *GAISEing into the Future with Fun, Flexible Mobile Data Collection and Analysis.*

Using real data with context and purpose, fostering active learning, and using technology to analyze data are three core components of the ASA's revised GAISE report. Classroom Stats is an integrated mobile and web-based data collection and analysis platform that can simultaneously facilitate all three of the aforementioned components. Free to download for iOS and Android, Classroom Stats lets instructors quickly send out questions (quantitative and categorical) that students can answer on their mobile devices and see the results analyzed in real time (descriptive and inferential statistics). Classroom Stats makes teaching and learning statistics fun and interactive as it seamlessly integrates real data into the classroom.

Note: If possible could we be include in the first section. Thanks! (Received September 18, 2018)

1145-N5-1047 **Rasitha R. Jayasekare*** (rjayasek@butler.edu). *Computational Experience for Linear Regression and Time Series using R.*

The Linear Regression and Time Series course offered by the Department of Mathematics, Statistics, and Actuarial Science is an upper level course required for both our Statistics and Actuarial Science majors. The course has been redesigned to emphasize the use of the software R in analyzing real world data. It is taught in a computer lab and students engage with the software in and out of class. In addition to weekly content quizzes and exams, there are two group projects where the students will be using R to analyze real datasets, and an R practical exam at the end of the semester. In this talk I will present the tools and activities that were implemented to provide a computational experience to learn linear regression and time series using R. (Received September 18, 2018)

1145-N5-1275 **Daniel A Showalter*** (daniel.showalter@emu.edu). *Using authentic data in spreadsheet assignments and quizzes to improve students' attitudes towards elementary statistics.* Preliminary report.

Introductory statistics courses are often a source of anxiety and frustration for students. Guided by current statistics education research, I implemented a "statistical reasoning learning environment" that emphasized the use of technology with authentic, relevant data to lower anxiety and improve students' attitudes towards statistics. I measured changes in attitude throughout four courses, two online and two face-to-face, using the Survey of Attitudes Towards Statistics (SATS-36). I will present results, both in general, as well as specifically for the subgroups of underrepresented minority students and first generation college students. (Received September 20, 2018)

1145-N5-2851 **Robert S. Owor** (robert.owor@asurams.edu), 504 College Drive, Albnay, GA 31705, and **Zephyrinus C. Okonkwo** and **Anilkumar Devarapu*** (Anilkumar.Devarapu@asurams.edu). *Nexus Degrees: Using Analytics to Create New Curricula in Mathematics, Computer Science and Beyond!*

In this paper, we discuss efforts in the Department of Mathematics and Computer Science at Albany State University to create new curricula in Mathematics and Computer Science. In studying employer job skill demand, student curricula demand and the demand projections in the job market, techniques from analytics can help us pinpoint key requirements from employers, the market demand for different skill sets and the most effective way to train students to meet business and industry demand. We review our efforts and the lessons we have learned along the way thus far (Received September 25, 2018)

The Teaching and Learning of Undergraduate Ordinary Differential Equations

1145-O1-177 **Chris Oehrlein*** (cdoehrlein@occc.edu). *Hamiltonian, Exact, or Conservative? YES!*

Most traditional ODE resources have a section on exact first-order equations. Many newer ODE resources with a more qualitative emphasis include the concept of Hamiltonian systems (sometimes to the exclusion of the exact concept). Then in most multivariable calculus and second-semester physics courses, students are presented concepts and computational skills about conservative vector fields and potential functions. Do our students recognize the similarities and differences among these three perspectives? How are we as instructors guiding them in seeing and using the three in different situations and what observations about one perspective can tell them about the others? Well, they don't, and we aren't – so what should we do about it in our ODE courses? (Received August 15, 2018)

1145-O1-219 **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. *Teaching an ODE Course with CoCalc, Sage, Jupyter Notebooks, and LaTeX.*

The use of technology for the teaching and learning of ordinary differential equations is now widely accepted. There is a wide variety of software such as Sage, MatLab, Maple, or Mathematica that can be used in the classroom. In addition, menu driven applications such as dfield and pplane can be used to find and plot solutions to equations or systems of equations. The next step is to provide an environment for using these tools that meets the needs of both the students and the instructor. CoCalc, a web-based cloud computing and course management platform for computational mathematics, can be used as an efficient method to provide examples and manage assignments. Using Jupyter notebooks, students can write their solutions in LaTeX and incorporate Sage computations into a single document. Since students only need to write their solutions in a Markdown cell, many of the barriers to learning LaTeX are removed. Furthermore, students can write executable Sage commands in a notebook. CoCalc makes it easy to collect, grade, and return these assignments. We will demonstrate how CoCalc and Jupyter notebooks can be used to improve an ODE course. (Received August 20, 2018)

1145-O1-244 **Viktoria Savatorova***, viktoria.savatorova@unlv.edu, and **Aleksei Talonov**. *Undergraduate ODEs and Linear Algebra for engineering majors: studying the foundations and learning by doing.*

Here we would like to introduce our approach to teaching linear algebra and ordinary differential equations simultaneously. Since our audience consisted mostly of engineering, computer engineering and science majors, we bound these two parts by means of engineering and science applications. The idea was to provide engineering students with a thorough grounding in mathematics while retaining the philosophy of learning by doing. The majority of topics presented in the course were accompanied by applications in various branches of engineering and science. The emphasis was made on examples propelling students' engagement, motivation, and interest. In class and at home exercises were used for individual or group study to assure that students master the foundations of the material. The core activities of the course were several group projects assigned in the form of engineering problems. Each problem solution involved using methods of linear algebra and differential equations. Possible examples of group projects varied including, but not limited to oscillation of a pendulum, motion in a viscous fluid, vibrational problem of capacity microphone, electrical circuits and impulse response, etc. We conclude providing students' success rate and their feedback. (Received August 24, 2018)

1145-O1-507 **Itai Seggev*** (is+research@cs.hmc.edu). *Stability of ODEs and Limits Superior/Inferior as Reinforcing Concepts.*

Many physical systems are described by ordinary differential equations in which the short-time behavior ("transients") are unimportant. The behavior of solutions at infinity describes the perceived response and stability of the system. The question naturally arises of how to compare different solutions that do not have a limit at infinity. Limits superior and inferior provide a useful quantitative framework for this question. The elementary notion of stability as a bounded response can easily be recast as a question about limits superior of the norm of solutions. For real-valued solutions $y(t)$, this condition can be formulated as

$$-\infty < \liminf_{t\to\infty} y(t) \le \limsup_{t\to\infty} y(t) < \infty.$$

Different solutions can be compared by examining the appropriate limits superior and inferior. Such comparisons will be illustrated using common systems, such as a mass-spring system. This point of view can be introduced in a course on ordinary differential equations and modelling as a means of analyzing systems with periodic forcing functions. Alternatively, it can be introduced in a course on real analysis as a concrete application of limits superior and inferior. (Received September 08, 2018)

1145-O1-1247 **Timothy A Lucas*** (timothy.lucas@pepperdine.edu). *Mobile Apps for Exploring Ordinary and Partial Differential Equations.*

I introduce two mobile apps developed by faculty and students at Pepperdine University that allow users to explore numerical methods and graphical solutions to ordinary and partial differential equations. *Slopes* contains activities for investigating slopefields, phase planes, oscillations and explicit numerical methods and is currently available for iPhone and iPad. *Waves*, in development, will allow users to plot and animate Fourier series as well as solutions to the heat and wave equations. The name of the app originates from the technique of expressing solutions as a linear combination of sine and cosine waves. One advantage of using these apps is that iPhones and iPads are highly portable and feature larger touch screens that allow students to view and manipulate content easily. Research based on observations of mathematics courses at Pepperdine University has shown that students are more willing to collaborate and share their results when using tablets such as the iPad (Fisher, Lucas et al. 2013). The intuitive interfaces of *Slopes* and *Waves* invite students to fully immerse /themselves in the world of differential equations so that they can understand the concepts from not only algebraic, but also graphical and numerical perspectives. (Received September 20, 2018)

1145-O1-1373 **Satyanand Singh*** (ssingh@citytech.cuny.edu). *An Enticing Simulation in Ordinary Differential Equations that predict tangible results.*

In this case study the distance traveled by a mass in an under damped system was simulated with the Maple software. This is an important problem in physical and quantum systems in mathematics and physics. The results touched upon an interaction between calculus and differential equations and illustrate a nice approach for collaboration in small student groups. This case study challenged students to conjecture on solutions, simulate them and prove them theoretically while they derived unexpectedly elegant closed form expressions and generalizations. This approach provided a medium for rich discussions, enhanced student success and retention and propelled some students into graduate programs. (Received September 21, 2018)

1145-O1-2143 **Francesca Bernardi*** (bernardi@math.fsu.edu) and **Manuchehr Aminian** (manuchehr.aminian@colostate.edu). *Teaching the SIR model in historical context: primary sources to modern applications.*

The majority of students enrolled in ODEs-focused classes are STEM majors, but not necessarily mathematics majors. Using ODEs to model real-world problems can be a gateway into applied mathematics for many students. Historical context adds to the full picture of why ODEs are important and attracts the students for whom cut and dry mathematics is not always appealing. We will discuss the use of historical documents and primary sources, as well as data and articles from the news, to teach students about mathematical epidemiology. Starting from the recent Ebola outbreak, we guide students through the derivation of the SIR model by reading historical documents the from early 1900s and the seminal 1927 paper from Kermack and McKendrick. Students explore mathematical aspects of the model and its implications on real-life scenarios. This curriculum has been assigned (in different versions) both as part of a class syllabus and as extra credit; feedback from students has been encouraging. (Received September 24, 2018)

1145-O1-2365 **Amine Benkiran***, azb165@psu.edu, and **Eric Simring**, **Andrew M. Baxter** and **Andrew Belmonte**. *Analyzing systems of differential equations by first-year life-science majors.* Preliminary report.

A first-year calculus sequence can meaningfully analyze not only a single ordinary differential equations, but systems of differential equations. The calculus sequence for life-science majors at Penn State University is a re-imagined treatment of calculus, starting from the traditional limits, derivatives, and integrals in the first semester, but then pivoting in the second semester to matrix algebra, Markov chains, differential equations, and systems of differential equations. By the end of the Biocalculus sequence students are fluent in using first-order differential equations to model dynamic systems as well as the use of elementary solution methods (separation and integrating factor). Students analyze the stability and asymptotic behavior of real-life scenarios such as population dynamics, harvesting natural resources, spread of epidemics, and so on. Our curriculum also focuses on solving 2x2 linear and nonlinear systems of ODEs, analyze their stability, and study applications such as predator-prey models, cooperation models, SIR model, and so on. In this talk we will describe how we have arranged the Biocalculus curriculum, the motivations for prioritizing the study of ODEs, share specific examples discussed in the course, and how a third-semester course continues this focus (Received September 25, 2018)

1145-O1-3033 **Dan Kalman*** (kalman@american.edu). *Newton Cooling in the Attic: Applying ODEs at Home.*

This talk describes an application of ODE modelling I found useful in my own home. It concerns a poorly insulated attic crawl space containing water pipes. To protect the pipes from freezing, I constructed a chamber (or cavity) around the pipes, heavily insulated from the larger crawl space, but not from the adjoining heated room. If the temperatures of the heated room and crawl space are known, what temperature should be observed in the cavity?

This situation can be modeled with a standard Newton's cooling ODE, modified to include heat flow with respect to two different ambient temperatures. Heat flows from the heated room into the cavity at one rate, and from the cavity into the crawl space at a second, lower rate. Solving the associated ODE reveals an intuitively appealing relationship between the two ambient temperatures, the ratio of the rates of heat flow, and the steady state temperature in the cavity. This in turn allows us to answer a very practical question: if the ambient temperature in the heated room is 70 degrees, and if we don't want the temperature in the cavity to be at or below freezing, how cold a sustained temperature can be tolerated in the crawl space? (Received September 26, 2018)

Inquiry-Based Learning and Teaching

1145-O5-237 **Thomas LoFaro*** (tlofaro@gustavus.edu), Gustavus Adolphus College, 800 W. College Avenue, Saint Peter, MN 56082. *Using Computer Simulations to Promote Conjecture in an IBL Dynamical Systems Course.*

There is a long history of using computer simulations in dynamical systems to engage students in self-discovery of mathematical ideas. I will discuss an ongoing project that combines these activities with Inquiry Based Learning that aims to provide students a more complete mathematical experience. In particular, the goal of this method (called ECAP) is to engage students in a mathematical **E**xperiment, encourage them the make a formal **C**onjecture based on the experiment, provide them an opportunity to **A**pply the resulting theorem, and finally to utilize IBL methods to help them **P**rove the result. In this talk I will outline the motivation and structure for such a course and demonstrate material for at least one topic. (Received August 23, 2018)

1145-O5-852 **Victor I. Piercey***, piercev1@ferris.edu. *Role-Playing Simulations in an Inquiry-Based Learning Quantitative Reasoning Class.* Preliminary report.

Role-playing activities and realistic simulations encourage students to contextualize their learning and develop higher-order thinking skills. As such, they fit well with inquiry-based learning. In our quantitative reasoning course designed for students in occupational majors, we begin and conclude the course with realistic role-playing simulations. In this talk, I will describe the simulations in detail, share the benefits and challenges of including these activities in an IBL course, and provide advice for those interested in doing so. (Received September 16, 2018)

1145-O5-1065 **Jamie Sutherland*** (sutherjr@udel.edu). *How Interactive is Your Class? Tracking Student Engagement with Active Learning Logs.* Preliminary report.

Is one of your goals to use more active learning in your classroom? Have you struggled with resistance to active learning - from students or yourself? Do find slipping into lecture mode all too easy? Active learning can transform how students learn mathematics by giving them agency in the classroom and real problem solving experiences. But using active learning in your classes takes a sustained effort and it is easy for students and professors to fall back on old habits. As a way to keep myself focused on active learning throughout the semester, I created specific active learning goals for my classes and tracked my progress using what I have called Active Learning Logs (ALLs). ALLs are a simple way to keep your goals in sight for the entire semester. ALLs also gave me a place to reflect on what worked and what I could improve on for my future activities. In this presentation I will share the organizational structure of Active Learning Logs, how I applied them to my own classes, and what I gained from using them in my classes. Come join in the discussion about how to keep active learning alive and well for your students. (Received September 18, 2018)

1145-O5-1188 **Abigail Higgins*** (abigail.higgins@csus.edu), **Sayonita Ghosh Hajra** (sayonita.ghoshhajra@csus.edu) and **Topaz Wiscons** (topaz.wiscons@csus.edu). *Taking the IBL plunge: Reflections on a mass implementation in entry-level mathematics courses.* Preliminary report.

At California State University, Sacramento (Sacramento State), two new entry-level college mathematics courses, serving approximately 700 students, were created for students identified as benefiting from additional support in the mathematical coursework for their degree program. In designing these courses, we saw an opportunity to use IBL-instructional methods to support increased student ownership in the problem-solving process and encourage a growth mindset towards the learning of mathematics. In this talk, we will reflect on the professional development structures in place to support instructors and course-designers and share experiences of instructors who are new to IBL-instruction. We will also present specific classroom materials and discuss the successes (and challenges) of the implementation of this instruction. We hope to offer ways in which instructors who are new to IBL-instruction could be supported by their departments and their colleagues. (Received September 19, 2018)

1145-O5-1251 **Aaron Trocki*** (atrocki@elon.edu), 2320 Campus Box, Elon, NC 27244, and **Ryan Bernardi** (rbernardi@elon.edu), 2320 Campus Box, Elon, NC 27244. *Assessing Student Engagement and Responsibility through Inquiry-Based Learning.*

Traditional instruction in college level calculus is instructor driven and predominantly lecture-based with students being passive recipients of knowledge. Inquiry-Based Learning (IBL) has shown promise to change instructor and student roles in the classroom to more active collaborators through exploring concepts and honoring student questions and contributions (e.g. Greene & von Renesse, 2017). This presentation delineates a case study (Creswell, 2013) of one Applied Calculus course in which IBL strategies were implemented. Investigated strategies include open-ended warm-up questions to begin class sessions, think-pair-shares to structure small group discussions, and concept checks to formatively assess class progress. These strategies emphasized developing mathematical knowledge through discourse, utilizing student questions to unpack concepts, and assessing student progress throughout the semester. Professor reflections, student responses to questionnaires, and recorded professor and student written questions were analyzed to assess broad effects of instructional strategies and in particular student engagement and responsibility for learning. Professors interested in employing IBL strategies into their mathematics instruction will particularly benefit from this presentation. (Received September 20, 2018)

1145-O5-1558 **Candice M. Quinn*** (cmq2b@mtmail.mtsu.edu). *Connecting Calculus to the Real World through a FAST, Fun, and Furious Problem.*

The Formula One Racing Strategy project has numerous solutions and covers a range of concepts learned in algebra, precalculus, and calculus. It was developed to help students make connections between a real-world competitive application of calculus and content in class such as constructing equations, averages, limits, rate of change, summation, and integration. A guided workbook containing the driving question, metacognitive questions, and questions linking the calculus in class to the project was created to help students reason through the project. Parameters about the current Formula One Grand Prix race are provided and students are asked to calculate the optimal refueling strategy for one of the drivers. First, they are asked to brainstorm ideas for solving the problem before learning any calculus. Next, students worked in groups for at least one hour a week for six weeks on aspects of the project leading toward a final solution. Last, a class wide race simulation brings the students solutions to life. The goal of the simulation is to beat the instructor, who has the optimal solution, and win the race. This presentation will include a description of the project, solutions, student work, and feedback from three years of implementation in an accelerated summer Calculus I course. (Received September 23, 2018)

1145-O5-1875 **Heather A. Lewis*** (hlewis5@naz.edu), 4245 East Avenue, Rochester, NY 14618. *IBL Calculus: Classroom Management and Assessment.* Preliminary report.

Several years ago our department switched to teaching calculus exclusively through inquiry-based learning: the students work on problems outside of class and class-time is spent almost entirely on presentation and discussion by students. This talk will cover the variations that we've done within this structure: how to decide who presents each problem, whether to grade presentations, whether to assign written homework and/or give quizzes, and how much weight to assign each aspect of the course. (Received September 24, 2018)

1145-O5-1883 **Erica R. Miller*** (ermiller2@vcu.edu), PO Box 842014, Richmond, VA 23284. *Using Daily Prep Assignments In IBL Calculus 1.*

Often, we tell students that for every one hour spent in the classroom, they should be spending at least one to two hours outside of the classroom studying. However, we often provide little guidance on how they should be spending this time (besides completing homework assignments). One way that we can help students structure their out-of-class study time is by using Daily Prep assignments. In this talk, I will discuss how I used Daily Prep assignments in my IBL Calculus 1 class, in conjunction with the "Active Calculus" textbook by Matthew Boelkins, to provide my students with an opportunity to reflect on what they were learning, identify lingering questions they still had, and begin thinking about the next topic we would discuss during the next class. In addition to talking about the structure of these assignments, I will also talk about student feedback that I collected throughout the semester that demonstrates the effect that these Daily Prep assignments had on their learning experience. (Received September 24, 2018)

1145-O5-2058 **Mami T. Wentworth*** (wentworthm1@wit.edu) and **Melvin S. Henriksen** (henriksenm@wit.edu). *Inquiry-Oriented Laplace Transforms.* Preliminary report.

For our introductory Differential Equations course, we have adapted the material from Inquiry-Oriented Differential Equations (IODE) developed by C. Rasmussen, K.A. Keene, J. Dunmyre, and N. Fortune. The IODE material aims to deepen conceptual understanding through engaging in mathematics, encouraging peer-to-peer interaction and focusing on student thinking, as referenced in the MAA IP Guide. Recently, we have developed a unit for the Laplace transform to supplement the existing IODE material. In this unit, students complete tasks that help them understand the transform, and work on examples with discontinuous forcing functions that motivate the need for the Laplace transform. We will show examples from the Laplace unit, and discuss student and instructor feedback on the implementation of this material. (Received September 24, 2018)

1145-O5-2060 **Aviva Halani*** (ahalani@exeter.edu). *Critiquing Activities in a Discussion-Based Introductory Proof Class.*

While studying mathematical notation and wrestling with increasingly abstract concepts, students in Introductory Proof classes focus on strategies for formulating and communicating mathematical arguments. In a discussion-based classroom, it is essential that these students are both willing to entertain proof techniques different than their own and able to identify flaws in logic. In this presentation, we discuss three types of activities where students were asked to analyze and critique proofs previously produced by others: 1) proofs written by a mathematician, 2) proofs written by previous students from the same course, and 3) proofs written by their peers in the course. We report on the implementation and the perceived impact of this instructional exercise. (Received September 24, 2018)

1145-O5-2085 **John Mosley*** (jmosley@exeter.edu) and **Aviva Halani** (ahalani@exeter.edu). *A Lab Approach to Calculus.*

In a problem-based course where students are expected to work on a set of tasks for homework and share their solutions in class, some students struggle to see connections between problems. In this presentation, we discuss another inquiry-based structure used in a class covering topics from differential and integral calculus. Here, the problem-centered curriculum is built around weekly labs that emphasize graphical and numerical investigations. The focus of these investigations is to develop understanding of essential calculus concepts and their symbolic representations. Through these labs, students often discover new concepts or deepen their understanding of topics with which they are already familiar. Throughout the problem sets and labs, students are also expected to explore and write about the calculus ideas they encounter. We report on the implementation of such a class structure and share student feedback. (Received September 24, 2018)

1145-O5-2132 **Ryan Gantner*** (rgantner@sjfc.edu). *Math Circles of Inquiry.*

The Math Circles of Inquiry project is a collaboration between high school teachers and college professors to create, test, utilize, and disseminate inquiry-based modules for middle and high school courses. The modules are created by teachers working in teams with college professors. Then the results are communicated to others using a Math Teachers' Circle model. In this way, the project blends two existing networks: the Greater Upstate New York IBL Consortium and the national Math Teachers' Circle Network. However, these networks are used in ways that they have not been used before in order to build connections, develop teams, and disseminate knowledge. This project is currently a work in progress and there are teams in the Buffalo and Rochester areas. (Received September 24, 2018)

1145-O5-2196 **Sarah S Hagen***, Department of Mathematics, Kidder Hall 368, Oregon State University, Corvallis, OR 97331. *A Transition-to-Graduate-School Boot Camp Using Active Learning and Primary Historical Sources: Revelations and Transformations.*

Active learning and primary historical sources formed the backbone of a week-long boot camp for incoming graduate students offered at Oregon State University. Readings from the NSF-funded TRIUMPHS projects (TRansforming Instruction in Undergraduate Mathematics via Primary Historical Sources) were assigned for most of the days and provided the structure for the morning sessions. Afternoon sessions were dedicated to solving problems in groups with students writing solutions on the board and "teaching" each other the material and techniques. The use of primary sources had benefits that ranged far beyond simple enrichment. The exclusive use of inquiry-based learning throughout the boot camp was transformative for this advanced graduate student instructor and led to a great many insights into the benefits of active learning over traditional lecturing. In this talk I will discuss these insights, as well as what worked and what didn't when it came to the use of primary sources and active learning in this unique setting. (Received September 25, 2018)

1145-O5-2211 **John M. Osborn*** (osbornj@southwestern.edu), Mathematics and Computer Science Department, Southwestern University, 1001 E. University Ave., Georgetown, TX 78626. *Peaks and valleys of first-time implementation of IBL methods in Calculus III and Intro to Statistics classes.* Preliminary report.

This will be a report on the author's experiences implementing IBL techniques for the first time in Calculus III and Introduction to Statistics classes during the Fall 2018 semester at Southwestern University - a small, private 4-year liberal arts university in Central Texas. At the time this abstract was submitted, we were only about one month into the semester. But already, several positive and a few negative results have been noted. The presentation will highlight the results of the entire semester, as well as ongoing, mid-semester adjustments to the format of the classes. Student responses to and feedback on the IBL methods will be included in this report. (Received September 25, 2018)

1145-O5-2349 **Samuel D Reed*** (sdr4m@mtmail.mtsu.edu). *Can Turtles do Math? Exploring Different Number-Bases Through a Novel Task.*

Why are do we use base 10 in mathematics? This is a question that elementary preservice teachers often are not even aware of as they enter the university or teaching force. The Ninja Turtle Math problem was developed to give elementary preservice teachers a novel avenue in which to examine place value, discover, and reflect on the base 10 system they will eventually be teaching to youngsters. This was accomplished by having preservice teachers reflect on the nature of base 8 versus base 10. The Ninja Turtle problem was introduced to the preservice teachers in their first of two elementary mathematics content courses. This problem stemmed from my observations on preservice teachers' lack of understanding of place value, as well as their reluctance to think about the base 10 system deeply and consider the questions that their future pupils will likely be asking. This problem could also be extended to courses in discrete mathematics where other number systems are used and highlighted. This presentation will include a description of the problem, student work and reactions, as well as other possible extensions. (Received September 25, 2018)

1145-O5-2364 **Rachid Ait Maalem Lahcen*** (rachid@ucf.edu), Rachid Ait Maalem Lahcen, Mathematics Department, University of Central Florida, Orlando, FL 32816. *Preparing students to succeed in subsequent math courses through mixed instructional approaches.*

Preparing students to be successful in subsequent courses is a challenge because many students don't retain or transfer the knowledge from those course to Pre-Calculus or Calculus. Consequently, there is a need to use various instructional methods to motivate the students and help them reach a certain level of mastery in the topics covered. We'll share case studies in which we used inquiry based learning and adaptive to personalized instruction. The results from those course and their subsequent mathematics courses were encouraging. (Received September 25, 2018)

1145-O5-2380 **Anna Mummert*** (mummerta@marshall.edu). *Using Guided Inquiry in Geometry – First-time Reflections.* Preliminary report.

In this talk I will discuss my first experience teaching Euclidean geometry using a guided inquiry approach. In the guided inquiry pedagogy students work through a set of specified problems and present solutions during class. Thus by design, the guided inquiry approach strengthens students' ability to present, discussion, and write mathematics. It also requires them to read and learn mathematics without lecture and assess the correctness of mathematical arguments without (immediate) instructor feedback. Students in the class are primarily math education majors, making this method ideal to help them develop skills they will need in their own classrooms. Student thoughts and my own will be shared. (Received September 25, 2018)

1145-O5-2485 **Sara Jensen*** (sjensen1@carthage.edu), 2001 Alford Park Dr, Kenosha, WI 53140. *From Candy to Social Justice.* Preliminary report.

This talk will discuss how a battle over the best candy was used to motivate students to learn about voting theory. Many benefits of using candy to teach will be discussed, but one principle mechanism of candy is the safety it provides to what can be a highly politicized environment. We will also discuss the transition that occurred from voting on candy to discussing real life election results and voting practices. (Received September 25, 2018)

1145-O5-2562 **Carl Mummert*** (mummertc@marshall.edu), Department of Mathematics, Marshall University, Huntington, WV 25755. *Can IBL mathematics pedagogy transfer across disciplines?* Preliminary report.

Looking at the very positive research results that have recently been published about IBL methods in mathematics, it is natural to ask whether these results carry over to other fields. Some aspects of IBL mathematics pedagogy are unquestionably specific to mathematics, but are there aspects that can be shared across disciplines and colleges, or which can fit with institutional degree profiles? Can we spread the benefits of IBL more broadly across a college or university? I received an internal grant for 2018-2019 to study these questions at Marshall University. This talk will report on the findings from this project from Fall 2018, which includes a collaboration with faculty in Mathematics Education, Pharmacy, English, and Communication Disorders. (Received September 25, 2018)

1145-O5-2566 **John D Ross*** (rossjo@southwestern.edu), SU Box 7371, 1001 E. University Ave, Georgetown, TX 78626. *Exploring Big Ideas in Calculus 1 Through Bite-Sized IBL Lessons.*

We discuss several small IBL projects or modules that are meant to explore some of the biggest concepts in a typical Calculus 1 course. These bite-sized IBL experiences were implemented in a hybrid lecture/active classroom, and meant to take no more than one or two class periods (or were meant to be completed outside the classroom). We present these projects and comment on their observed effectiveness. (Received September 25, 2018)

1145-O5-2682 **Phong Le** (phong.le@goucher.edu), Goucher College, Center for Data, Math, and CS, 1021 Dulaney Valley Road, Baltimore, MD 21204, and **Rachel Grotheer*** (rachel.grotheer@goucher.edu), Goucher College, Center for Data, Math and CS, 1021 Dulaney Valley Road, Baltimore, MD 21204. *A 1st and A 10^{1st} IBL class: transformation and shared struggle.*

Over time, how has your IBL practice changed? What do you continue to feel challenged by?

In this talk we will compare experiences from an instructor new to IBL and another who has taught using an IBL format for several years. By contrasting the experiences of two faculty, we learn what gets easier with practice, what remains a challenge no matter how many times you teach, and what IBL habits (good and bad) can develop over time. Our discussion will include classroom expectations, methods, transparency, student feedback and culture. (Received September 25, 2018)

1145-O5-2715 **Lipika Deka***, ldeka@csumb.edu. *Can Complex Instruction and Inquiry-Based-Learning make a first-semester Real Analysis course more accessible for students?* Preliminary report.

Real Analysis sequence is one of the most challenging courses for our undergraduate students at California State University, Monterey Bay (CSUMB). This is one of the main barriers for students to graduate on time. After teaching this course for many years with a problem-solving approach and the traditional lecture format we moved to teach an IBL course this year. We are using the IBL pedagogy in a group work format where students work in groups on group-worthy tasks, a concept inspired by Complex Instruction. The challenges our students face ranges from not having good proof writing skills to not having enough time to study due to working full time. Bringing components of Complex Instruction to the IBL course is helping to have an equitable learning environment in the classroom. This session will share the specifics of the course and how we are incorporating both IBL and Complex Instruction to the benefits our students. We will share students' experience and what we learned from this implementation and whether we are able to make real analysis more accessible to our students. (Received September 25, 2018)

1145-O5-2743 **Steven W Morics***, University of Redlands, 1200 E. Colton Ave., Redlands, CA 92373. *An IBL First-Year Experience in Mathematics and Social Choice.*

One of the goals of first-year seminars at many institutions is to introduce students to critical thinking. This first-year experience explores questions in the mathematics of social choice as a means to encourage students to think critically, using several applications of inquiry-based learning techniques. The text and class sessions are structured around group explorations, students are encouraged to bring questions suggested by current events to class, and writing exercises are used to introduce problems to students ahead of any mathematical terminology. The presentation will provide examples of assignments and classwork, discuss the potential to rapidly adapt the material to current events or recent advances in the field, and consider the issues in implementation at two different institutions. (Received September 25, 2018)

1145-O5-2760 **Shadisadat Ghaderi*** (shadisadat.ghaderi@guttman.cuny.edu), 50 West 40th Street, Room 605, Guttman Community College, New York, NY 10018. *Developing and Implementing a Flipped Model in Statistics Course at Community College.* Preliminary report.

In this talk, we will discuss a flipped model developed and implemented for the statistics course in our First Year Experience Program at Guttman Community College. The main objectives of the model were to improve student's mathematical comprehension, to provide them an opportunity to learn at their own pace and reflect on their own learning, to motivate classroom participation and student's engagement, and to bolster peer-to-peer learning. We will describe the pre-class reading assignments and practices used to prepare students for an active learning experience in the classroom, along with in-class hands-on activities which involved individual or group-based work. Achievements and challenges of the model and its implementation will also be shared, as well as student's feedback. (Received September 25, 2018)

1145-O5-2835 **Brian P Katz*** (briankatz@augustana.edu). *New context, Same educator?*

This year, I am on leave from a position in HigherEd to teach high school. In this talk, I will reflect on my experience with this transition, including some differences between college/university and high school teaching for me and my identity as an educator. In particular, I am teaching at a school that has an institutional commitment to problem-based learning, which shares important features with my experience with inquiry-based learning; I will compare these two pedagogies and this institutional commitment in the context of my own transitional experience. (Received September 25, 2018)

1145-O5-2849 **Brandon Samples*** (brandon.samples@gcsu.edu), Georgia College, Department of Mathematics, CBX 017, Milledgeville, GA 31061. *Statistics Reimagined: The Courage to Make Substantial Changes.*

Every educator wants their classes to be impactful. Moreover, every educator knows that students have to take ownership of their learning for this to be realized. Often our teaching is - at least initially - a reflection of our own past learning experiences. In time, our teaching evolves as we implement modest, incremental changes based on the theories of ourselves and others. For myself, many years of modest changes produced modest positive improvements. During this talk, I will share with the audience my new probability and statistics inquiry-based course. I will share my course text and materials, my student-centered instructional methodologies, and some comparative analysis of past and present. Ultimately, I will discuss my decision to break free from the incremental changes in favor of having the courage to make a substantial change. (Received September 25, 2018)

1145-O5-2980 **Alex D Austin*** (aaustin@math.ucla.edu). *Reinventing the Graduate Boot Camp.*

All students accepted to the UCLA graduate program are invited to attend a five-week intensive summer course called the 'graduate boot camp'. Its purpose is to prepare the students to pass the Basic Exam, the first hurdle to be cleared in order to progress through the program (it uses not-so-basic questions to examine knowledge of undergraduate linear algebra and analysis). For many years it has been taught (typically by senior faculty) using a traditional lecture course format. This past summer another postdoc and I led the boot camp using an inquiry-based learning format. We incorporated elements that went beyond exam preparation with the aim of fostering the development of peer networks and an increased readiness for teaching assistant responsibilities. Student response to the new format has been very positive. I will discuss our methods and conclusions and the talk should appeal to others considering a similar approach. (Received September 26, 2018)

1145-O5-2990 **Elizabeth Thoren*** (ethoren@pepperdine.edu). *Shifting Beliefs about Mathematics in Future Elementary Teachers.*

Pre-service elementary teachers often enter college with a variety of beliefs about mathematics that inhibit learning and obscure the discipline. Given that each of these future teachers will be charged with shaping the formative mathematical experiences of hundreds of children, it is critical to address and shift these non-availing beliefs. In this talk we will examine an IBL elementary mathematics content course designed to challenge non-availing beliefs in pre-service teachers through their mathematical inquiry. (Received September 26, 2018)

Approaches to Mathematics Remediation in Baccalaureate-Granting Institutions

1145-P1-410 **Victoria Brown**, **Adam Childers**, **Jan Minton**, **Hannah Robbins*** (robbins@roanoke.edu), **Kristin Emrich** and **David Taylor**. *Analyzing the effectiveness of two-track calculus with built in algebra review.* Preliminary report.

In 2014, our department restructured our first calculus course to address the fact that it has perennially had one of the highest DFW rates at the college. Our solution was to start offering a two semester version of calculus 1 which contains just-in-time algebra review alongside our usual one semester calculus 1 course. We use a placement test, along with SAT math scores and high school GPAs, to place students into the appropriate version. Additionally, we allow students to switch from the one semester version back to the two semester version after their first test.

The goal of our study is to see how successful this new course structure is in helping students succeed in their first and second calculus courses. We collected and analyzed students' grades and placement test scores in the restructured courses, and compared them to similar data from the last year of our old version of calculus. Additionally, we collected grades for those students who continued on into our second calculus course. In this talk, I will give details about implementing this new calculus curriculum and discuss what we learned from our assessment of its effectiveness. (Received September 05, 2018)

1145-P1-494 **Ryan Shifler*** (rmshifler@salisbury.edu), 1101 Camden Ave., Salisbury, MD 21801, and **Erika Gerhold**, **Steve Hetzler** and **Lori Carmack**. *Calculus Readiness.* Preliminary report.

We will be discussing a department wide initiative to decrease the number of students receiving a D,F, or W in Calculus I. Our approach to improve student success is based on students significantly lacking algebra and trigonometry skills. The initiative includes weekly student lead precalculus review sessions and weekly assessments on topics that are relevant to the material that students are currently learning in Calculus I. We will present the initiative's motivation, implementation, and preliminary results. (Received September 07, 2018)

1145-P1-936 **Kimberly J Presser*** (kjpres@ship.edu), Shippensburg University, Department of Mathematics, MCT 250B, Shippensburg, PA 17257, and **James Hamblin**. *Remediation Beyond The Classroom: Assessing efforts to improve the remediation process in addition to developmental coursework.* Preliminary report.

Our departmental view on mathematics remediation has led to various members of the department taking an active role in the entire process of remediation. While a developmental course is a part of our curriculum, it is not the only aspect of remediation. Mathematics Department faculty work closely with various campus organizations associated with this issue: the Office of Placement Testing, Orientation Committee, Academic Success Program, Exploratory Studies advisors, and the Developmental Education Council. Together we have revised placement procedures to allow challenge testing and created alternative curricular pathways to non-algebraic coursework. Mathematics faculty have worked on the curriculum beyond the remedial level to make sure that there is a clear connection between outcomes from challenge testing and the remedial course and expectations in the subsequent courses. For this talk, we will present the innovations we have tried and the data comparisons between course only remediation and our current holistic approach to remediation. (Received September 17, 2018)

1145-P1-1220 **Alison Ahlgren Reddy*** (ared@illinois.edu). *Getting College Ready at The University Illinois: Co-Requisite Support College Algebra at a R1 University.*

In 2015 the number of students deemed not mathematically college ready at the University of Illinois doubled and has since doubled again. Additionally this population is disproportionally first generation and underrepresented minority students. Getting students started, and retaining them, in the appropriate math course is important for their mathematical success and success on campus in general. The challenges were, and are, to maximize student outcomes within the context of a single course, identify which students are good candidates for such a course, maintain rigor for a successful transition to subsequent mathematics coursework, and to design and implement such changes with minimal additional resources. The stark reality is that these courses are taught in lectures of 200+ students, so an additional challenge is to maximize success on a large scale and impersonal setting. The use of technology, breakout sessions, partnering with other offices for supplement instruction, and an overall keen commitment to the students has lead to 80% course success rates, when as many as 50% of the students are in a co-requisite situation, and similar success rates in subsequent mathematics coursework. Collected data will be shared. (Received September 20, 2018)

1145-P1-1307 **Alana Unfried*** (aunfried@csumb.edu), 100 Campus Center, Seaside, CA 93955, and **Peri Shereen** (pshereen@csumb.edu), 100 Campus Center, Seaside, CA 93955. *Adapting General Education Mathematics Courses to Support Underprepared Students.* Preliminary report.

This session is designed to accompany the sessions regarding implementation of the co-requisite model for general education (GE) mathematics and statistics courses at California State University, Monterey Bay (CSUMB). The monumental shift from traditional remediation to a co-requisite structure means that many students are not considered proficient in pre-college mathematical skills prior to beginning their GE mathematics courses. Therefore, in addition to developing effective co-requisite courses, it is also crucial to adapt GE courses to ensure successful experiences for underprepared students. This does not mean that GE courses are “watered down,” but rather that appropriate pedagogy must be implemented to create an equitable learning environment for a diverse group of students. This talk will discuss how CSUMB GE courses have implemented Reading Apprenticeship (supporting mathematical literacy and apprenticing students into mathematical problem-solving) and Complex Instruction (a combination of pedagogical strategies that attend to problems of social inequality in the classroom) to effectively support student learning. We will present sample participation structures, group-worthy tasks, and course-embedded reading assignments across the four-course curriculum. (Received September 20, 2018)

1145-P1-1308 **Judith E Canner***, 100 Campus Center, Mathematics and Statistics Department, Seaside, CA 93955. *Instantaneous Rate of Change: Overhauling Developmental Math and Campus Practice in One Year.* Preliminary report.

In August 2017, the California State University System ordered all 23 campuses to implement either stretch or co-requisite models for all developmental math support. At California State University, Monterey Bay, the Mathematics and Statistics Department revised its entire general education curriculum (e.g., Precalculus, Statistics), developed associated support (co-requisite) courses, and adopted the practice of student directed self-placement. To achieve success within a one-year timeline, the process required extensive coordination, communication, and training with faculty, staff, and administration across the campus and CSU System. We will present the lessons learned, positive and negative, from our transition process and provide practical and transferable plans of action for addressing faculty training and professional development, curriculum development, and coordination among campus co-curricular organizations (e.g, advising, counseling services) and administration. In addition, we will provide preliminary evaluation of our overall program after one semester of implementation, plans for future evaluation of success, and anticipated revision processes. (Received September 20, 2018)

1145-P1-1381 **Jennifer Elyse Clinkenbeard*** (jclinkenbeard@csumb.edu) and **Jeffrey Wand** (jwand@csumb.edu). *Co-requisite design across first-year mathematics and statistics courses.*

This session is designed to accompany the sessions regarding implementation of the co-requisite model for general education mathematics and statistics courses at California State University, Monterey Bay. We will present the design, implementation, and sample curriculum for support courses for four general education math and stat courses. These courses have widely different student audiences, from STEM-intending majors, to students for whom the GE course is their last formal math/stat education. Each support course was designed to address the specific content needs for each general education course. However, we also emphasize shared structures, values, and common practices across the co-requisite courses that are relevant to student success in math/stat. For example, on-campus experts facilitated workshops during class time on skills that students need to succeed in any discipline, such as time management, mindfulness, test anxiety, etc. In addition, we provide preliminary analysis of student persistence in the support course alongside their general education course, as well as students' perceptions of the relevance and value of their support course. (Received September 21, 2018)

1145-P1-1389 **Kathy Andrist*** (kathy.andrist@uvu.edu) and **Carolyn Hamilton**. *Changing the Numbers Game: Guided Math Placement and Co-requisite Math Courses at Utah Valley University.* Preliminary report.

UVU is an open-admissions, public, four-year, regional teaching institution. In 2013, 75% of incoming students placed directly into developmental math courses, failure rates for these courses hovered around 40% and the statistical probability that the lowest placing students would reach credit-bearing mathematics within two years was 13%. After a several-year campus-wide effort, Co-requisite Quantitative Literacy courses were developed and a Guided Math Placement process was implemented. As a result, students now place higher (1.2 courses higher, on average) and pass at increased levels (73.9 % vs 69%). During Fall 2017, 75% of students placed directly into general education math courses and developmental math enrollment decreased by more than 30%. Math pathways at UVU are now 2-3 semesters shorter and 8,000 fewer credits of mathematics courses were needed during 2017-18 as compared to 2016-17. Anxiety surrounding mathematics has been reduced and student feedback has been phenomenal. This Guided Placement and co-requisite course implementation is scalable and flexible for a wide variety of institutions. (Received September 21, 2018)

1145-P1-1704 **Katie Louchart***, Katie.Louchart@nau.edu. *Exploring Mathematics Placement Indicators.*

Mandatory mathematics placement testing resulted in a dramatic increase in the number of students placed into remedial courses. Alternative mathematics placement indicators were developed as the negative impacts of remedial placement became apparent. This talk will describe the use of several different placement measures, impacts on student success and course-wide pass rates, and challenges encountered in accessing and using these indicators. (Received September 24, 2018)

1145-P1-2210 **Ian Besse***, 2043 College Way, Forest Grove, OR 97116, and **Chris Lane**. *A student-centered redesign of college algebra.* Preliminary report.

The mathematics program at Pacific University has embarked on an ambitious redesigned of its College Algebra course. In this redesign, we seek to leverage emerging instructional technologies to reshape and enhance the way the course is structured, the way faculty and students interact, and the way students engage with course content. Our aims of the redesign are threefold – to improve student learning outcomes, to increase student retention/persistence, and to reduce instructional costs. This talk will discuss key pedagogical observations made during our first semester of full implementation, and will examine the degree to which our new approach to the course has achieved its aims. (Received September 25, 2018)

1145-P1-2316 **Sarah V Cook*** (sarah.cook@washburn.edu), Topeka, KS 66609. *Two-Semester College Algebra Stretch Course for Developmental Students.* Preliminary report.

In response to developmental algebra courses with low success rates, the Washburn University Mathematics Department developed a two-semester stretch College Algebra course. This allows students at the developmental level to immediately start learning material for their required math course while also learning essential background skills. This session will discuss the reasons for implementation, course logistics, assessment measures, and success rates for both semesters of the course sequence. (Received September 25, 2018)

1145-P1-2484 **Paul N Runnion*** (prunnion@mst.edu). *The Challenges – and Successes – of Remediation in Calculus.*

Calculus students at Missouri University of Science and Technology arrive in Calculus I having officially met the prerequisite either by transcripted credit or by placement exam, yet they often lack the necessary foundational knowledge – and life skills – to succeed in Calculus I. These students frequently find themselves in a situation where, by midterm, they are almost guaranteed not to pass Calculus I. The Success for Calculus program was designed to provide these students with an opportunity to strengthen their foundational knowledge (and the calculus they've already seen). Students successfully completing this program are showing promising results in future mathematics and other STEM coursework. Information about Success for Calculus and data about its impact on student performance will be presented. (Received September 25, 2018)

1145-P1-2590 **Alice E Petillo*** (alice.petillo@marymount.edu), 2807 N Glebe Road, Arlington, VA 22207. *Corequisite Mathematics Remediation: An Impetus for College Completion?*

National research shows first-time freshmen who enroll in traditional remedial math classes struggle to earn required college math credits compared with non-remedial students. A major roadblock for them is that they often do not earn credit towards their degree for remedial courses, further challenging progression through their major. Beginning in 2007, Marymount University developed and implemented a curricular innovation to more quickly prepare students for college-level math and have some of that credit count toward graduation. This study examines multiple cohorts of first-year students to determine if there is a relationship between this intensive corequisite mathematics course and higher persistence and completion rates compared to other types of mathematics remediation. Results of this study indicate that this model of corequisite remediation is related to both higher retention and graduation rates. (Received September 25, 2018)

1145-P1-2860 **Ben Atchison*** (batchison@framingham.edu), Framingham State University, 100 State St., Framingham, MA 01701. *Corequisite Remediation for GenEd Mathematics and Statistics Courses: Year Two.*

At Framingham State University, all students must complete one credit-bearing mathematics course as part of their general education requirements. For many years, students who did not achieve a satisfactory placement exam score were required to complete a non-credit bearing General Mathematics course prior to fulfilling their general education mathematics requirement. In an effort to improve retention rates and foster student success in the first year of study, the University decided to adopt a corequisite remediation model for each of its general education mathematics offerings. Beginning in Fall 2017, students who would have previously been required to complete General Mathematics were instead enrolled in a credit-bearing mathematics course and an accompanying 2-hour weekly mathematics lab, intended to feature just-in-time remediation via an online learning system. This talk will focus on the results from the past three semesters, the changes made between them, and a comparison to a separate University program for STEM majors who have also been identified as in need of remediation. (Received September 25, 2018)

1145-P1-2863 **Matthew Jura*** (matthew.jura@manhattan.edu), 4513 Manhattan College Parkway, Riverdale, NY 10471, and **Ira Gerhardt** (ira.gerhardt@manhattan.edu), 4513 Manhattan College Parkway, Riverdale, NY 10471. *Examining the Effectiveness of an Online Summer Bridge Course to Prepare Students for Calculus.* Preliminary report.

Since the summer of 2013 at Manhattan College, an "online summer bridge to calculus" course has been offered to eligible incoming first-year students. Students majoring in the schools of science and engineering (as well as in secondary mathematics education) who marginally do not receive a calculus placement (based on the results of a mathematics placement test) are eligible to take the course during the summer before they begin fall classes. If students successfully complete the online bridge course, then they are placed in a major-appropriate calculus course in the fall (and if not, they are placed in Precalculus for the fall). We discuss how this course was designed, as well as its effectiveness for the cohorts of students who took the course between the summers of 2013 and 2017. (Received September 25, 2018)

Fostering Creativity in Undergraduate Mathematics Courses

1145-P5-243 **Yajun An*** (yajuna@uw.edu), **Alan Bartlett** (alanmb@uw.edu), **Ryan Card** and **Haley Skipper**. *Teaching mathematical paradoxes as a general education course.*

The majority of students who take general education courses in mathematics do not experience mathematics beyond the level of college algebra and trigonometry.

In our course "Paradoxes: mathematics of nonsense", we introduce students to content in logic and set theory, probability and statistics, limits and infinity, graph theory, game theory, topology and geometry. Using paradoxical problems to introduce these topics allow us to de-emphasize quantitative skills in favor of critical thinking, and shows students how formalism is used to simplify problems rather than create them.

We have taught the course seven times and have received overwhelmingly positive reviews from the students, despite that many indicated a negative affect towards mathematics in a precourse survey.

In this talk, we will give an overview of the course, demonstrate pedagogy through example paradoxes, and share student feedback from anonymous course evaluations. (Received August 23, 2018)

1145-P5-641 **Kimberley Cadogan***, University of Northern Colorado, Ross Hall 2239, Campus Box 122, Greeley, CO 80639, and **Gulden Karakok** and **Spencer Bagley**. *Creativity in Problem Solving for non-STEM Majors in Calculus Courses.*

Given the critical role mathematics has played in contemporary innovation, the development of the talent pool in mathematics has great scientific and economic impact. As research studies exploring math majors' creativity in undergraduate math courses commence (e.g., Savic, et al., 2017), there is still a need to explore how such emphasis can be shifted to explore creativity at lower-level math "service" courses such as calculus. At this talk, we share a qualitative study that aimed to investigate creativity in problem solving for non-mathematics tracked students enrolled in a calculus course. Individual students' problem-solving process and their self-perception of mathematical creativity were documented through interview data. These task-based semi-structured interviews with 3 volunteered participants were analyzed using a modified whole-to-part inductive approach (Erickson, 2006). Although no explicit description of the creative process in problem solving emerged from the data, each participant was observed to exhibit all four phases of Carlson and Bloom (2005)'s problem-solving framework. Our findings suggest that even though students may perceive creativity as a process, this understanding may not necessarily be reflected in their written work. (Received September 12, 2018)

1145-P5-807 **Margaret Smolinka Adams*** (margaret.adams@sgsc.edu), South Georgia State College, 2001 South Georgia Parkway W, Waycross, GA 31503. *Outcomes of Three Creative Math Art Projects Integrated into Undergraduate Probability and Statistics.*

Undergraduates learning statistics often portray an aura of fear, anxiety and social isolation observed by disconnectedness, reluctance to answer questions or problem-solve collaboratively. To enhance the classroom learning atmosphere and encourage more social collaborative involvement, three creative statistic art projects were developed with a social-constructivist theoretical framework and assigned for homework with easy to follow grading rubrics. All students designed their own statistics vocabulary crossword-puzzles with answers on decorated cardstock. Student pairs created large poster-size vocabulary word walls and imaginative graffiti art posters using paint, markers, glitter, and objects such as dice and marbles. Outcomes included qualitative feedback from students: therapeutic aspects of using artist tools; using their imagination; reduced math anxiety; relief from cell phone addiction; ignition of genuine interest and appreciation in statistics; enjoyment coming to class; and having learned to talk, collaborate and problem-solve with their partners. Evidence of success includes acceptable grades on the projects and in the course along; comments about life-time learning, and course ratings as positive, helpful and therapeutic. (Received September 15, 2018)

1145-P5-1062 **Emerald T Stacy*** (estacy2@washcoll.edu), Chestertown, MD. *Inspiring Wonder in Calculus Through Student-Designed Projects.*

A Differential Calculus class was given a term-long assignment to do a deep dive into a topic that connects Calculus to a field they are passionate about. Students wrote project proposals, participated in the peer review process, completed multiple drafts, and presented their final project to their classmates. Students were given freedom to interpret the prompt, and they were encouraged to seek out advice from professors in other departments to learn how Calculus impacts their field. The goal of this project is for students to recognize that mathematics, and problem solving in general, is a creative endeavor. From Navier-Stokes equations to tomography, students pushed past the boundaries of what they thought it meant to take a Differential Calculus. Examples of student work will be presented, illustrating how students observed the wonder within mathematics. (Received September 18, 2018)

1145-P5-1455 **Maria G Fung*** (mfung@worcester.edu), Mathematics Department, 486 Chandler Street, Worcester State University, Worcester, MA 01602, and **Pamela Hollander**. *Children Literature Project in a Number and Operations Course for K-6 Teachers.*

In this talk, we describe a semester-long project centered children's literature on mathematics topics. We create a learning community between a mathematics content course and an education literacy course for pre-service elementary teachers. Students from both courses read a series of four children literature books, then discuss their mathematical and literacy components in a series of reflective writing assignments. At the end of the semester, students participate in a joint session to share children's books they have written as the capstone piece of the project. (Received September 22, 2018)

1145-P5-1484 **Malgorzata Marciniak*** (mmarciniak@lagcc.cuny.edu). *Creative assignments in upper level undergraduate courses inspired by mentoring undergraduate research projects.*

The idea of bringing creative assignments to my classroom occurred to me while mentoring successful creative undergraduate student projects. I observed that my research students were full of enthusiasm and attention but at the same time I observed insufficient levels of those traits in my classrooms. Engineering students of Linear Algebra, Calculus 3, and Differential Equations seem to have enough mathematics and background knowledge to pursue brief creative problems proctored in the classroom and long creative problems assigned as group projects. The main challenge is overcoming students' fear in doing something outside of the usual class curriculum. Even if the quality of the outcomes is uneven and student involvement vary, the overall benefit seem to override the difficulties. My presentation will contain some theoretical background of the theory of creative thought as presented by Graham Wallas in "The Art of Thought". In addition I will describe examples of creative assignments in my classrooms together with their assessments. (Received September 22, 2018)

1145-P5-1690 **Justin R. Dunmyre***, jrdunmyre@frostburg.edu. *How much pavement do you need? A simple prompt with rich opportunities for creativity in first semester Calculus.*

During the last week of the first semester of Calculus, my students receive the following: a screen capture from Google Maps, a superimposed grid, two points labeled A and B, and the prompt "How much pavement would you need to cover the surface of this road between A and B?" This prompt is both relatable and has a low barrier to entry, but most importantly, it inspires many creative ideas that will bring together essential concepts of Calculus. In this talk, I will share what creative approaches my students have used, and how I leverage those approaches to introduce topics including: the area between two curves, the arc length, Lagrange interpolation, and numerical integration. (Received September 23, 2018)

1145-P5-1859 **Ceire H Monahan***, Department of Mathematical Sciences, 1 Normal Avenue, Montclair, NJ 07043, and **Ashwin Vaidya** and **Mika Munakata**. *Juggling: Mathematical exploration through play.*

The Creativity in Mathematics and Science project, funded by NSF's Improving Undergraduate STEM Education program, seeks to develop opportunities for students to make connections between the creative process in general and the creative process in STEM fields. One way we have done this is by developing interdisciplinary modules for a general education mathematics course that challenge students' conceptions about mathematics and encourages them to see unexpected connections. Connections can be between ideas or processes required in two seemingly unrelated fields. Here, we describe our experience creating and implementing a module on the mathematics of juggling. We drew from research on the mathematics of juggling (Beek & Lewbel, 1995; Naylor, 2011, Widenhorn, 2016) and used a professional juggling performance at our university for inspiration. Students explore the patterns, notations, and mathematical components of juggling and engage in processes associated with creativity such as being inquisitive, connecting ideas, questioning norms, and having flexibility (Sternberg & Williams, 1998). We will share our experience developing and implementing the juggling module and report preliminary findings related to students' work and reactions. (Received September 24, 2018)

1145-P5-1935 **Samuel H. Lee*** (`samlee1097@yahoo.com`). *How Creativity Influenced my Academic Work and Lifestyle.* Preliminary report.

As I quietly entered a small room and sat in the back of my first Introduction to Applications of Linear Algebra lecture, I opened the syllabus for the course on my phone. Shocked that the grading was based solely on both of my weakest qualities, group work, and presentations, I questioned whether I made a mistake taking this course. I asked myself, "What do I have to offer to others?" and my mind began racing, making endless excuses to make me leave the room. I took a deep breath, cleared my mind, and decided to stay. While working with an inspirational professor and driven peers, I have learned that I can offer my creativity. Creative ideas come to life and nourish once they are shared and assessed by others. This statement captures a vital personal and academic lesson that I had learned from working with a supportive professor and peers. In this presentation, I will share how I came to this realization and how creativity was integrated and influenced my work on one of the topics in the course: perspective projection in 3D. (Received September 24, 2018)

1145-P5-2461 **Stephen Balady*** (`sbalady@oberlin.edu`), 614 Beech St, Oberlin, OH 44074. *Running a Project-Based Linear Algebra Course Through MATLAB.* Preliminary report.

Many undergraduate linear algebra courses have a scientific computing component, and MATLAB is a popular choice of language. In a traditional lecture-based linear algebra course, students can find it difficult to see MATLAB work as significant or meaningful. Last spring, I designed and ran a project-based course in applied linear algebra in which assignments and student work were presented entirely through MATLAB .m files. I'll describe the technical and social challenges that I and my students faced over the course of the semester, a selection of the prompts that I developed with my students, and what I learned about the importance of a robust feedback cycle.

To me, creativity in the classroom is about legitimizing student voices. As such, I asked an aspiring mathematics educator who was a student in the course if he would present his perspective. I hope that my talk will be one half of a pair in this session: I can tell you about what I hoped students would find inspiring, and he'll tell you a specific story of inspiration. (Received September 25, 2018)

1145-P5-2646 **Sarah Vigliotta*** (sarah.vigliotta@yale.edu). *Connecting Class Topics to Student Interests.*

"When will I ever use this?" This question is asked by students repeatedly in classrooms. By asking them to try and answer this question themselves, we allow students the creative freedom to explore topics that we otherwise might not cover in class. In this talk, we will discuss an article project used in a course titled Estimation and Error as a way for students to discover how the material discussed in class related to topics of interest to them. We will highlight the course itself including topics covered and student demographic, and end with some student remarks related to this particular end of term assignment. (Received September 25, 2018)

1145-P5-2660 **Julia Eaton*** (jreaton@uw.edu), 1900 Commerce Street, Box 358436, Tacoma, WA 98402. *A problem of their own: using student creativity to create ownership of learning.* Preliminary report.

Course projects are built into the mathematics curriculum at the University of Washington Tacoma. These projects are intended to give students continual experience writing and presenting mathematical applications to a peer audience, as well as navigating group work. I am happy to provide students with suggested topics. Most often students select their topic from the list of suggestions list rather than generate their own. Something magical happened when a group of students invented their own problem for a multivariable calculus project. They were invested in and passionate about their project to a much higher degree than the other (already very motivated) students. The act of creating their own problem engendered an sense of ownership to their learning that I hope to replicate in more contexts. In this talk I'll share my experiences in this class, thoughts about project-based learning, and strategies for celebrating students' ideas. (Received September 25, 2018)

1145-P5-2713 **Kayla K. Blyman** (kayla.blyman@usma.edu), United States Military Academy, Department of Mathematical Sciences, 646 Swift Road, West Point, NY 10996, and **Kristin M. Arney*** (kristin.arney@usma.edu) and **Lisa Bromberg** (lisa.bromberg@usma.edu). *An Experiment in Assessing Creativity and Critical Thinking in a Freshman-Level Mathematical Modeling Course.*

Many undergraduate mathematics courses list developing creative and critical problem solving skills as a higher order learning goal. But so often testing, grades and traditional teaching methods reward the use of predetermined answers and therefore overshadow the critical role creativity plays in real world problem solving with mathematics.

In our course we are working to find ways to develop creative and critical problem solvers. We are looking for our students and instructors to gain the ability to overcome fixations in mathematical problem-solving and are working to reward divergent solution techniques within situations that best utilize mathematical solution techniques.

In an attempt to assess if our course improves mathematical creativity through problem solving, we conducted an experiment with over 200 students during the Fall 2018 semester. We chose two critical thinking problems that do not require the foundational knowledge of our course and can be solved using multiple methods. The students were given one of two critical thinking problems to solve on the first day of class and then on the last day of class were given the remaining problem.

The experimental design and preliminary results will be discussed. (Received September 25, 2018)

1145-P5-2716 **Annela R Kelly*** (annela.kelly@regiscollege.edu). *Designing in Multivariable Calculus.* Preliminary report.

It is exciting to move to the three-dimensional space in multivariable calculus after studying xy-plane in most of the previous mathematics classes. The talk will showcase several creative activities that acquaint students with 3D objects. For instance, to understand the coordinates of points in 3D and spheres, the students created an emoji. The worksheets and projects to design and analyze the 3D objects will be shared with the audience. The presentation will demonstrate the designed objects and discuss the student feedback from the course. (Received September 25, 2018)

1145-P5-2740 **Andrea Young***, younga@ripon.edu. *Developing storytelling using improvisation.*

Improvisational comedy techniques have widely been used to foster creativity in business and other settings. I will discuss some uses of improv in the mathematics classroom for the purposes of developing creativity. I will also discuss ways that improvisation can be used to help students learn how to tell stories, in particular how to create compelling arguments (stories) using mathematical evidence. (Received September 25, 2018)

1145-P5-2902 **Milos Savic*** (savic@ou.edu), **Paul Regier**, **Kimberley Cadogan**, **Emily Cilli-Turner**, **Houssein El Turkey**, **Gail Tang** and **Gulden Karakok**. *A framework for fostering mathematical creativity in the undergraduate classroom.* Preliminary report.

In our examination of the creativity literature, we found a subset that examined teacher actions that foster creativity in the classroom. While the focus is on teacher actions, the categories are usually defined by student outcomes. Therefore, we aimed to investigate teacher actions using three main dimensions: the latent, personal, and social. Each dimension will be discussed in the presentation, with emphasis on concrete examples of teacher actions in data we've collected. (Received September 25, 2018)

1145-P5-2947 **J. Lyn Miller***, lyn.miller@sru.edu. *Outside-the-Box Thinking about Number Theory for Future Elementary Teachers...and for Math Majors.* Preliminary report.

Creative mathematical thinking for pre-service elementary teachers can be as basic as breaking them away from the common settings of demonstrating direct mastery, conceptual understanding, and/or justification of procedures. However, when it comes to elementary number theory, math majors often are no better equipped to make this break, for their own number theory experience exceeds that of the future K-6 teachers only by the inclusion of rigorous proof. Thus, there is a rich trove of creative thinking tasks that can be mined from the gap between mastery of 4th-8th grade number theoretic algorithms and their underlying concepts, and proving that those algorithms and concepts are valid. This talk presents a few examples of such tasks that are accessible to both groups of students. (Received September 25, 2018)

Inclusive Excellence - Attracting, Involving, and Retaining Women and Underrepresented Groups in Mathematics

1145-Q1-155 **Sarah J Greenwald*** (greenwaldsj@appstate.edu). *Women in Mathematics Badge/Patch for Girl Scouts.* Preliminary report.

Amber Mellon, Jill Thomley and the speaker co-designed and co-organized a women in mathematics badge/patch program for Girl Scouts. We will explain our motivations for designing and continuing to offer the program, including feedback from participants. This will include results from a student survey on mathematical experiences conducted by the speaker with Tameshia Fisher, Wilt Latham, Lauren Murray, and David Sawyer. Appalachian State University's Institutional Review Board has determined these results to be exempt from IRB oversight. We will also share our badge/patch steps and design for those who want to offer a similar program themselves. (Received August 11, 2018)

1145-Q1-313 **Helen Burn*** (hburn@highline.edu), 2400 S. 240th Street, MS 18-1, Des Moines, WA 98198, and **Vilma Mesa**, **J. Luke Wood** and **Eboni Zamani-Gallaher**. *Dimensions of an Equity-Based Mathematics Program.*

Transitioning Learners to Calculus in Community Colleges (NSF IUSE 1625918) is a research project aimed at improving the transition of historically underserved students to and through calculus in two-year colleges by identifying programs, structures, instructional strategies, and key transition points within the mathematics curriculum that influence the success of URM students. This paper draws from data collected from a National Survey of mathematics chairs and case studies of Minority Serving Institutions and presents dimensions and indicators for the TLC3 Model for an equity-minded mathematics program. (Received August 30, 2018)

1145-Q1-381 **Jacqueline Jensen-Vallin*** (jjensenvalli@lamar.edu), PO Box 10047, Beaumont, TX 77706. *Lamar University STEM Students of Color Alliance.* Preliminary report.

Thanks to generous funding from the MAA Tensor SUMMA Grant Program, in Fall 2018, Lamar University initiated the LU STEM Students of Color Alliance. This group supports STEM students by providing external role models, especially for African-American and Latinx students. Four speakers were invited to campus to present their mathematical research and then to interact with students during a follow-up reception. These are the beginnings of creating a community of STEM scholars of color at Lamar University. We will discuss our victories and plans for the future. (Received September 04, 2018)

1145-Q1-623 **Jana Talley***, jana.r.talley@jsums.edu, and **Carmen Wright**, carmen.m.wright@jsums.edu. *The Jackson State University Girls Engaging in the Mathematical Sciences Program: A Summer Enrichment Experience for Middle School Girls.* Preliminary report.

The Jackson State University Girls Engaging in the Mathematical Sciences Program (JSU GEMS) is a one-week summer enrichment program for middle school girls who are members of groups underrepresented in the mathematical sciences. Jackson State University is an urban, Historically Black University situated within a low performing school district. The summer program addresses the underrepresentation of women and minorities by offering participants several rigorous learning experiences and engagement with mathematicians and other professionals in mathematically intensive careers.

This study is designed to examine the impact of participation in the program on girls' propensity to engage in the mathematical sciences. Both surveys and interviews are being collected to address the following research questions: RQ1: How has participation in JSU GEMS impacted participants' propensity to engage in mathematics activities? RQ2: How has participation in JSU GEMS impacted participants' propensity to enroll in elective or advanced mathematics courses? RQ3: How has participation in JSU GEMS impacted participants' interest in pursuing a career in mathematics? RQ4: How has participation in JSU GEMS impacted participants' mathematics self-efficacy? (Received September 11, 2018)

1145-Q1-636 **Liz Andrus**, **Daniel Horns** and **Violeta Vasilevska*** (violeta.vasilevska@uvu.edu), 800 W University Parkway, Orem, UT 84058, and **Krista Ruggles**. *PREParing underrepresented students through Intensive Summer STEM Program.* Preliminary report.

To address the need for early preparation in mathematics, Utah Valley University (UVU) initiated the summer intensive program PREP (https://www.uvu.edu/partnership/prep/) in 2013, patterned after The University of Texas at San Antonio program. The PREP program identifies low-income, underrepresented, first-generation, and female students entering seventh grade who have interest and aptitude in math and science, and involves them in this seven-week, three-year summer intensive STEM program. It prepares and encourages students to take higher-level math courses in junior high and high school and builds a foundation in mathematics, scientific application, and problem solving, through rigorous academic instruction, educational hands-on projects, challenging homework assignments, daily career awareness and field trips.

In 2016, UVU was awarded an NSF-INCLUDES grant that allowed the creation of UTAH PREP collaboration with other PREP sites in Utah and the development of a shared measurement system.

In this presentation, the structure and course content of UVU PREP program will be discussed. In addition, some of the survey results and data collected as part of the NSF-INCLUDES grant will be shared. (Received September 11, 2018)

1145-Q1-800 **Ryan Roger Moruzzi, Jr*** (rmoru001@ucr.edu). *A math enrichment program for underserved 4th and 5th grade students.* Preliminary report.

There has been much research showing early exploration of advanced mathematics is beneficial for students overall success in K-12 . Though there are many outreach programs for students in middle school and high school, not as many have been formed at the elementary school level. For these reasons, I have teamed up with my department to create a math enrichment program at an elementary school in an a low socio-economic district, influenced by math circles through the MSRI. This program is geared towards fostering the excitement and exploration of mathematics to underrepresented groups at an early age in hopes of building a more equitable and accessible mathematical community.

I will discuss the origins and motivation of our program, along with our goals and where we envision this program heading in the future. I will also be discussing some types of lessons we have done, along with activities we hope to do with the students. (Received September 15, 2018)

1145-Q1-831 **Tim McEldowney*** (tmcel001@ucr.edu) and **Po-Ning Chen**. *A Better Path to Math Careers.*

To help advance women and minorities in mathematics, we first need to ensure individuals are aware of the different options and pathways available to them. Many women and underrepresented minorities graduate with a degree in mathematics without even knowing about the possible career paths in math, or are underprepared to pursue them. Last year, as a graduate student at University of California, Riverside, I decided to do something about this. I created the Advanced Mathematics Program (AMP) with the support of Drs. Po-Ning Chen and Yat-Sun Poon, graduate students, and staff. AMP is a free Summer Program that prepares students for abstract algebra and real analysis, two topics which often prove to be barriers to reaching careers in math. In addition, we helped students learn about what future careers they can consider with talks from mathematicians in pure math, applied math, and math education. I will address how I initially designed the program and the lessons I learned in its implementation. I will also address how we have expanded the program in its second year to include events we had during the academic year, including attending conferences with the former AMP participants and the additional invited speakers. (Received September 15, 2018)

1145-Q1-861 **Yevgeniya Rivers** (yrivers@newhaven.edu), University of New Haven, 300 Boston Post Rd, West Haven, CT 06516, and **Yasanthi Kottegoda*** (YKottegoda@newhaven.edu). *Pitching a Passion for Mathematics and Computer Science in a Summer Camp Setting for Females Entering Grades 7 through 12.*

In the Status of Women & Girls in New Haven, CT Report, researchers found that, "Changes to public policies and program initiatives provide opportunities to create a better future for women and girls in New Haven. Recommended changes include... female-specific programs in New Haven, implementing strong career and education counseling for girls beginning in elementary school." The lack of opportunities for low cost STEM enrichment programs undermine the social and economic prospects for girls in New Haven and justify the need for a summer math camp. The University of New Haven All Girls Math Academy is a one-week summer enrichment program in Mathematics and Computer Science for girls entering grades 7-10. The curricula provides a hands-on experience for the campers in maths to which they would have had little or no prior exposure, thus challenging any disparities that would exist in their prior knowledge. The main objectives are to improve recruitment and retention of girls in math and computer science majors and careers by increasing awareness of career options, demonstrating that mathematics can be fun and challenging, strengthening problem solving skills, improving attitudes, self-image in mathematical literacy and also developing written and verbal communication skills. (Received September 16, 2018)

1145-Q1-892 **Eugene Fiorini***, 2400 Chew Street, Allentown, PA 18104, and **Gail Marsella** and **James Russell**. *InForMMS: Investigating Forensic Mysteries through Mathematics and Science.*

InForMMS is a week-long summer camp paired with academic year follow up activities in which students from underrepresented groups learn forensic techniques that apply mathematics and science. The camp culminates with a staged crime scene that the participants process and report on the results. The academic year follow up includes forensic activities, college prep assistance, and the creation of a forensic science club at each of the participating high schools. Participants were recruited from high schools with large populations of underrepresented groups in the mathematical sciences. This talk presents program outcomes and descriptions of some representative activities. (Received September 17, 2018)

1145-Q1-993 **Guadalupe Lozano*** (guada@math.arizona.edu), **Marla Franco** and **Vignesh Subbian**. *Mathematics, Science, and Engineering at Hispanic Serving Institutions (HSIs): Recommendations for Better Serving Undergraduate Students.*

The number of colleges and universities earning the designation of Hispanic Serving Institution (HSI) more than doubled between 2005 and 2016, and accounts for 15% of all non-profit, higher-education, degree-granting institutions. In 2017, in response to two Congressional Acts, the National Science Foundation (NSF) funded a total of 11 national conferences to inform the design & subsequent call for proposals of their new HSI Program. The University of Arizona, one of four initial awardees, held a working conference that brought together over 100 faculty, students, and administrators from 42 Southwestern HSIs, including 17 two-year HSIs and four Research I (R1) universities. In this talk we will describe six themes and 13 focus areas of recommended practices that emerged from the analysis of the Arizona conference transcripts, and illustrate how newer and emerging HSIs may begin to shape an institutional culture aimed at better serving the Hispanic students they admit, particularly in Mathematics, Engineering and Science. (Received September 18, 2018)

1145-Q1-1278 **Cara Peters*** (cpeters3@math.umd.edu) and **Sarah Burnett** (burnetts@math.umd.edu). *Girls Talk Math: Pursuit of Representation through Media.*

Girls Talk Math (GTM) is an inexpensive two-week, day camp for high school students at the University of Maryland (UMD) that promotes participation of women in mathematics. This program features three interconnected components: to explore new mathematical concepts, to learn about the role of women in math and their current contributions to the field, and to develop verbal and written communication skills. With the help of a mentor, groups of participants completed a problem set on a particular topic in abstract geometry, applied mathematics, scientific computing, or cryptography. This approach allowed both the participants and volunteer mentors to build their communication skills, develop mentoring relationships, and boost their confidence in mathematical language. The goal of this camp is two-fold: to provide an opportunity for young women to realize their potential for a career in math, and to create a local sustainable community of female mathematicians. The first year of GTM was sponsored by the Math Department and the AMSC program at UMD. GTM is an adaptation of the University of North Carolina's GTM camp, preserving much of its structure and utilizing its camp materials with the support of the UNC co-founders. (Received September 20, 2018)

1145-Q1-1366 **Li-Mei Lim*** (mei121@bu.edu), Boston University, Department of Mathematics and Statistics, 111 Cummington Mall, Boston, MA 02215. *PROMYS Math Circles and PROMYS Math Circle Girls.*

In 2016, thanks to funding from a local family foundation, PROMYS (a summer math program for talented high school students held at Boston University) launched an initiative to increase its outreach efforts to Massachusetts students from low-income and under-served backgrounds. PROMYS for Teachers alumni nominated students to participate in PROMYS Math Circles (PMC) and served as mentors with support from PROMYS. During the 2017-18 school year, the first full year of PMC activities, we had 91 students participate in 10 math circles. In addition to their regular meetings, we held a few events at Boston University, including a highly successful Math Field Day, where all the math circles could come together as a community. In both 2017 and 2018, PROMYS welcomed a small group of students from PMC to the summer program.

In April 2018, PROMYS received a Tensor Grant for our proposal for the PROMYS Math Circle Girls initiative. We aim to further support the existing math circles by providing supplemental opportunities for female PMC participants during the 2018-19 school year. (Received September 21, 2018)

1145-Q1-1488 **Lyn McQuaid*** (mcquaid@kutztown.edu), Department of Mathematics, Kutztown University, Kutztown, PA 19530. *Encouraging Women to Study Mathematics.* Preliminary report.

When I was hired as a tenure-track faculty member almost 20 years ago, there were no STEM courses included in my university's Women's Studies Program. This inspired me to create a course entitled "Women in Mathematics", which has been offered every semester for the past 15 years. In this talk, I will discuss some of the inspiring women studied in the course and how the stories of their lives influence the young women in my classes to study mathematics when they perhaps never had considered it as a possible major. I will also offer suggestions of how to incorporate such encouraging stories about female mathematicians into other mathematics courses such as Number Theory, Analysis and Abstract Algebra. (Received September 22, 2018)

1145-Q1-1822 **Christina Therkelsen*** (christina.therkelsen@uc.edu), University of Cincinnati, Department of Mathematical Sciences, PO Box 210025, Cincinnati, OH 45221, and **Vita Borovyk**. *Starting Young: Connecting Kids to the University.* Preliminary report.

In our talk we will describe the outreach program we developed in Fall 2017, a continuation of which is now supported by a Tensor-SUMMA Grant from the MAA. As mathematics faculty at the University of Cincinnati, we worked closely with a 7/8th grade teacher in a Cincinnati Public School with a population of students of which 99.4% are economically disadvantaged, 78.7% African American, 13.2% White, 4.8% Multiracial and 2.8% Hispanic. In mathematics, this school ranks as one of the lowest performing schools in the state of Ohio. Our goal is for these students to experience (and enjoy) mathematics outside of a classroom environment driven by test preparation, and to give them an opportunity to consider future aspirations that they may not have been exposed to before. (Received September 24, 2018)

1145-Q1-1954 **Tracii Friedman*** (tfriedma@coloradomesa.edu) and **Cathy Bonan-Hamada**. *GirlsDoMath Summer Camp at Colorado Mesa University.* Preliminary report.

The GirlsDoMath Summer Camp is a week-long mathematics enrichment camp for girls entering 8th or 9th grade. The goals of the GirlsDoMath Camp are to provide mathematics enrichment activities and a "mini-research" experience to girls early in their education; to introduce girls to careers that require a strong background in mathematics; and to improve girls' perceptions of women as mathematicians. The camp uses hands-on activities to introduce exciting topics in mathematics that the girls are not likely to have seen in their traditional school curriculum. Camp participants choose one of the topics to explore in more depth, resulting in a presentation on the final day of the camp. The GirlsDoMath Camp ran for the first time in July 2018 and was supported by an MAA Tensor Women and Mathematics Grant. Colorado Mesa University is located in rural, western CO, over 200 miles from the nearest major university and our camp is the first of its kind in the region. We believe that by giving the young women who attend our camp the opportunity to engage with and explore interesting mathematics in a supportive environment, they will achieve greater confidence and mathematical growth. In this presentation, we will describe the GirlsDoMath Summer Camp experience and report on its success. (Received September 24, 2018)

1145-Q1-1980 **Matthew Voigt*** (mkvoigt@gmail.com). *Queer Spectrum Students in Undergraduate Mathematics: How their Identity impacts their instructional experience and views of mathematics.* Preliminary report.

There is growing evidence that queer and trans spectrum students (e.g., those identifying as lesbian, gay, bisexual, transgender, or queer) are less likely to be retained in STEM degrees, report hostile campus climates, and are less likely to take advanced math courses in high school. In this study we utilized a mixed-methods design drawing on student surveys and interviews to document how queer spectrum students in precalculus and calculus courses across 14 universities report their instructional experiences and how their identity has impacted their experiences and relation to mathematics. Based on survey responses (n=15,607), queer spectrum students (n=1449) were more likely to report their math classroom as hostile or excluding and anticipated receiving a lower course grade. Follow-up Interviews with 16 students who completed the survey highlighted that many of the students viewed the nature of math through a paradoxical lens of a discipline that is objective and thus neutral to issues of identity, yet hostile and exclusionary to non-normative identities in math spaces. Students expressed a desire for math faculty to use more inclusive practices such as introducing pronouns, including a diversity statement and featuring math problems that included LGBT representation. (Received September 24, 2018)

1145-Q1-2092 **Yuju Kuo*** (yjkuo@iup.edu) and **Rick Adkins** (fadkin@iup.edu). *NSF S-STEM – Creating Opportunities for Applying Mathematics.* Preliminary report.

Building on prior S-STEM awards providing 120 scholarships, NSF-funded Scholarships-Creating Opportunities for Applying Mathematics (S-COAM) project establishes a supportive connection of master's students with undergraduates, engages them in cohort activities, encourages research and internship opportunities, provides conference travel support, offers hands-on technology workshops, empowers students to pursue advanced math courses, and connects students with mentors and external speakers. New initiatives include building a pipeline of STEM students via focused minority recruiting; supporting success through peer-led learning, linked curricula and research; and studying how formation of mathematics identity enhances persistence in STEM. Working closely with Admission Office, minority students are contacted for scholarship cohort opportunities. This comprehensive approach is expected to improve recruitment, retention, mathematical training, and career preparation for women, minorities, economically disadvantaged, rural, and first-generation students resulting in more graduates ready to conduct research and pursue advanced STEM studies or careers. (Received September 24, 2018)

1145-Q1-2095 **Zoë Misiewicz*** (zoe.misiewicz@oneonta.edu). Hidden Figures *in a History of Mathematics Course.* Preliminary report.

The textbook begins with a disclaimer: there will not be very many women mentioned, due to historical forces that hindered their participation in the mathematical community. This is only one way in which these historical disadvantages persist to the present day, making it more difficult for female students to see themselves in the discipline. *Hidden Figures* by Margot Lee Shetterly offers a partial corrective to this situation, introducing students to the mathematical accomplishments of Black American women in the mid-twentieth century. Reading this book in a classroom setting sends a message to students that gender- and race-based disparities in mathematics are worth discussing and provides an opportunity for students to share their own experiences. I will describe how I incorporated *Hidden Figures* into my syllabus and discuss some of the effects that I have observed in my classroom since I started assigning it, including a shift in students' selection of research paper topics. I will also highlight some student comments about the book, with an emphasis on pre-service teachers' remarks about how it will affect their own teaching practice in the future. One key takeaway is that a relatively small curricular change can potentially make a big difference. (Received September 24, 2018)

1145-Q1-2437 **Joel Kilty** (joel.kilty@centre.edu), Mathematics Department, Centre College, Danville, KY 40422, **Alison Marr** (marra@southwestern.edu), Mathematics Department, Southwestern University, Georgetown, TX 78626, and **Alex M. McAllister*** (alex.mcallister@centre.edu), Mathematics Department, Centre College, Danville, KY 40422. *Enabling Student Persistence and Success in the Calculus Sequence.* Preliminary report.

While traditional methods of teaching and learning mathematics ostensibly served well for decades, the mathematics community is re-examining and re-envisioning these approaches in response to multiple changing realities, which include: evidence that the standard approach "filters" traditionally under-represented students, extremely different levels of student preparedness, the diverse career and continuing education paths of students, more sophisticated technologies, and access to large data sets that enable more realistic and more relevant applications. This talk shares the outcomes of a 2018 project at Centre College and Southwestern University that sought to understand and address filters that inhibit student persistence and success in mathematics and other STEM disciplines, particularly among under-represented minority, first-generation, low-income, and female students. We provide details about two particular efforts that sought to make a positive difference in improving persistence and success:

- designing, implementing, and assessing a pilot cohort model for Calculus I students in Fall 2018, and
- re-envisioning the entire calculus sequence during 2018 with planned implementation beginning in Fall 2019.

(Received September 25, 2018)

1145-Q1-2572 **P. Gavin LaRose*** (glarose@umich.edu) and **Nina White**. *A Mathematics Learning Community on Inclusive Teaching: Improving Understanding and Implementation of Inclusive Instruction.*

The process of attracting and retaining underrepresented groups in mathematics begins in the mathematics classroom; however, many instructors in mathematics are unaware of the research on and developing understanding of inclusive classroom practices, reducing their opportunity to implement these in their classes. In this talk we describe one model for addressing this, by which we sought to move our department forward in its understanding and adoption of such teaching practices: a Learning Community on Inclusive Teaching for instructors. In winter 2018, a group of instructors from our department met six times to discuss readings and topics in inclusive teaching, how to implement the ideas in their own classrooms, and where changes may be made in the Department's approach to teaching and new instructor training. In this talk we discuss the structure of the community, its effectiveness, changes that we were able to effect as a result of the community, and we look forward to manners in which we will build on our work. (Received September 25, 2018)

1145-Q1-2635 **Matthew Voigt*** (mkvoigt@gmail.com), **Jessica R. Gehrtz** (gehrtz@math.colostate.edu) and **Jess Ellis Hagman** (jess.ellis@colostate.edu). *Programs to support underrepresented students in STEM and the role of mathematics departments.* Preliminary report.

Math departments are becoming increasingly attuned to the particular challenges faced by underrepresented students in STEM and are seeking new ways of supporting student success in introductory mathematics courses. Faculty members often recognize issues of equity and inclusion, but underestimate the extent to which STEM departments can impact and make a difference on these issues at their institution (Apkarian, Kirin, Gehrtz & Vroom, under review). We use open coding of responses to a national survey of math departments to categorize the reported types of support programs for traditionally underrepresented groups of students. Nearly 45% of departments reported that they were unaware of any programs, that none existed, or that some unspecified support was offered by the university. Our work suggests that many of these programs are relatively rare across the universities sampled and are often not deeply connected with the mathematics department. Drawing on case study analysis, we then highlight several programs designed to support underrepresented students in STEM involving math faculty. We target the rationale for the development of these programs as examined through a critical lens (Basile & Lopez, 2015) and how their enactment is experienced by students and faculty. (Received September 25, 2018)

1145-Q1-2803 **Cayla D. McBee*** (cmcbee@providence.edu). *Increasing Women's and Underrepresented Groups' Sense of Belonging through High Impact Practices.*

Many students from underrepresented groups often lack a sense of belonging within the mathematics and STEM majors. This in turn impacts the success and retention of these individuals. There are a number of actions that can be implemented to help address these issues. This talk will examine the use of high impact practices to increase students' persistence and sense of belonging in mathematics. (Received September 25, 2018)

1145-Q1-2911 **Luis A Leyva*** (luis.a.leyva@vanderbilt.edu), **Emily A Wolf** (emily.wolf@gse.rutgers.edu), **Kristen Amman** (kma198@scarletmail.rutgers.edu) and **Dan Battey** (dan.battey@gse.rutgers.edu). *An analysis of student perceptions of positive instructional practices that potentially disrupt racial-gender marginalization in undergraduate mathematics classrooms.*

Inquiry about instruction in entry-level mathematics courses that promotes academic success and positive identity development is critical to address issues of STEM retention. This report presents an analysis of positive instructional features that 16 first-year college students, including white women and students of color, reported as potential challenges to marginalization that they encountered in pre-calculus and calculus classrooms. Three themes that characterize such positive instructional practices were revealed. First, instructors getting to know and building strong relationships with students, in and out of the classroom, challenge the impersonal nature of large lectures. Second, instruction that challenges notions of innate ability and holds high expectations for students' success was perceived as minimizing students' emotional labor of managing how they are perceived by others. Lastly, disruptions of exclusionary values in STEM disciplines (e.g., authoritarianism, individualism) reshapes hierarchical power dynamics between instructors and students, which broadens opportunities to learn for understanding and sets a positive emotional tone for the classroom. These findings are used to raise implications for equitable classroom instruction in undergraduate mathematics. (Received September 25, 2018)

1145-Q1-2934 **Kathleen Wong*** (kathwong1@yahoo.com) and **Devonna Alatorre**. *Redefining mathematics and mathematicians.* Preliminary report.

By making movement towards redefining the way we talk about success in math to students, we are challenging students to see themselves as capable in mathematics and adapting a growth mindset.

Through the Prison Education Project (PEP), in-custody students at the California Rehabilitation Center learn to contribute to mathematics as well as to civic life with classes such as Introduction to College Math and Graph Theory. This Level II all-men's facility located in the city of Norco in California consists of a high population of African Americans and Hispanics who are refining their attitudes towards math and their futures. On the other hand, teaching at Summit Tahoma High School in San Jose, a Title 1 school with around half of its students being low-income poses its own challenges and fosters innovative techniques through its project-based learning approach.

As math educators, whether in a public school system or in a prison, our goal is to continue to redefine what the term mathematician means for students. We want to make the term more inclusive so that math students are able to associate their success in math, even within a small concept, as them becoming experts in math and thus becoming mathematicians. (Received September 25, 2018)

1145-Q1-2952 **Lauren L Rose*** (rose@bard.edu), 30 Campus Road, Annandale-on-Hudson, NY 12571. *Girls Math Club: Connecting Female Math Majors with Middle School Girls.* Preliminary report.

The Girls Math Club is a monthly enrichment program for middle school girls led by female math majors at Bard College. The impetus for this club came from noticing that very few girls entered our Bard Math Circle math competitions. Middle school is the time when many girls turn off to math, and those that still like math often feel isolated and ostracized. Our goal was to create a community of girls who come together each month to learn about mathematical ideas, play games, and meet and engage with other girls and women who love math. An interesting side benefit has been the growth in mathematical maturity, development of leadership skills and increased confidence exhibited by the female math majors leading the club. This initiative has created a unique opportunity for both middle school girls and female math majors at Bard. (Received September 25, 2018)

1145-Q1-2963 **Brandy S Wiegers*** (brandy.wiegers@cwu.edu), 400 E University Way, Ellensburg, WA 98926. *Converging support towards includes excellence at Central Washington University.*

Central Washington University (CWU) has worked to create an environment that is most supportive of the diversity of students in the Pacific Northwest that are underrepresented in the field of mathematics. This has been made possible with a specific focus on developing out programs at CWU to include more connections to the successful national programs of the MAA and the Mathematical Alliance. In addition, CWU has created a bi-weekly mathematical seminar, a second-year mathematical orientation course, graduate school professional development summer programs, mathematical outreach programs that encourage more double majors, and more.

This presentation will share lessons learned leading over the last five years, with a focus on the lessons learned and used in the Central Convergence REU program first run in summer 2018. We will also discuss how students are prepared, encouraged, and supported to seek future research experiences (graduate programs, conferences, advanced courses, etc.) to further participate in the professional field. Our success has been demonstrated with a steady increase in the number of female students staying in the major and applying/ attending graduate programs. (Received September 25, 2018)

Innovative Pathways to Quantitative Literacy

1145-Q5-164 **Samuel Luke Tunstall*** (tunstal1@msu.edu). *Measuring the Effectiveness of Quantitative Literacy Curricula—The Importance of Construct Validity in Assessment.*

Assessment is a persistent concern for those teaching or administering coursework related to quantitative literacy (QL). Beyond issues such as appropriate placement and student success rates, one issue that merits particular consideration is that the ways in which we interact with and act on quantitative information is different when we are not being assessed on that interaction. Though assessments of any construct offer only proxies for that construct, assessments of QL are especially tenuous, as the setting and assessment itself can fundamentally obfuscate the construct of interest. In this presentation, I present a theoretical overview of the issue of construct validity, and then use that lens to share findings from recent work, where I have analyzed QL items from the Programme for International Assessment of Adult Competencies (PIAAC), as well as interviewed students about those specific items. I raise and discuss both theoretical and practical questions for the QL community to consider as we consider how to assess the effectiveness of QL-focused curricula. (Received August 14, 2018)

1145-Q5-1142 **Vesna Kilibarda*** (vkilibar@iun.edu), Indiana University Northwest, Department of Mathematics & Actuarial Science, 3400 Broadway, Gary, IN 46408, and **Yuanying Guan**. *Active Collaborative Learning and Faculty Development in the Redesign of Introductory Mathematics Course.*

Introductory courses enroll twice as many students as all other mathematics courses combined [CBMS, 2000]. These courses have the greatest impact on strengthening students' quantitative and logical reasoning abilities which are needed for informed citizenship and success in the workplace [CUPM, 2004]. A multifaceted innovative redesign of a quantitative course for liberal arts and health professions has the goal of strengthening these abilities in our students.

Our redesign starts with Mathematics Placement peer coaching that precedes carefully calibrated Placement Exams. In the collaborative learning component students explore meaningful problems in groups, test conjectures, find solutions, and explain results. Common Exams are an important assessment component. Attendance and homework are mandatory and built into the grade. The Faculty Development Workshop is a very important part of course redesign. We obtained a grant with stipends for associate faculty to become familiar with the course redesign.

The results have shown an increase of 6% in the means of scores on midterm and final exams, and a 17% increase in retention after a semester, while the DFW rates have not shown a consistent trend. In the paper we share elements of the course design and the latest results. (Received September 19, 2018)

1145-Q5-1873 **Jennifer Anne Bergner*** (jabergner@salisbury.edu), Department of Math & CS, 1101 Camden Ave, Salisbury, MD 21801. *Building Quantitative Literacy through the Mathematics of Voting and Elections.* Preliminary report.

In this session, I would like to share the challenges and successes I have had in creating a course that engages liberal arts majors in the mathematics present in voting and elections. In this course, my students discover how to reason and use the tools of mathematics to create mathematical models to look at different election decision methods. We examine such topics as the various methods of aggregating individual preferences into an aggregate choice, the desirable properties of a voting system, gerrymandering, and apportionment methods. I will share the impact this class has had on my students and how their quantitative literacy naturally developed throughout the course. (Received September 24, 2018)

1145-Q5-2178 **Russ F. deForest*** (rfd131@psu.edu), 109 McAllister Bldg, University Park, PA 16802. *Mathematics for Sustainability: A General Education Mathematics Course.*

Mathematics for Sustainability is a general education math course offered at Penn State that engages students in a quantitative approach to sustainability questions. Students are introduced to interesting mathematical ideas in a context requiring minimal mathematical background, build their skills in quantitative reasoning, and are empowered in using quantitative arguments in effectively advocating for issues they care about.

We view quantitative reasoning as part of a broader set of essential skills for citizens who are prepared to be engaged in sustainability questions and we develop mathematical topics in the course with this purpose in mind. These include: basic computations using units; estimation and precision; communicating quantitative information in relevant terms; logical fallacies and the misleading use of quantitative information; computations involving energy and power; dynamic equilibria and the energy balance of the Earth; feedbacks and tipping points in ecosystem models; models of exponential and logistic growth; risk and uncertainty; bayesian inference;

game theory; and potential mechanisms for resolving the tragedy of the commons. (Received September 24, 2018)

1145-Q5-2284 **Betty Love*** (blove@unomaha.edu), Mathematics Department, University of Nebraska - Omaha, Omaha, NE 68144, **Victor Winter** (vwinter@unomaha.edu), Computer Science Department, University of Nebraska - Omaha, Omaha, NE 68144, **Michael Matthews** (michaelmatthews@unomaha.edu), Mathematics Department, University of Nebraska - Omaha, Omaha, NE 68144, and **Michelle Friend** (mefriend@unomaha.edu), Teacher Education Department, University of Nebraska - Omaha, Omaha, NE 68144. *Introduction to Mathematical and Computational Thinking: A New Gen-Ed Math Course.*

We report on an NSF-funded project to develop and assess a new course designed to satisfy the math general education requirement at our institution. The course combines mathematical thinking and computational thinking. At the heart of the course lies the study of patterns, which are fundamental to mathematics and to computer science. Specifically, we explore a variety of visual patterns and examine how to express these mathematically as algebraic expressions and sequences. These abstractions form the basis for creating algorithms that are then implemented in Bricklayer code to create a virtual visible representation of the pattern. Developed by the presenters, Bricklayer (bricklayer.org) is a set of apps, online tutorials, curriculum, and documentation that provides an example-rich and problem-dense domain in which students learn to write programs in the functional programming language SML. When executed, Bricklayer programs can produce LEGO artifacts, Minecraft artifacts, and artifacts suitable for 3D printing. Opportunities for creativity and artistic license provide powerful motivation for students. (Received September 25, 2018)

1145-Q5-2407 **McKenzie Lamb*** (lambm@ripon.edu), 300 W. Seward St., Ripon, WI 54971. *An Inclusive Framework for Quantitative Reasoning.* Preliminary report.

Ripon College has recently designed a novel framework for a QR course, one that is inclusive enough, in theory, for any faculty member on campus to teach it. At the same time, our framework is specific enough to guide instructors and to allow for meaningful assessment. Rather than organizing our course around quantitative methods, we have designed a new framework based on numerical comparisons. This organizing principle is motivated by the observation that numbers presented without context are not meaningful, and the real value that numbers add to an argument is that they can be compared to each other in a precise way. In addition to describing the evolution of our new QR framework, I will describe both student and faculty responses and outcomes. (Received September 25, 2018)

1145-Q5-2773 **Craig M. Johnson*** (johnsonc@marywood.edu), 2300 Adams Ave, Marywood University, Scranton, PA 18509. *Mathematical Modeling in the Liberal Arts Course.*

I strongly feel that the liberal arts math students should be exposed to easily mastered methods of creating their own mathematical relationships from data sets they have actually collected themselves. The construction of functional relationships strikes at the heart of what people in "real world" jobs often do who depend on mathematics as their operative tool. The emphasis here is on finding an appropriate model of a two-variable phenomenon from a table of paired data rather than the traditional approach of being given the model at the outset. Linear fits are found using the much simpler Wald Method rather then memorizing the daunting formulae of linear regression. Then exponential functions are also constructed again with a more intuitive approach.

The hope is that long after the student has forgotten a collection of formulae he needed to memorize in order to pass a test, he will retain a general methodology or "sense" for identifying a quantitative relationship in a set of data. This approach not only highlights the exploratory nature of mathematics, but also comes significantly closer to truly mathematically empowering the liberal arts student. Examples of data sets from past semesters will be presented. (Received September 25, 2018)

Incorporating Programming and Computing in the Math Major Curriculum

1145-R1-816 **Mahmud Akelbek*** (makelbek@weber.edu), Department of Mathematics, Weber State University, Ogden, UT 84408. *Implementing MATLAB Programming to Beginner Users in Math Courses.*

Using MATLAB to teach computation and modeling exposes students to a powerful tool for research and discovery. MATLAB is one of the commonly used software in our university. Many of our math major students are dual majors, either computer science , engineering or many other science majors. Their background in any

computing software also varies widely. In this talk, we will present hybrid approach to teaching computation using various recourses. We will also talk about some of the challenges encountered when teaching computation and strategies to develop students competence in computations. (Received September 15, 2018)

1145-R1-1026 **Albert W Schueller*** (schuelaw@whitman.edu), 345 Boyer Ave, Walla Walla, WA 99362. *Using Smartphone Sensors in Applied Math.*

Smartphones are ubiquitous. They are also a rich source of real data that can be used as motivating examples for students in applied math subject areas. We discuss two examples and invite others to suggest their own ideas for how to incorporate GPS, accelerometer, g-Force, gyroscope and other smartphone data into their curricula. In both examples, we will demonstrate the use of python to analyze and extract information from raw phone sensor data. The first example involves finding the fastest one-mile segment in a GPS recording of one of the author's exercise runs. The second example involves analyzing accelerometer data using discrete Fourier transforms to determine whether an unknown exercise activity is running or walking.

Through these examples, we illustrate the importance of the interplay between theoretical and numerical mathematics. That interplay is an essential component of the process of bringing programming and computing into the mathematics major. (Received September 18, 2018)

1145-R1-1166 **Eric Sullivan*** (esullivan@carroll.edu) and **Jodi Fasteen** (jfasteen@carroll.edu). *Integrating Programming Education Across the Undergraduate Math Curriculum.*

Our undergraduate STEM students take a sequence of four courses in their first two years, each of which is paired with a weekly 75-minute computer lab period that has a dual purpose of both computationally exploring the mathematical concepts from the lecture portion of the course, while simultaneously teaching programming fundamentals. Building on this foundation, we require significant programming assignments for our upper division students, requiring them to regularly use and apply their programming skills to investigate mathematical topics. In this presentation we will showcase sample programming assignments, and discuss transferability of skills, assessment of programming, suggestions for multi-section courses, and logistical concerns. (Received September 19, 2018)

1145-R1-1398 **Scott Zinzer*** (szinzer@aurora.edu). *Number Theory Through Programming.* Preliminary report.

While a mathematics major prepares a student well for a variety of careers, employers have consistently reported a strong desire for candidates with an established computer science background. In response to this need, our program has begun to capitalize on opportunities to encourage computer programming throughout the mathematics major. In this talk, I will describe the inclusion of short programming assignments throughout my department's Elementary Number Theory course for the mathematics major. The assignments are designed to increase familiarity with the theoretical aspects of the course, to promote the further development of mathematical habits of mind, and to develop or refine computer programming skills in students with varying backgrounds. In addition to sharing sample assignments, I will give an overview of student reactions to the assignments and the impacts on student learning and engagement. (Received September 21, 2018)

1145-R1-2116 **Holly Hirst*** (hirsthp@appstate.edu), Box 32092, Appalachian State University, Boone, NC 28608, and **Gregory Rhoads** (rhoadsgs@appstate.edu), Box 32092, Appalachian State University, Boone, NC 28608. *Designing a Computational Mathematics Course for Math Majors.*

This presentation will provide an overview of the sophomore computational mathematics course required for many of our math majors, specifically students concentrating in computation, life sciences, physical sciences or statistics. The course is also a popular math elective for other math majors. The computational mathematics course provides students with an overview of common computational tools – spreadsheets and computer math systems – and also introduces them to programming and issues that arise in numerical computation such as floating point arithmetic, error, and conditioning. The emphasis is on solving pure and applied mathematics problems, including numerical solution of problems encountered in calculus 1 and 2, the prerequisites for the course. (Received September 24, 2018)

1145-R1-2433 **Joel Kilty*** (joel.kilty@centre.edu), Mathematics Department, Centre College, Danville, KY 40422, **Alison Marr** (marra@southwestern.edu), Mathematics Department, Southwestern University, Georgetown, TX 78626, and **Alex M. McAllister** (alex.mcallister@centre.edu), Mathematics Department, Centre College, Danville, KY 40422. *Developing Computing Skills in Calculus Courses.* Preliminary report.

Finding meaningful ways to incorporate computing into mathematics courses without removing important mathematical topics is often difficult to impossible. Accomplishing this goal in the Calculus sequence is even more challenging because of even greater content pressures. In response to multiple changing realities at both the local and national level including evidence that the standard approach "filters" traditionally under-represented students, extremely different levels of student preparedness, the diverse career and continuing education paths of students, more sophisticated technologies, and access to large data sets that enable more realistic and more relevant applications, faculty members at Centre College and Southwestern University have re-envisioned how we teach our calculus courses. In this talk, we present a model for incorporating computing into Calculus I, which moves beyond just one-line commands and into more complicated multi-line algorithms and loop-based problems. (Received September 25, 2018)

1145-R1-2659 **Nicholas Gorgievski*** (nick.gorgievski@nichols.edu), Nichols College, Center Road, Dudley, MA 01571. *Data Camp: Statistical Computing Made Easy.* Preliminary report.

This presentation will focus on my experiences teaching a Statistical Computing course with the help of the Data Camp platform. Data Camp's claim is "The smartest way to learn data science online." I will share my experiences as well as share feedback from my students on some of the pros and cons which were encountered during the semester. Furthermore, I will discuss how I integrated Data Camp into my course and show you how you can use Data camp in your course. (Received September 25, 2018)

1145-R1-2691 **Kwang Hyun Kim*** (kkim@qcc.cuny.edu). *Embedding python programming experiences in Calculus I with Sage.* Preliminary report.

Computer Science (CS) is one of the popular degrees and mathematics is an important part of CS. But we believe that CS can also help students master their core math. Programming improves problem solving skills. Visualization and experimental learning from programming allows students to understand abstract concepts concretely. But there are some risks. Some students may not have suitable programming experiences. Students in remedial level mathematics courses may not be ready to get enough benefits from programming and lose opportunity to develop good "basic math sense". Therefore, it is important to integrate an appropriate math course and programming environments properly. In this presentation, we share our experiences in embedding a python programming with the Sage library in a calculus I course and introduce some of sample lab activities. (Received September 25, 2018)

1145-R1-2698 **Yevgeniy V. Galperin*** (egalperin@po-box.esu.edu), 200 Prospect St, East Stroudsburg, PA 18301. *Digital Image Processing in the Math Major Curriculum.*

We discuss the use of digital image processing as a vehicle to review the fundamental concepts and techniques taught in the undergraduate mathematics curriculum as well as basic computer programming techniques in a fun and engaging context. We also demonstrate that digital image processing (combined with MATLAB programming) is the right context for introducing Complex Analysis, Fourier Analysis, and Wavelet Theory. Our presentation includes a sample of student projects. (Received September 25, 2018)

1145-R1-2723 **Hunter R Johnson*** (hujohnson@jjay.cuny.edu), John Jay College, Mathematics & Computer Science Dept., 524 W 59th St, New York, NY 10019. *A Difference Oriented View of Leibniz's Early Ideas.*

We seek to deepen student understanding of the derivative by analyzing some of Leibniz's early ideas on differences. In particular we explore the use of the symbol d as a difference operator and $\int$ as cumulative sum on discrete lists of increasing abcissae. These operations map neatly onto the Numerical Python (numpy) operations of diff and cumsum. Using these tools we make sense of statements such as $d\int x = \int dx = x$. The aim is to achieve a deepened understanding of Leibniz notation, the derivative, and the historical evolution of Leibniz's ideas. (Received September 25, 2018)

1145-R1-2959 **Andrew J Krause** (krausea3@msu.edu), **Ryan J Maccombs*** (maccomb1@msu.edu), **Willie W Wong** and **Mark Iwen**. *Case study of MATLAB integration in Calculus II: Insights and Improvements.* Preliminary report.

Traditionally Calculus II this has been a course focused on integration techniques and methods for determining if a series converges which is arguably becoming less important in the age of computers. To help prepare our students for 21st Century problems we have begun piloting another model for Calculus II in which students utilize MATLAB and complete lab assignments, developed by two of our faculty, during small (35person / 50 min) recitation sections. We have completed Quantitative comparison of content-knowledge learning outcomes, surveyed student experiences, and held interviews of participating students. During this session we will explore the specific labs, go over results of our analysis, and state how we plan to move forward with the lessons learned from this experiment. (Received September 25, 2018)

Meaningful Modeling in the First Two Years of College

1145-R5-1739 **Suzanne Sumner*** (`ssumner@umw.edu`), 1301 College Avenue, Fredericksburg, VA 22401. *Engaging Modeling Students through Epidemiology.* Preliminary report.

The University of Mary Washington's "Introduction to Mathematical Modeling" lower-level course is taught to satisfy Quantitative Reasoning and Speaking Intensive general education requirements. The course focuses on two projects that cover curve-fitting to environmental data sets in the first half the semester and using difference equations to model environmental scenarios in the second half. Each of these group projects involves a paper and a poster presentation. A third project covers modeling the spread of disease with an SIR model and difference equations. Students present their research on a disease topic of their choice in an individual presentation. Rather than write another paper, students instead create a brochure about their disease topic, similar to what is distributed at the doctor's office or health department. This assignment allows the students to showcase their research in a creative manner. Overall, this epidemiology project engages students because they find the topic directly relevant to their lives. (Received September 24, 2018)

1145-R5-2270 **Andrew M. Baxter*** (`amb69@psu.edu`), **Amine Benkiran**, **Eric Simring**, **Russell deForest** and **Matthew Willyard**. *Let the Model Drive the Bus: A model-motivated approach to first-year calculus.*

The first-year biocalculus sequence at Penn State University has seen dramatic improvements in student achievement without compromising mathematical rigor or scalability. The success is due to various factors, but one major element is how we treat mathematical models as central to mathematical analysis. Each major calculus topic is introduced with a specific set of applications and models which drive our decision-making as to what is important, rather than work with the abstract concepts and bury their utility as a final homework problem. Since the course is intended for life science majors, we specifically sought out models from ecology, epidemiology, and biochemistry rather than the traditional Newtonian physics examples. We will provide an overview of the biocalculus sequence's success and share the mathematical models that motivate differentiation, integration, matrix algebra, and differential equations. (Received September 25, 2018)

1145-R5-2674 **Kayla K. Blyman** (`kayla.blyman@usma.edu`), United States Military Academy, Department of Mathematical Sciences, 646 Swift Road, West Point, NY 10996, and **Kristin M. Arney** (`kristin.arney@usma.edu`) and **Scott D. Warnke*** (`scott.warnke@usma.edu`). *Assessing Modeling Meaningfully in a Freshmen-Level Mathematical Modeling Course through Discovery Learning Assessments.*

Regardless of how engaging we make our classes, come exam time there is often a sterile facade that falls over the classroom. As instructors we can find ourselves struggling to develop realistic problems that can be solved meaningfully given exam time constraints and the limited mathematical toolbox that our students have available to them.

In an attempt to remove the exam-day facade we began assessing students with more meaningful problems in a more realistic environment with collaboration and technology available to assist them. Starting in the Fall 2017 semester, we began developing and implementing Discovery Learning Assessments in our course. This method entailed weekly assessments in place of major exams. The assessments consisted of three parts: a night before read-ahead focused on a new application, an in-class individual portion where students responded to short answer questions, and an in-class group portion where groups of 3-4 students provided team responses to similar questions after discussion, learning, and consensus.

As a result of what we learned that semester, the classrooms in our course, Discovery Learning Assessments, and the point structure of our course all look different.

We will discuss the impacts of Discovery Learning Assessments on our course. (Received September 25, 2018)

1145-R5-2950 **Adam J Castillo*** (adam.castillo@fiu.edu), Florida International University, 11200 SW 8th St., VH 160D, Miami, FL 33199, and **Charity Watson**, **Eddie Fuller**, **Geoff Potvin** and **Laird Kramer**. *Findings from One Year of Implementation of the Modeling Practices in Calculus Curriculum.* Preliminary report.

The STEM Transformation Institute, along with the Department of Mathematical Sciences, at Florida International University is developing and conducting research on the Modeling in Practices in Calculus (MPC) curriculum, a student-centric design in which students emulate the authentic practices of mathematicians and practice mathematical modeling in the classroom to learn both Calculus 1 and Calculus 2. These authentic practices include students actively working in groups to develop modeling and problem-solving skills; a culturally responsive learning environment that features multiple representations, argumentation and fosters constructive perseverance; and building proficiency with mathematical terminology, language constructs and symbols. Presenters will highlight curriculum artifacts and results from the first year of implementation of the MPC curriculum. Presenters will also highlight the ongoing process of evaluating, modifying, and implementing curricular materials and research instruments. (Received September 25, 2018)

1145-R5-2976 **Ahlam Tannouri*** (ahlam.tannouri@morgan.edu), Mathematics Department, Morgan State University, 1700 E. Cold Spring, Baltimore, MD 21251. *Integrating Science and Technology to motivate the learning of Trigonometry in a Precalculus course.* Preliminary report.

I will share in in presentation a collection of mathematical models I used to teach Trigonometry in a Precalculus course for Biology, Chemistry and Medical Technology majors. I will discuss the impact and the performance of the students when using these models. (Received September 25, 2018)

History or Philosophy of Mathematics

1145-VB-1058 **Paul R. Bialek*** (pbialek@tiu.edu), 2065 Half Day Rd, Deerfield, IL 60015. *Euler's proof that every integer is the sum of four or fewer square fractions.*

In his paper entitled Proof of a theorem of Fermat that every number whether whole or fraction is the sum of four or fewer squares (E242 in the Eneström index), Euler uses quadratic residues to prove that every integer or fraction is the sum of four or fewer square fractions. We will present a translation from the Latin and summary of this previously untranslated paper. (Received September 18, 2018)

1145-VB-1140 **Steven W Davis*** (sdcomet900@att.net), 864 S Wildflower Ln, Anaheim, CA 92808. *History of Math in Competitive Math Problems.*

Where do writers get their ideas for competitive math problems? Sometimes we just steal a concept from the history of math. Mathematicians over the centuries have always tried to outdo their colleagues by dreaming up more complicated problems for each other to solve. I try to outdo high school students by dreaming up competitive problems that rely on some historical concepts. I will demonstrate 11 problems I dreamed up with some help from the history of math. I hope you will participate. (Received September 19, 2018)

1145-VB-1478 **Patricia Baggett*** (pbaggett@nmsu.edu), Dept of Math Sci, MSC 3MB P.O. Box 30001, New Mexico State University, Las Cruces, NM 88003-8001, and **Andrzej Ehrenfeucht**. *Teaching the meaning of arithmetic in early nineteenth-century England, according to teacher William Russell.*

In 1821 English accountant and teacher William Russell published a book, "A Companion to Every Treatise to Arithmetic". It was not an arithmetic textbook; it contained explanations of arithmetic concepts and procedures that were currently taught. The author stated that his goal was to help students to understand arithmetic as well as to learn how to carry out arithmetic procedures and use them in practice. The book is brief. It is divided into 48 short chapters, each dealing with a different topic of arithmetic or its application. Each chapter contains a sequence of questions and answers. The author explains his opinion about the meaning of arithmetic in another book, "The Philosophy of Arithmetic; or a Complete Analysis of Integers", printed in London for J. Souter School Library, 73, St. Paul's Church Yard, which is available on the internet (in Google, William Russell "The Philosophy of Arithmetic"). In the talk, we'll briefly describe the author, his books, and their intended audience. And we'll present in detail his ideas about understanding arithmetic, which were very different from current ideas of "teaching for understanding" that underlie today's pedagogy of mathematics. (Received September 22, 2018)

1145-VB-2474 **Deepak Basyal*** (deepak.basyal@uwc.edu). *Napier, Todhunter and Nayaraj Pant: A discussion on 'The Rules of Circular Parts'.*

The so called 'Rules of Circular Parts' related to Spherical Trigonometry were published by John Napier (1550-1617), the inventor of logarithms, in his book *Mirifici Logarithmorum Canonis Descriptio* (A Description of the Wonderful Law of Logarithms). Isaac Todhunter in his book *Spherical Trigonometry* (1886) claimed that these rules were first published by Napier in 1614. Nayaraj Pant in his book *Prachina Ganita ra Navina Ganita ko Tulana* (Comparison of Ancient and Modern Mathematics) published in 1982 claims that these rules of circular parts were already developed by Bhaskaracharya in 1150 in his book *Siddhanta Siromani* (Crown of treatises). This presentation will revolve around this phenomenal historical discussion on 'The Rules of Circular Parts'. (Received September 25, 2018)

Interdisciplinary Topics in Mathematics

1145-VC-606 **Krishnamurthy Dvijotham**, **Bala Krishnamoorthy** and **Ben Rapone***, benjamin.rapone@wsu.edu. *Robust Feasibility of Systems of Quadratic Equations Using Topological Degree Theory.*

We consider the problem of measuring the *margin of robust feasibility* of solutions to a system of nonlinear equations. This problem turns out to be NP-hard in general. We study the special case of a system of quadratic equations, which shows up in many practical applications such as the power grid and other infrastructure networks. We develop approaches based on topological degree theory to estimate bounds on the robustness margin of such systems. Our methods use tools from convex analysis and optimization theory to cast the problems of checking the conditions for robust feasibility as a nonlinear optimization problem. We then develop *inner bound* and *outer bound* formulations for this optimization problem, which could be solved efficiently to derive lower and upper bounds, respectively, for the margin of robust feasibility. We evaluate our approach numerically on standard instances taken from the MATPOWER database of AC power flow equations that describe the steady state of the power grid. The results demonstrate that our approach can produce tight lower and upper bounds on the radius of robust feasibility for such instances. (Received September 11, 2018)

1145-VC-745 **C. Ray Rosentrater*** (rosentr@westmont.edu), 955 La Paz Rd., Santa Barbara, CA 93108, and **Thomas Knecht**. *Celebrities in Politics.*

We all know of celebrities who have gone on to hold high political office. Is this phenomenon more common recently? We have data that suggest this is so, but that the number of celebrities entering politics remains low. Do celebrities have a significant advantage over seasoned and amateur (those having not held office previously) politicians? Initial results seem to give a resounding "yes," but a closer analysis indicates that things might not be simple as they first appear. The apparent advantage enjoyed by celebrity politicians may come from the races they choose to enter. (Received September 13, 2018)

1145-VC-980 **Sheik Ahmed Ullah*** (saullah@crimson.ua.edu) and **Shan Zhao**. *A new ADI method for the Poisson-Boltzmann equation with a two-component regularization.* Preliminary report.

The Poisson Boltzmann Equation (PBE) is a well-established implicit solvent continuum model for the electrostatic analysis of solvated biomolecules. The solution for the nonlinear PBE is still a challenge due to its strong singularity by the source terms, dielectrically distinct regions, and exponential nonlinear terms. In this paper, a new alternating direction implicit method (ADI) is proposed which inherits all the advantages of the two-component regularization and the time-dependent PBE with ADI method, while possessing a novel approach to combine them. A modified version of the ghost fluid method has been introduced to incorporate the jump conditions into the new ADI method. The proposed scheme produced better accuracy than previous ADI methods for a benchmark problem and simpler to implement. Though this scheme can use larger time increments than the previous ADI methods, it still blows up for some special cases. Later to improve the stability, Locally One Dimensional (LOD) method has been used to replace the ADI method. Finally, to test the ability of this newly proposed ADI-GFM and LOD-GFM method, we have evaluated the solvation free energy for a collection of 24 proteins with various sizes and the salt effect on the protein-protein binding energy of the complex 1beb. (Received September 23, 2018)

1145-VC-2205 **Emily Hendryx*** (ehendryx@uco.edu). *A Framework for ECG Feature Identification.*

The electrocardiogram (ECG) conveys important information about a patient's cardiac health. With each part of the cardiac cycle reflected in the ECG, tracking changes in individual ECG features over time can provide insight regarding changes in a patient's clinical status. This work presents a framework for automated ECG feature identification that relies on techniques from numerical linear algebra and data science, some of which have been extended to better suit the application at hand. (Received September 25, 2018)

1145-VC-2453 **Patrick DeBonis*** (pdebonis@unm.edu), **Siri Mellem**, **Thomas M Fiore** and **Emma Bidwell**. *The voiced Tonnetz and the $\mathcal{J}$-group, with illustrations in Schubert's B♭ major Sonata.* Preliminary report.

Motivated by Schubert's Piano Sonata in B♭ Major, D. 960, we expand knowledge of the $\mathcal{J}$ group developed by Fiore and Noll. In the spirit of David Lewin, we use the PLR-group to make both global and local maps of the sonata, following Richard Cohn. We use the Structure Theorem of Fiore-Noll to find $\mathcal{J}$ group operations that realize some of these musical motions while preserving voice ordering. As an enrichment of the neo-Riemannian *Tonnetz* we develop a voice leading *Tonnetz* for the $\mathcal{J}$ group as a simplicial set, rather than simplicial complex. As we explore the topological structure of our *Tonnetz*, we observe the elements of the extended $\mathcal{J}$ group that preserve Cohn's hexatonic set. Finally, we propose three new groups of singular (!) matrices that accomplish major to diminished triad movement, motivated by Schubert's use of diminished triads. Main results: The geometric realization of the voice leading *Tonnetz* is a 6-fold cover of the neo-Riemannian *Tonnetz* and there does not exist a matrix that sends diminished chords to major chords compatible with transposition. (Received September 25, 2018)

1145-VC-2650 **Tomas Gedeon**, **Bree Cummins** and **Ying Xin*** (yingxinac@gmail.com). *Exploring reversible EMT using DSGRN.* Preliminary report.

Epithelial-to-mesenchymal transition (EMT) and its inverse are essential in many biological processes. Mathematically, one can model the interaction among the regulatory elements as a dynamical system and consider each cell phenotype as an attractor. Previous studies suggested that in addition to E, M states, the network responsible for these phenotypes may also exhibit intermediate phenotypes. The number and importance of such states is subject to intense discussion in EMT community.

Previous modeling efforts used traditional bifurcation analysis to explore such systems by varying one or two parameters at a time. Since the system has tens of parameters that are largely unknown, this limits the range of questions that can be answered.

We present a study where we use computational tool DSGRN (Dynamic Signatures Generated by Regulatory Networks) to explore the dynamics of the network by computing summaries of the dynamics across the whole parameter space. We found that there are parameter regimes where up to 5 additional mixed stable steady states can co-exist with the E and M states. We then explored how various types of perturbations to the system can lead to a monostable M or E state, thus exploring potential pathways between these states in the full parameter space. (Received September 25, 2018)

1145-VC-2703 **Rachelle R Bouchat*** (rbouchat@iup.edu), 1303 Water Street, Indiana, PA 15701. *Interdisciplinary Applications for the Linear Algebra Classroom.* Preliminary report.

Often when we are teaching linear algebra, we have so much information to cover that we don't get to delve into very many cool applications or activities. In this talk, I will share several activities that I have developed for a linear algebra classroom that connect the material to other STEM fields. The activities are packaged through a process-oriented guided-inquiry approach. These activities could be assigned to students as homework or group work outside of class. All activities will be shared with those in the audience. (Received September 25, 2018)

1145-VC-2771 **Nathan Morris** and **Haley A Yaple*** (hyaple@carthage.edu). *Political Polarization: Voting Patterns in the Senate.* Preliminary report.

It seems from the current political climate that partisanship is on the rise, but how can this be quantified? In this work, we investigate partisanship in the the U.S. Senate using methods from a recent paper which studied the U.S. House of Representatives [Andris et al. 2015]. By comparing agreement both within and between parties, we create a network structure defined by vote records. An analysis of this network highlights the range of Senator behaviors and allows us to track changes in partisanship, both on the individual and party level, over decades of vote history. (Received September 25, 2018)

1145-VC-2806 **Daniel Ozimek*** (dozimek2@pacollege.edu), PA , and **Rebecca Hartzler** (rebeccahartzler@austin.utexas.edu). *High Quality Mathematical Preparation and Quantitative Reasoning for Nurses: A New Partnership Between the Math and Nursing Education Communities.* Preliminary report.

The Charles A. Dana Center at UT Austin and the MAA are excited to work in partnership with the nursing community to explore and implement best practices for the mathematics education of nurses. We are excited to catalyze the improvement of both nursing student success and quality practice. Effective quantitative reasoning skills are essential for safe nursing practice. A national initiative is needed to identify the key mathematical concepts and skills that nurses need to be successful, to guide reform in educational practices and assessment, and to create a set of student learning outcomes for associate and baccalaureate nurses. Our vision is that All students in nursing programs gain the mathematical knowledge, skills, and attitudes to promote and provide safe, high-quality health care. Our working team has spent the past year developing a task force of and learning from nursing faculty, leaders and practitioners. The time is now to add the mathematics community. We are excited to use this session to outline our learnings about the issues, describe our current research, and next steps for establishing this work as a national initiative. Please join us in this very important work to provide high quality mathematical preparation and quantitative reasoning for nurses! (Received September 25, 2018)

1145-VC-2884 **Anilkumar Devarapu*** (anilkumar.devarapu@asurams.edu), 504 College Drive, Albany, GA 31705, and **Zephyrinus C. Okonkwo** and **Robert S. Owor**. *Mixed Convection Flow Over a Slender Cylinder.*

This paper deals with the similarity solution of double-diffusive mixed convection flow over a vertical slender cylinder due to the combined effects of thermal and mass diffusion. With the help of a set of suitable similarity transformations, the nonlinear coupled partial differential equations governing select phenomena (such as flow, thermal and concentration field) have been reduced to a set of nonlinear coupled ordinary differential equations. Numerical solution of the resultant system of nonlinear ordinary differential equations is derived using an implicit finite difference scheme along with quasilinearisation technique. (Received September 25, 2018)

Mathematics and Technology

1145-VD-1617 **Matthew Weihing*** (mcweihing@hotmail.com) and **Philip B Yasskin** (yasskin@math.tamu.edu), Department of Mathematics, Texas A&M University, 3368 TAMU, College Station, TX 77843-3368. *MYMathApps Tutorials.* Preliminary report.

Over the past 12 years, Yasskin and Meade have developed a collection of Maple-based applets called the Maplets for Calculus which generate random practice problems on calculus concepts and help students learn these step by step. More recently, Yasskin is writing an online calculus text called MYMathApps Calculus incorporating these calculus drills. However, Maplets require Maple installed on the device, and display in Java which does not run on most tablets. So they can't easily be incorporated into MYMACalc. In response, the authors are creating browser based tutorials similar to the Maplets which can be incorporated into any page of the textbooks. These use the Sage computer algebra system to perform all of the math computations except for interactive graphics. For these, they use Three.js which is a WebGL based JavaScript library which is far more powerful than Maple's or Sage's graphics. These are used in conjunction with HTML5, CSS, JavaScript, React, Node.js, MathJax, to render LaTeX and MathLex, to parse student input. We will demonstrate several of the tutorials. (Received September 23, 2018)

1145-VD-1989 **Joseph M Martinsen*** (joseph@martinsen.com), 6305 Ravenwood Dr., Pearland, TX 77584, and **Philip B Yasskin** (yasskin@math.tamu.edu), Department of Mathematics, Texas A&M University, 3368 TAMU, College Station, TX 77843-3368. *Textbook Problem Dependency Web.* Preliminary report.

After a textbook has been written and published, one may want to customize it for a particular audience; it may be desirable to delete or reorder some of the chapters or sections. However, there may be dependencies among the chapters, sections, examples and exercises which make it very tedious to rearrange the order of not only the chapters but also, the associated exercises. Martinson is building a graph database to describe the dependencies among the chapters and sections in a portion of the online Calculus book, MYMathApps Calculus, being written by Yasskin. In addition there will be a database of examples and exercises which describes their dependencies on the chapters and sections. Further, he is building a GUI for an instructor or institution to reorder the chapters and sections by drag and drop and have the examples and exercises automatically reorder. (Received September 24, 2018)

1145-VD-2265 **Neil Sigmon*** (npsigmon@radford.edu), Department of Mathematics and Statistics, Radford University, Radford, VA 24142, and **Rick Klima** (klimare@appstate.edu), Department of Mathematical Sciences, Appalachian State University, Boone, NC 28608. *The Logic Behind the Turing Bombe's Role in Breaking Enigma.*

The work of the codebreakers at Bletchley Park in breaking the German Enigma cipher during World War II was one of the most extraordinary events in human history. Led by Alan Turing, the codebreakers employed an electromechanical device known as the bombe to regularly cryptanalyze and read German encrypted communications throughout much of the war. This work likely helped the Allies to win the war much sooner than expected and saved countless lives. Due to the extraordinary number of combinations that the Enigma could be set to, the Germans believed that the Enigma was impenetrable. However, Turing and the codebreakers were able to use the bombe to exploit the part of the Enigma that the Germans thought gave the device its most security. This paper will describe the logic behind how the bombe exploited the Enigma cipher. To demonstrate the process involved, technology involving Maple will be used to describe the cryptanalysis. (Received September 25, 2018)

1145-VD-2667 **Jason A. Hardin*** (jhardin@worcester.edu). *Using LaTeX to Optimize Proof Writing.*

Upon first exposure to writing formal mathematical proofs, students face the crucial component of rewriting a draft of their proof that incorporates necessary details and fills in any gaps of their original arguments. In the past, many of my introductory proof students found this process encumbersome and time consuming, and so opted not to rewrite their proofs. To mitigate this development in my most recent introductory proof course, I required students to write selected proofs in LaTeX using a template I created and shared via ShareLaTeX (now merged with Overleaf); this granted students the ability edit their proofs easily, adding details and/or taking out unnecessary statements without the task of rewriting the entire proof. In this talk, I will discuss how I incorporated LaTeX in this course, how it worked from both my and my students' perspectives, and what I will be changing in preparation to teach this course again. (Received September 25, 2018)

Modeling and Applications

1145-VF-85 **Sarah Neitzel*** (sarahbneitzel.wa@gmail.com), **Kathryn Haglich** (haglichk@lafayette.edu), **Amy Pitts** (amy.pitts1@marist.edu) and **Jeffrey Liebner** (liebnerj@lafayette.edu). *A Bayesian method for locating breakpoints in time series.* Preliminary report.

Our presentation proposes a new approach to finding the quantity and location of breakpoints, or change points, in time series data. This allows for more appropriate data modeling by accounting for structural changes. Bayesian Adaptive Auto-Regression (BAAR) is a Bayesian technique that samples from the distribution of number and locations of possible breakpoints. It proposes new sets of breakpoints as determined by a reversible-jump Markov Chain Monte Carlo and evaluates the proposals using the Metropolis-Hastings algorithm. Simulation results have shown that our method is able to detect changes in models, and we have provided a demonstration of BAAR as applied to the population of Pacific brown pelicans. (Received July 25, 2018)

1145-VF-301 **Andrew Plucker*** (andrew.plucker@usma.edu), andrew.plucker@usma.edu, West Point, NY 10996, and **William Corson** (william.corson@usma.edu), william.corson@usma.edu. *Defeating Ambiguity: Modeling Problems with Calculus.*

Many first year calculus students struggle to see the value in learning single variable calculus. They often focus their efforts on learning the rules of differentiation and integration, losing sight of the broader picture for how calculus is leveraged to solve problems. While rudimentary calculus problems are necessary for the sake of understanding basic rules and concepts, larger and more complex problems are critical to opening the doors for students to gain a practical understanding of the applications. Through a series of Problem Solving Labs and written reports, the single variable calculus program at West Point not only focuses on learning calculus, but also how the core concepts can be used to conduct quantitative analysis that can be communicated to decision makers.

Throughout the semester-long course, single variable calculus students complete 4 to 5 different Problem Solving Labs where they leverage technological tools such as excel and mathematica to develop mathemaical models to formulate overall recommendations. Each lab report prompt is designed to present an ambiguous problem that requires critical assumptions to enable mathematical modeling. (Received August 29, 2018)

1145-VF-413 **Shandelle M. Henson**, **Robert A. Desharnais** and **Eric T. Funasaki*** (eric.funasaki@sulross.edu), Department of Computer Science & Mathematics, Sul Ross State University, PO Box C-18, Alpine, TX 79832, and **Joseph G. Galusha**, **James W. Watson** and **James L. Hayward**. *Predator-prey dynamics of bald eagles and glaucous-winged gulls at Protection Island, Washington.*

Bald eagle populations in North America rebounded in the latter part of the 20th century, the result of tightened protection, reduction in the use of lead shot by hunters, and the banning of pesticides such as DDT. An unintended consequence of this recovery may be a negative impact on seabirds. During the 1980s, few eagles disturbed a glaucous-winged gull colony on Protection Island, WA. Breeding gull numbers in the colony rose nearly 50% during the 1980s and early 1990s. In the 1990s, however, an increase in eagle activity ensued, after which began a decline in gull numbers. To examine whether trends in the gull colony could be explained by eagle activity, a predator-prey model was fit to gull nest count data and Washington State eagle territory data collected between 1980 and 2016. The model fit the data with R2 = 0.82, supporting the hypothesis that the rise and decline in gull numbers are due largely to the decline and recovery of the eagle population. Within the 95% confidence intervals for parameters related to coexistence, 11.0% of parameter vectors predict gull colony extinction. This suggests that the effects of eagle activity on the gull colony are explained by a predator-prey relationship that includes the possibilities of coexistence as well as gull colony extinction. (Received September 05, 2018)

1145-VF-842 **Imelda Trejo*** (imelda.trejo@mavs.uta.edu), **Hristo Kojouharov** and **Benito Chen-Charpentier**. *Modeling the Effects of the Macrophages on Bone Fracture Healing.*

A new mathematical model is presented to study the effects of macrophages in the bone fracture healing process. The model consists of a system of nonlinear ordinary differential equations that represents the interactions among classical and alternative macrophages, mesenchymal stem cells, and osteoblasts. A qualitative analysis of the model is performed to determine the equilibria and their corresponding stability properties. A set of numerical simulations is presented to support the theoretical results. The model is also used to numerically monitor the evolution of a broken bone for different types of fractures and to explore possible treatments to accelerate bone healing by administrating anti-inflammatory drugs. (Received September 16, 2018)

1145-VF-979 **Junyan Duan**, **Mykhaylo Malakhov**, **Jordan Pellett*** (pellett.jordan@uwlax.edu), **Ishan Phadke** and **Julie Blackwood**. *Efficacy of Control in a Spatially Dynamic Model of White-Nose Syndrome.*

White-nose syndrome (WNS), caused by the invasive fungal pathogen *Pseudogymnoascus destructans*, is a virulent disease that has plagued North American bat populations since 2006. Over the past decade, WNS has rapidly spread throughout much of the eastern United States, leading to mass mortality and threatening range-wide extinction in a number of bat species. Thus, the need for development and implementation of effective control strategies has become increasingly exigent. Previous studies have explored disease dynamics and control in a single hibernaculum model. Here, using a continuous-time two-hibernacula model, we incorporate spatial dynamics to investigate the effects of seasonal bat dispersal on the efficacy of five developing control strategies. We demonstrate that informed management decisions must take inter-population movement into account, and find the effects of dispersal on control efficacy to be dependent on both the control combination and the primary mode of disease transmission. (Received September 17, 2018)

1145-VF-1177 **Jakob J. Kotas*** (kotas@up.edu), 5000 N Willamette Blvd, Portland, OR 97203, and **Andrew Bracken**. *Optimal Airline De-ice Scheduling.*

We present a decision support framework for optimal flight re-scheduling on an airline's day of operations when de-icing suddenly becomes necessary due to snow and ice events. Winter weather, especially in areas where such weather is not commonplace, can cause cascading delays and cancellations throughout the system due to the unforeseen need to add de-ice time to each aircraft's turnaround time. Our model optimally re-schedules remaining flights of the day to minimize system delays and cancellations. The model is formulated as a mixed integer linear program (MILP). Structural properties of the model allow it to be decomposed into a finite set of linear programs (LP) and a computationally tractable algorithm for its solution is described. Finally, numerical simulations are presented for a case study of Horizon Air, a regional airline based in the Pacific Northwest of the United States. (Received September 19, 2018)

1145-VF-1191 **Elaine Terry*** (terry@sju.edu), 5600 City Avenue, Philadelphia, PA 19131. *Using Graph Theory to Model Connectivity in the Human Brain.* Preliminary report.

The brain is often described as the most complex organ that humans possess. Most research involving the brain focuses on analyzing the makeup and responsibilities of the six anatomical regions that comprise the brain. However the billions of nerve cells and connections together make it possible to view the brain as a graph. The research effort to construct complete connectivity in the human brain, called the Human Connectome Project, makes use of concepts in graph theory to model and quantify connectivity in the brain. In this presentation I will briefly summarize concepts in graph theory that are used to quantify the properties of brain networks. (Received September 19, 2018)

1145-VF-1280 **Abdullah Ossama Ateyeh*** (abdullah.ateyeh189@topper.wku.edu), 1906 College Heights Blvd., Bowling Green, KY 42101, Bowling Green, KY 42101, **Rithik Ghanta Reddy** (rithik.reddy714@topper.wku.edu), 1906 College Heights Blvd., Bowling Green, KY 42101, Bowling Green, KY 42101, and **Richard Schugart** (richard.schugart@wku.edu), 1906 College Heights Blvd, Bowling Green, KY 42101, Bowling Green, KY 42101. *Using Global Sensitivity Analysis to Find Influential Parameters in a Wound-Healing Model.* Preliminary report.

To formulate a mathematical model that accurately represents the physiology of a wound, the model must easily predict the most influential factors that affect the wound-healing process. Using a differential-equation model that describes the interactions among matrix metalloproteinases, their inhibitors, the extracellular matrix, and fibroblasts (Krishna et al., 2015), this work focuses on two approaches using global sensitivity analyses. In the first approach, two matrices are constructed and then filled with quasi-random numbers chosen from a specified uniform distribution. From this, Sobol or "sensitivity" indices are computed for each patient, and then results are evaluated. The next method is Morris screening, which measures the change in the state variables when a specific parameter is slightly modified from the predicted value. This change can be obtained by finding the difference between the original model and the model with the modified parameter. A sum of squares of these differences can be used to give the overall influence each parameter has on the model. Overall, these methods have allowed us to find the most significant factors in the wound-healing process, which can further be used to more accurately predict the healing process for individual patients. (Received September 20, 2018)

1145-VF-1465 **Edward T Dougherty*** (edougherty@rwu.edu), One Old Ferry Road, Bristol, RI 02809, and **James C Turner** and **Frank Vogel**. *Efficient Iterative Methods for Finite Element Based Neurostimulation Simulations.* Preliminary report.

Mathematical simulations of transcranial direct current stimulation (tDCS) allow researchers and clinical practitioners to investigate this form of neurostimulation computationally. For these simulations to be of practical use to the medical community, patient-specific head geometries and finely discretized computational grids must be used, and as a result, solving the partial differential equations that govern tDCS can be computationally burdensome. To address this issue, we compare the convergence performance of diverse numerical approaches when solving the linear system generated from a finite element discretization of the tDCS governing equations. Simulations consist of common tDCS electrode configurations on MRI-derived head models with physiologically-based tissue conductivities. Convergence metrics of each linear solver are examined, and compared and linked to theoretical estimates. It is shown that Krylov subspace based methods achieve superior convergence rates only when preconditioned with an appropriately configured multigrid algorithm. In addition, we show that characteristics of tDCS simulations make multigrid as a stand-alone solver highly ineffective. These findings help to extend tDCS simulation support to high resolution and high-volume computing applications. (Received September 22, 2018)

1145-VF-1555 **Joel Odongo Olielo** (joelodongo1964@gmail.com), P.O.Box 210-40601, Bondo, Siaya, Kenya, **Prof. Omollo N Ongati** (nomoloongati@gmail.com), P.O.Box 210-40601, Bondo, Siaya, Kenya, and **Dr. Boniface Otieno Kwach*** (bkwach@kibu.ac.ke), Kibabii University, P.O.Box 1699-50200, Bungoma, Kenya. *Mathematical Model for Nutrient Exchange Across the Placenta.*

This study presents a new mathematical model for nutrient exchange across the placenta which include nutrient exchange from foetus to mother to provide a system of equations in the form, $\dot{\mathbf{Y}} = A\mathbf{Y} + \vec{r}(t)$ and whose solution was analyzed for equilibrium and stability. This model introduces another parameter that takes care of waste elimination from foetus to mother. It was established that the final model is stable compared to the existing models, that is, the eigenvalues of the coefficient matrix are negative real number and complex numbers with negative real parts. This shows that the new model provides one straight line of solutions tending to the

origin and a plane of solutions which spiral towards the origin. This gives a more accurate mathematical model for nutrient exchange in the placenta. This model would create a lot of insight into nutrient exchange in the placenta, the elimination of waste from the foetus and open room for further research from the mathematical concept developed.

Mathematics Subject Classification: Primary 93A30; Secondary 91B74, 93C15, 92C50, 92C42, 91B50, 03C45, 45M10

Keywords: Mathematical model, Linear system, Equilibrium, Stability (Received September 25, 2018)

1145-VF-1580 **Chris McCarthy*** (cmccarthy@bmcc.cuny.edu), Dept of Math, BMCC CUNY, 199 Chambers Street, New York, NY 10007. *Modeling and Design of Adsorption Based Filters: Bio-remediation of Heavy Metal Contaminated Water.*

I will discuss a one dimensional model of an adsorption based filter developed in support of our interdisciplinary lab group. Our group conducts research into bio-remediation of heavy metal contaminated water via filtration. The filters are constructed out of biomass, such as spent tea leaves. 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). I will compare the model's predictions to data obtained experimentally by our lab group. I will discuss using this model to design filters. (Received September 23, 2018)

1145-VF-1823 **Mitchell Collin Will*** (will005@connect.wcsu.edu), 20 Benson Road, Bethel, CT 06801, **Leland Roberts** (roberts133@connect.wcsu.edu), 20 Harrison Street, Danbury, CT 06810, **Ralph Venezia** (venezia006@connect.wcsu.edu), 39 Cross Hill Road, Monroe, CT 06468, and **Xiaodi Wang** (wangx@wcsu.edu), 310 Lexington Blvd, Bethel, CT 06801. *Wavelets and machine learning based music information retrieval.*

Entertainment firms utilize different methods for optimizing user's entertainment and to maximizing profit. For example, Pandora takes songs you like, evaluates their features and provides users with similar songs they may enjoy. The purpose of our research is to develop a new method for classifying music using wavelets and machine learning techniques, such as support vector machines, logistic regression, and neural network to identify a song's genre and recommend similar songs. To accomplish this we must gather a database of Songs. Songs take up lots of space to store, so we must convert each song into wavelet domain. From here, we can reduce its dimension using principal component analysis, and extract the most important features using feature analysis. To classify songs, we will use either support vector machine or logistic regression or neural network, and combine with feature analysis and principal component analysis to find a match. Once we have a match, we can recommend other songs from our database with similar features. We are very confident that our state-of-the-art method is different that other research sources. This is because we are classifying and recommending songs based on the features of the song not just its genre making our method superior. (Received September 24, 2018)

1145-VF-1871 **Eva Strawbridge*** (strawbem@jmu.edu). *N-Patch Model of Arabian Oryx Population Dynamics.*

Here we use discrete time modeling to study population level outcomes for species which may be separated into distinct groups which can only interact after migration between metapopulations. In this talk, we will discuss a model for an arbitrary number of geographically separated populations and the existence and stability of equilibria in this system. We then apply this model to the Arabian Oryx. (Received September 24, 2018)

1145-VF-1897 **Xiaotong Gui*** (alex.gui@pomona.edu), 170 E 6th St, Claremont, CA 91711, and **Xinru Liu**, **Qi Tian** and **Weihong Guo**. *Multimodal Data Fusion in 3D Printing Quality Prediction.*

This paper presents a data-driven approach to predict the quality of 3D printing objects using multiple measurement data sources. Three kinds of data sources with different accuracy and measurement efficiency are considered. Dimension reduction techniques are employed for extracting features from measurement data, and quality metrics are defined. The final result is a two-level classification model trained with printing input parameters and measurement data from the two sensors respectively at each step to predict quality. The proposed model uses a preliminary classifier for the initial inspection, followed by a more refined classifier trained by high resolution measurements to further classify the samples predicted as uncertain in the previous round. Such method could guarantee time efficiency while maintaining high accuracy. The result shows feature extraction from high-dimensional image data as a promising technique for efficient and automated quality inspection. (Received September 24, 2018)

1145-VF-2171 **Mohamed Allali*** (allali@chapman.edu). *Adaptive Thresholding and Binarization.*
Binarization is the classification of pixels in an image as either black or white to separate an image into background and object. Adaptive thresholding methods have been developed to automatically separate images into multiple regions beyond just background and object. In this talk I will show, using some mathematical and statistical methods and techniques, how binarization and adaptive thresholding of digital images can be incorporated into some mathematics courses. Images are the most effective medium of human communication and, when processed under the control of students and teachers, they put mathematical ideas in an exciting new light. (Received September 24, 2018)

1145-VF-2351 **Ian Griffiths**, **Peter Stewart**, **Ivan Mitevski*** (ivan.mitevski@columbia.edu), **Ines Vujkovac** and **Matthew Illingworth**. *The Role of Tortuosity in Filtration Efficiency.*
Membrane fouling during particle filtration occurs through a variety of mechanisms, including internal pore clogging by contaminants, coverage of pore entrances, and deposition on the membrane surface. Each of these fouling mechanisms results in a decline in the observed flow rate over time, and the decrease in filtration efficiency can be characterized by a unique signature formed by plotting the volumetric flux, Q , as a function of the total volume of fluid processed, V.

With asymmetric multilayered filters, comprising a series of membranes with constant pore sizes stacked on top of one another, filtration can be tailored in a variety of novel ways. We develop a network model that allows for a random pore distribution within the filter, which captures the behavior of a globally connected filter in 3D. The model allows us to understand the relationship between tortuosity and efficiency, and establish when maximum efficiency can be expected, with respect to flux, and throughput.

The filter is characterized through particle size, adhesivity to the membrane, pore size, and pore distribution, which allows for sweeps in parameter space that can be conducted to determine an optimal filter configuration for a given filtration challenge. (Received September 26, 2018)

1145-VF-2362 **Nicholas A Battista*** (battistn@tcnj.edu), 2000 Pennington Rd, Ewing Township, NJ 08628, and **Jason Miles** and **Christopher Jakuback**. *Don't get tangled or weigh me down: testing the limits of jellyfish locomotion.* Preliminary report.
Jellyfish contract their bells to create complex vortex rings that propel it forward for locomotion. It is a beautiful example of seeing Newton's laws of motion. Working in a fluid-structure interaction framework, we used a combination of springs, beams, and poroelastic elements to model the material properties of the jellyfish and tested the limits of jellyfish locomotion for a variety of bell geometries, complex tentacle morphologies, additional mass, and scale. We found interesting bifurcations in swimming performance across a diverse range of the overall parameter space. (Received September 25, 2018)

1145-VF-2396 **John G. Alford*** (jalford@shsu.edu) and **William I. Lutterschmidt** (lutterschmidt@shsu.edu). *From Conceptual to Computational: the Cost and Benefit of Lizard Thermoregulation Revisited.*
Endotherms (for example, humans) typically maintain body temperature via metabolic processes whereas ectotherms (for example, lizards) use behavioral thermoregulation in order to maintain body temperature. Examples of behavioral thermoregulation include shuttling between sun and shade and altering body posture. A classic paper published in 1976 in The Quarterly Review of Biology by Raymond Huey and Montgomery Slatkin presented a mathematical model of the benefits and costs of behavioral thermoregulation to predict the optimal thermoregulatory strategy of a lizard. Their paper has served as the theoretical foundation for hundreds of investigative studies. Huey and Slatkin used strictly qualitative methods to analyze their model. We analyze the Huey and Slatkin model using both theoretical and computational methods and demonstrate both the utility and inherent accuracy of their qualitative analysis. However, our results also reveal some interesting new insight into the model. For example, contrary to Huey and Slatkin's predictions we show that perfect thermoregulation is never an optimal strategy and that an ectotherm may behaviorally thermoregulate more often with increasing cost. (Received September 25, 2018)

1145-VF-2458 **D Brian Walton*** (waltondb@jmu.edu), James Madison University, MSC 1911, Roop Hall, 800 S Main St, Harrisonburg, VA 22807. *Maximizing asymptotic growth subject to random season durations.* Preliminary report.
Consider a population of plants that grow during a single season and produce seed at the end of the season. The longer a plant grows prior to going to seed, the more seeds it can produce but the greater the probability that the season ends before the seeds are released. Given a fecundity function that is increasing in time and a probability distribution for the timing of the end of the growth season, we optimize the asymptotic growth rate

of the population with respect to the population's seed release strategy. In certain cases, the population will schedule gaps of time where no seeds should be released. (Received September 25, 2018)

1145-VF-2524 **Brooks K Emerick*** (bemerick@kutztown.edu), 15200 Kutztown Rd, Kutztown, PA 19530. *Stabilizing effects of patch-use and migration in semi-discrete host-parasitoid models.*

Extensive work has been done on analyzing host-parasitoid interactions using discrete-time models, the most notable of which is the Nicholson-Bailey model. Recent work on host-parasitoid modeling incorporates a continuous feature in the traditional discrete-time system. We use this semi-discrete approach to study the effects of parasitoid migration between two sites, both of which contain a proportion of the entire host population. We find that in the simplest case, when the migration and parasitism rates are constant, a stability region exists. This suggests that parasitoid migration to and from host sites has a stabilizing effect that depends on the distribution of the host population among each site at the beginning of the vulnerable period. The stability of the system is characterized by relatively lopsided migration rates in the sense that parasitoids will likely not revisit a patch previously parasitized. In this work, we present analytic and numerical results that describe the region in parameter space in which coexistence among the two species is possible. This parameter space is characterized by two factors: the number of viable larvae per adult host and the fraction of host larvae present at the initial location each year. (Received September 25, 2018)

1145-VF-2542 **Noura Yassine*** (noura.yassein@bau.edu.lb), P.O.Box 11 - 50 - 20 Riad El Solh, Beirut, 1107 2809, Lebanon. *An Economic Order Quantity Model for Bundled Items with Imperfect Quality Components and Probabilistic Lead Times.*

A mathematical model is developed for an inventory situation that considers a bundled item consisting of N components each of which is obtained from a supplier. Each lot of components of type j, $1 \leq j \leq N$, received is assumed to contain a percentage γ_j of perfect quality components, a random variable having a known probability distribution. The lead times, Lj , $1 \leq j \leq N$, between placing the N orders and receiving them are also assumed to be random variables with known probability distributions. Using the mathematical model, an expression for the optimal solution is derived by maximizing the total profit function. Both the mathematical model and the optimal solution are shown to depend on the minimum of the random variables $\gamma_1, \gamma_2, \ldots, \gamma_N$ and the maximum of the random variables $L1, L2, \ldots, LN$. The minimum of the percentages of the quality of the components and the maximum of the lead times are investigated using various probability density functions identified by the extent literature in the area. (Received September 25, 2018)

1145-VF-2643 **Khoa D Dinh*** (kdinh@vols.utk.edu), 227 Ayres Hall, 1403 Circle Drive, Knoxville, TN 37996. *Effects of surface free energy on morphological stability in epitaxial crystal growth.* Preliminary report.

The author shows by changing surface free energy, one can delay the onset of morphological instability on epitaxial crystal growth. The finding is illustrated by the linear stability analysis of the classical Bales-Zhangwill and Kinetic Monte-Carlo simulations. (Received September 25, 2018)

1145-VF-2666 **Stephanie Maria Skelly*** (stephanieskelly@outlook.com), 4 Birchwood lane, New Milford, CT 06776, **Mackensie A King** (king174@connect.wcsu.edu), 31 George Street, Apt 1, Danbury, CT 06810, and **Xiaodi Wang** (wangx@wcsu.edu), 310 Lexington Blvd., Bethel, CT 06801. *Advertisement detection using Wavelet-based Machine Learning Algorithm.*

Internet advertisement is the most popular form of advertisement today. Advertisement agencies use this approach by collecting data from the user to display advertisements customized by the user's web history. This includes search history, recently visited websites and more. Some known companies in this field are Google and Facebook, as well as others that are comparable. The advertisements seen by users are accurate, meaning users are more likely to purchase the product being advertised to them. The purpose of this research project is to create a wavelet-based machine learning algorithm to compare with existing Naïve Baye algorithm used by Google, Facebook, and etc. We will compare the effectiveness of our method with the Naïve Baye algorithm to show that our method is more accurate in advertisement detection. (Received September 25, 2018)

1145-VF-2793 **Nicole M Panza*** (npanza@fmarion.edu), Department of Mathematics, Francis Marion University, PO Box 100547, Florence, SC 29502-0547. *Modeling Menstrual Cycle Follicle Dynamics with Applications.* Preliminary report.

Ovarian follicle waves have been reported in women by Baerwald et al. (2003). A nonlinear differential equation model representing the hormonal regulation of the menstrual cycle with follicle waves is presented. The model exhibits waves of antral follicles using a Follicle Stimulating Hormone threshold function. The model is used to explore phenomenon such as early menopause and superfecundation. (Received September 25, 2018)

1145-VF-2870 **Robert S. Owor*** (robert.owor@asurams.edu), 504 College Drive, Albany, GA 31705, and **Zephyrinus C. Okonkwo** and **Anilkumar Devarapu**. *A Scalable Pluggable Cryptographic Algorithm for Enterprise Blockchain Sub-Channels.*

In this paper, we review the state of pluggable Cryptographic algorithms for Enterprise Blockchains. Cash Fault Tolerant (CFT) and/or several variants of Byzantine Fault Tolerant (BFT) protocols are increasing being used in enterprise blockchain systems. Privacy and Security in Enterprise-Grade Permissioned Blockchain networks is accomplished by the use of sub channels which are set up to enable communication among only approved blockchain nodes. When the number of transactions becomes large, initiation, establishment, communication, and dissolution of sub-channels can become expensive, time consuming and prohibitively slow for Enterprises requiring fast and efficient smart contracts and transaction processing. We propose the development of pluggable pre-programmed standardized sub-channels which can greatly increase the efficiency and speed of initiation, establishment, communication, and dissolution of communications sub-channels (Received September 25, 2018)

1145-VF-2955 **Rinni Bhansali*** (rinnibhansali@gmail.com), 179B Old South Path, Melville, NY 11747, and **Laura Schaposnik**. *A Trust Model In Bootstrap Percolation.* Preliminary report.

Bootstrap percolation is a class of monotone cellular automata describing activation processes which follow certain activation rules. In the classical r-neighbor bootstrap process on a graph G, a set A of initially infected vertices spreads by infecting vertices with at least r already-infected neighbors. Motivated by the study of social networks on graphs, where vertices represent people and edges represent relationships amongst them, we introduce a novel model: the Trust Model for Bootstrap Percolation (TMBP), where vertices of G are assigned different labels, and the set A spreads by infecting vertices with at least a fixed number of already-infected neighbors of each label. In particular, TMBP requires an infection (or rumor) to be “validated” by various groups before it spreads, hence imposing a predetermined level of trust needed for its percolation. By considering different networks, we describe various properties of this new model (e.g., the critical probability of infection and the confidence threshold), and compare it to other forms of bootstrap percolation from the literature. Finally, we describe its implications when applied to rumor spread, fake news, and marketing strategies, along with potential future applications in modeling the spread of genetic diseases. (Received September 25, 2018)

1145-VF-3000 **Amanda L Hattaway*** (hattawaya@wit.edu), 550 Huntington Ave, Boston, MA 02115. *A First Semester Modeling Course for Applied Math First Year Students.* Preliminary report.

This is a course, called Foundations of Applied Math, that is populated mainly by college freshmen majoring in applied math and some talented high school students during their first semester in college. Students learn how to write code in a high level programming language (this semester it is R), investigate problems using simulations, construct models to represent a problem, explain how applied mathematics is used in industry and academia and how to create a personal website. Curriculum (including a "how-to"), student feedback and assessment results will be presented. (Received September 26, 2018)

1145-VF-3032 **Leonard Mushunje*** (leonsmushunje@gmail.com), Midlands State University, 9055 Senga Road, Gweru, Zimbabwe., Gweru, Midlands, Zimbabwe. *Modelling the effects of variations in corporate tax effort on revenue output in Zimbabwe.*

From different taxation forms, corporate tax, has significantly become one of the major sources of revenue to the government.Whether the economy is shadow, enriched or booming, its government needs some revenue to promote and to lubricate its formal sector.Because of this corporate tax has become one of the sources.However, less on the effects of corporate tax on revenue yields seems to be known and understood in Zimbabwe.This paper tried to provide a better insight on the relation of the two.Our conjecture was to study the effects of varying corporate tax rate on revenue.We used the simple logistic harvesting model with varying effort coefficient.Quantitative, qualitative and geometric methods were used for model results and analysis.The research was more of theoretical with a small data set used only for validating the polynomial estimation model.Interestingly, all the methods seem to move in the same direction.The results suggest that revenue is inversely related to company tax.Lastly, we used a Lagrange polynomial to predict possible revenue output from any given corporate tax rate.To validate the polynomial function, we applied the mean absolute percentage error method which supported its use. (Received September 26, 2018)

Outreach

1145-VG-1904 **Elizabeth A Donovan*** (edonovan@murraystate.edu). *Math Day: increasing math awareness in a rural area.*

Math Day is a day-long annual event at Murray State University focused on raising math awareness in local high school students through a series of math-related activities. Located in the western "tail" of Kentucky, an area of the nation that is in urgent need for improved access to high-quality STEM education, Murray State aims to recruit students for this historically economically depressed region for various STEM programs, including mathematics. School recruitment efforts, types of activities, needs of the students and schools as well as other information in Math Day will be discussed. (Received September 24, 2018)

1145-VG-2685 **Katrina Morgan*** (katri@live.unc.edu) and **Francesca Bernardi** (fbernardi@fsu.edu). *Promoting diversity through outreach at the Girls Talk Math camp.*

There are several known barriers to girls and other underrepresented groups entering mathematics. These include not seeing themselves represented amongst mathematicians and lack of confidence and encouragement. The Girls Talk Math camp was founded in 2016 by the authors with the goal of addressing such barriers. The core curriculum of the program breaks campers into groups, with each group working on one of several advanced problem sets, researching a female mathematician, writing a blog post about the problem sets, and writing and recording a podcast about their female mathematician. This talk will focus on how various elements of the camp support diversity and the role of outreach in promoting diversity in mathematics. (Received September 25, 2018)

Teaching and Learning Developmental Mathematics

1145-VH-1007 **Gary C Hall*** (gary.hall@lipscomb.edu), One University Park Dr, Nashville, TN 37204-3903. *Overcoming Math Anxiety: A Twelve Step Approach.* Preliminary report.

So many students are in developmental math courses because they have been told that they have "math anxiety." Our culture has convinced many students that they can not succeed in math classes and that math is boring and useless. Utilizing work from so much known research and some personal experience we have come to these twelve steps to help these students overcome or at least deal better with their so-called math anxiety. (Received September 18, 2018)

1145-VH-1309 **Anne Turner*** (aturner@naperville203.org). *Graspable Math in the Algebra Classroom.* Preliminary report.

Graspable Math brings algebra from paper-and-pencil to the current digital one-to-one age. This free online tool allows students to interact directly with algebraic expressions and equations. In this talk, I will provide an overview of the capabilities of the program, citing specifically its ability to simplify polynomial expressions, solve linear and quadratic equations, and solve systems of equations. I will also discuss the benefits Graspable Math has provided to my students in my algebra classroom. (Received September 20, 2018)

1145-VH-1444 **Jennifer Zakotnik-Gutierrez*** (jennifer.zakotnik@unco.edu). *Developmental Mathematics Reform: Analyzing Experiences in Corequisite College Algebra at an Urban Community College.* Preliminary report.

Each year, thousands of students entering community college find they are underprepared for college-level mathematics and are required complete one or more pre-college level courses. Many of these students never make it into, let alone through, the college-level math courses required for their academic major. In fact, roughly half of the nearly 44% of students referred to developmental mathematics do not successfully make it into the first relevant college-level course. Given that most community college students are from underrepresented groups who are referred disproportionately to developmental education, the status quo of developmental mathematics is an inequitable disservice to students. Fortunately, many community colleges are critically reevaluating and reforming their developmental mathematics programs. The purpose of this qualitative case study is to provide an account of one community college's experience in implementing a corequisite college algebra course. I use Gutierrez's equity framework and Tinto's model of persistence to examine the experiences of students, instructors, and administrators, employing activity theory to analyze the resulting interactions and contradictions. This talk is a report of preliminary results following the first phase of data collection. (Received September 21, 2018)

1145-VH-2401 **Dushanthi N Herath*** (dherath@maryville.edu), Department of Mathematics and Data Science, 650 Maryville University Drive, St. Louis, MO 63141, and **Guangwei Fan** (gfan@maryville.edu), Department of Mathematics and Data Science, 650 Maryville University Drive, St. Louis, MO 63141. *Creating an Engaging Environment and Revolutionizing Teaching and Learning in Introductory Statistics.* Preliminary report.

Faculty at Maryville University created an introductory course in statistics which connects mathematical education to real world data and analysis. In this course students use statistical concepts learned in class to work on real world projects using R Commander (Rcmdr). Rcmdr is a graphical user interface which is free, open source, and a point and click interface which generates data analysis and related graphics. Rcmdr is easy and intuitive for students in introductory level statistics with minimum math background to perform statistical analysis on real world problems. The introductory statistics course will maximize student's ability to meet expectations in critical thinking, communication, presentation, and creativity. By assigning projects from collecting, processing, analyzing, and presenting real-world data from multiple disciplines, inviting guest speakers to class, we are able to create an engaging and revolutionized teaching and learning environment. Some examples of projects and tools used in teaching will be demonstrated. The students are provided with an eBook on the LMS, and by the end of the semester students create their own customized eBook with their projects. (Received September 25, 2018)

1145-VH-2558 **Cameron Sweet*** (csweet@stmartin.edu), 5000 Abbey Way SE, Lacey, WA 98503. *Representational Adaptivity in Multiplying Polynomials.*

While there is an extensive amount of research on representations for solving problems involving functions, there are few studies on student use of multiple representations for multiplying polynomials. This study contributes to current mathematics education literature by focusing on the appropriateness of student choices of representations for multiplying. Choice/no-choice assessments were administered to determine representational adaptivity with standard distribution, lattice and place value multiplication of polynomials. Semi-structured task-based interviews were also conducted to examine student choices of representation for multiplying polynomials. The results of generalized estimating equations for ordinal logistic regression reveal that students are more likely to accurately use lattice than standard distribution to obtain accurate solutions for polynomial multiplication tasks. Students also tended to transition from choosing standard distribution to the lattice as the number of terms in the polynomials to be multiplied increased. The value of teaching polynomial multiplication with multiple representations was found to be introducing students to adaptive choices for differing tasks and preferences as well as relating the representations to familiar integer multiplication. (Received September 25, 2018)

1145-VH-2560 **Francisco J. Savina*** (fsavina@austin.utexas.edu), 3925 W Braker Ln, Suite #3-801, Austin, TX 78759-5316, and **Rebecca Hartzler** (rebeccahartzler@austin.utexas.edu), 3925 W Braker Ln, Suite #3-801, Austin, TX 78759. *Meeting Students Where They Are: Successful Co-requisite Course Design.* Preliminary report.

The need for well-designed co-requisite courses has greatly increased due to recent statewide mandates to rethink developmental courses. In this presentation, participants will learn about key considerations for designing successful co-requisite developmental courses including course structure, content, and placement. Participants will also learn about useful resources to start co-requisite conversations at their institutions. (Received September 25, 2018)

1145-VH-2857 **Brendan Kelly*** (kelly@math.harvard.edu), 1 Oxford Street, SC 422, Cambridge, MA 02138, and **Emina Alibegovic**, **Rebecca Noonan-Heale**, **Anna Schoening** and **Amanda Cangelosi**. *Intermediate Algebra: A Retelling of an Old Story.* Preliminary report.

Across the country, Intermediate Algebra acts as a gatekeeper to college mathematics courses. The traditional curriculum is an inch deep and a mile wide, reinforcing student attitudes that mathematics is a long list of rules to memorize. How can we change this paradigm and build an entry-level course that promotes productive mathematical practices, encourages ambitious interactive instruction, highlights mathematics as a sense-making tool that explains the world in which we live, and better serves students? This complex question was our starting point five years ago. Today we are excited to share an open source curriculum that makes progress on this difficult question. This session will focus on the ways in which the new curriculum builds a mathematical story, satisfies students' intellectual needs, and supports ambitious instruction. (Received September 25, 2018)

Teaching and Learning Introductory Mathematics

1145-VI-53 **Jathan Austin*** (jwaustin@salisbury.edu), Dept. of Mathematics and Comp. Sci., 1101 Camden Avenue, Salisbury University, Salisbury, MD 21801. *Teaching Mathematics Through Games.* Preliminary report.

Games are a useful context for teaching mathematics. In particular, games can be used as a hook to engage students who may not be interested in mathematics. In this talk, we will examine a general-education mathematics course for liberal arts taught at a medium-size university. We will discuss how a variety of games has been incorporated into the course to provide students with opportunities to see mathematics in perhaps unexpected contexts. (Received July 09, 2018)

1145-VI-721 **Jingzhong Zhang*** (zjz2271@163.com), School of Computer Science and Educational So, Guangzhou University, Guangzhou, Guangdong 510006, Peoples Rep of China, **Zengxiang Tong** (ztong@otterbein.edu), Department of Mathematical Sciences, Otterbein University, Westerville, OH 43081, and **Hongguang Fu** (fu_hongguang@hotmail.com), University of Electronic Science of China, Chengdu, Sichuan , Peoples Rep of China. *The Integrated Trig-Geometry — A Revolution in Euclidean Geometry and Math Education Happening in China.*

This paper, a result of Jingzhong Zhang's research in educational mathematics, presents a new logical structure of teaching Euclidean Geometry and Trigonometry to junior middle school students, which has been experimented with great successes in more than 50 middle schools in China in the past six years. The Integrated Trig-Geometry defines the trigonometric function sinA as the area of a unit rhombus with angle A, develops theorems of sine and cosine, co-height theorem, co-side theorem, and co-angle theorem, which play powerful roles in revealing geometric properties of triangles, polygons, and circles. Six years of teaching experiment have proven that this new approach can help the 7th and 8th graders to see the connection of trigonometry, geometry, and algebra, to develop an holistic view of mathematics, and to learn geometry and mathematics much more effectively. A great number of Chinese mathematicians have been working on improving and rewriting the K-12 math curriculum. We are witnessing a revolution in Euclidean Geometry and Math Education happening in China. (Received September 13, 2018)

1145-VI-881 **Gangadhar Acharya***, 3299 Adams Street NE, Apt C70, Albuquerque, NM 87110. *Students Participatory Approach in a College Algebra Class.* Preliminary report.

Most of the students get a better grade in their online homework assignment in comparison to their other class performances in introductory math classes. Even if you ask problems similar to their homework assignment, most of the students can't solve in the in-class exams. Research on mathematics suggests students' interaction with their peers and instructors to successfully learn the mathematical concept of what is expected to learn from the study of that course. In this quasi-experimental study, I taught two parallel sections of college algebra. Two sections were taught in a similar way keeping all variables constant (as much as possible) except a weekly 20-25 minutes homework discussion session in one section. I compared attendance, performance on exams, in and out of class participation, overall grade, and students' perceptions. In this talk, I will present the complete research process and the observed results. (Received September 17, 2018)

1145-VI-1274 **Melissa Tolley Nink*** (m.nink@wingate.edu), 3506 Brookstone Trail, Indian Trail, NC 28079. *Approaching the Quiet.* Preliminary report.

In this talk I discuss the effectiveness of two new approaches to my teaching: 1) required office visits and 2) test reflections. Over the course of the semester I track how students are affected by communication outside the classroom: both in person and written. The goal is to raise retention as well as grades, and to directly help those students who are more introverted. (Received September 20, 2018)

1145-VI-1386 **Stephen Liddle*** (sliddle@gmu.edu), 2916 Dover Lane #203, Falls Church, VA 22042. *Math Readiness and STEM Boot Camp for Incoming Freshman.*

The Math Readiness Camp and STEM Boot Camp at George Mason University strives to help incoming freshmen by assisting the students in mathematics and preparing them for their STEM classes. The Math Readiness Camp is a three day course where students are immersed in a wide range of topics varying anywhere from basic algebra to precalculus, in hopes to boost their understanding and gain entrance into their desired math course. The STEM Boot Camp is a six day camp where students live in the campus dorms, attend different academic and career driven courses, and engage in fun activities. This presentation will discuss in detail the layout of the two camps and some preliminary data on how the students are doing in their classes. (Received September 21, 2018)

1145-VI-1533 **Manyiu Tse*** (mtse@molloy.edu), Molloy College, Math and Computer Studies Department, 1000 Hempstead Avenue, Rockville Centre, NY 11570. *Teaching Using Non-Traditional Styles.* Preliminary report.

There has been much research discussing the advantages of non-traditional pedagogical approaches in teaching mathematics. From flipped classroom to guided discovery, the goal is to stimulate discussion, inquiry and exploration of mathematics. But do the methods really work, that is, do they show a statistically significant effect? We will explore and discuss two methodologies: learning through error analysis in Pre-Calculus and the use of Python in Discrete Mathematics. (Received September 23, 2018)

1145-VI-1581 **Brian D. Darrow, Jr.*** (bd2499@tc.columbia.edu). *Moving Beyond Conversations and Anecdotes: A Pilot Study of Academic Self-Concept, Word Problem Solving, and Having an Effective "Game Plan" in Introductory College Mathematics.*

A study was conducted in introductory mathematics courses at a four-year public university to analyze students' sentiments about learning and doing mathematics. Students indicated that they have considerable difficulty reading, understanding, and solving word problems and many cited this as their biggest difficulty in mathematics. To investigate these sentiments and their origins, a sample of students responded to writing prompts and took a psychoeducational survey to measure their learning, development, and academic habits of mind. The results suggest that students' academic self-concept in mathematics is closely related to students' future orientation outcomes and propensity to seek help when experiencing difficulty. Also, students seem to identify with the phrase of "having a game plan" for tackling homework, studying, solving word problems, and self-regulating, and that this is related to several mathematics education outcomes. Authentic student responses also indicated that the most difficult part of solving word problems for many students might have more to do with reading and understanding language than the use of the mathematical facts themselves. These and other results are presented as well as implications for teaching, curriculum, policy, and future research. (Received September 23, 2018)

1145-VI-1644 **Ariel Setniker*** (asetniker2@unl.edu). *Examining Graduate Teaching Assistants' Noticing of Department-Provided Precalculus Curriculum Materials.* Preliminary report.

In recent years, there has been a large shift to easily accessible online curriculum materials, such as online textbooks, applets, and homework interfaces. However, we do not know much about how such curriculum materials are used by teachers in planning their mathematics lessons, especially at the post-secondary level. In this talk, we present preliminary findings of graduate teaching assistants' use of department-provided curriculum materials to plan lessons for undergraduate precalculus courses, namely, an open educational resource (OER) and Wiki lesson guides. We use the Curricular Noticing Framework (Dietiker et al., 2018) to describe graduate teaching assistants' interactions with these curriculum materials, and to study how the format of the curricula plays a role in influencing these interactions. We end with a discussion of implications around the need for curriculum use practices in graduate teaching assistant professional development. (Received September 23, 2018)

1145-VI-1813 **Donna A. Dietz*** (dietz@american.edu). *Smartphone GPS use in an Introductory Statistics Course.*

In many universities today, instructors may presume that all their students have access to a smart-phone and (therefore) have access to a free GPS device! Students enjoy collecting their own data and working on it. This presentation reflects on some basic points of preparation for such a lab, including smart-phone software advice, information on free web tools for converting the data (from GPS data into a proper format for entry into statistical software environments), classroom exercises, and reactions given by students who have done this. As an added bonus, each student ends up with a unique data set, ensuring that students help each other properly without sharing files. (Received September 24, 2018)

1145-VI-1937 **G Michael Guy*** (michael.guy@cuny.edu), The City University of New York, Office of Academic Affairs, 205 E. 42nd St. #930A, New York, NY 10017, and **Mari Watanabe** (mari.watanabe@cuny.edu), The City University of New York, Office of Academic Affairs, 205 East 42nd Street Room 933, New York, NY 10017. *What Do Students Who Fail Corequisite Math Need? A Preliminary Report.* Preliminary report.

Community college students who are predicted to struggle in credit-bearing math are typically assigned to zero-credit developmental/remedial math courses. Current evidence, including randomized controlled experimentation, suggests that corequisite remediation is the most successful path for students to earn credit. In a corequisite model, developmental support is offered while the students are enrolled in credit-bearing math courses, rather than prior to credit-bearing enrollment. While corequisite remediation being the most successful known path to credit, some students still fail these courses. Data from 5,000 students enrolled in corequisite math courses at eight associate-granting colleges indicate students who fail corequisite math have academic struggles beyond math. In this preliminary report, we will discuss what we learned about students who fail corequisite math courses and suggest how we might improve their outcomes. (Received September 24, 2018)

1145-VI-2200 **Sean Corey***, corey.osumath@gmail.com, Columbus, OH , and **Mary Pilgrim**, mpilgrim@sdsu.edu, San Diego, CA. *Using the "5 Practices" to Actively Engage in Mathematics.*

Active engagement in the classroom has been well established as a key component for student success. As Freeman et al. (2014) affirm, active learning classroom interventions of any kind are better than lecture. However, implementing engaging student-centered strategies in a sustainable way can be challenging. Smith and Stein's (2011) "5 Practices for Orchestrating Productive Mathematics Discussions" provides a pedagogical model for effectively utilizing student work to promote mathematical discourse and deepen learning. We will provide a brief overview of the 5 Practices (anticipating, monitoring, selecting, sequencing, and making connections), and specifically highlight implementation of selecting and sequencing student work. (Received September 25, 2018)

1145-VI-2315 **Perry Y.C. Lee*** (plee@kutztown.edu), Lytle Hall 267, Department of Mathematics, Kutztown University of Pennsylvania, Kutztown, PA , and **Padraig M. McLoughlin** (mcloughl@kutztown.edu), Lytle Hall 265, Department of Mathematics, Kutztown University of Pennsylvania, Kutztown, PA 19530. *An Assessment Study of College Algebra Classrooms.* Preliminary report.

An assessment study to obtain student-learned outcome data from multi-sections of College Algebra for 'large' and 'small' classrooms was conducted during the past academic years (2013 – to present). The lead author incorporated active learning strategies into his 'large' and 'small' classrooms to engage students in his classrooms. Student-learned outcomes will be presented (from 2013 to present) based on his 'large' and 'small' classrooms, and compared with student-learned outcomes from other 'large' and 'small' multi-section classrooms taught by other instructors.

Also, issues in obtaining properly controlled student-learned data will be discussed and presented. (Received September 25, 2018)

1145-VI-2515 **George Tintera*** (george.tintera@tamucc.edu) and **Ping-Jung H Tintera** (pingjung.tintera@tamucc.edu). *Recasting Instruction in Trigonometry - A Preliminary Report.* Preliminary report.

The study of trigonometry in college is an area in which skill efficiency and conceptual understanding are posed as alternative learning goals. Generating proofs of ad hoc trigonometric identities is seen as needing conceptual understanding but it supported by recall of standard identities. A study of using mnemonics to support this procedural knowledge was undertaken using a switching replication methodology. This is a preliminary report based on analysis of the data from that study. (Received September 25, 2018)

1145-VI-2680 **Kyle L. Golenbiewski*** (kgolenbiewski@una.edu). *Strengthening Students' Problem Solving Skills in a Flipped Finite Mathematics Course.*

The Finite Mathematics course at the University of North Alabama serves to introduce students to set theory, probability, counting principles, and statistics among other topics. The course concludes with a summative assessment of a student's ability to apply the techniques learned throughout the semester in the form of a departmental final exam. We present a flipped classroom approach that cultivates students' problem consciousness and discuss the importance of course design in this endeavor. (Received September 25, 2018)

Teaching and Learning Calculus

1145-VJ-112 **Karen B. McCready***, karenmccready@kings.edu. *Practice makes perfect & explaining makes experts!* Preliminary report.

There are many ways to encourage students to study and look at material in more depth. We will consider one method for promoting regular study habits that also provides the opportunity for students to develop leadership and communication skills by guiding a group of their peers. Some modifications for applying this design both in and out of class will be considered. (Received August 01, 2018)

1145-VJ-183 **Douglas Magomo*** (doug.magomo@gmail.com), Department of Mathematics, 8099 College Pkwy, Fort Myers, FL 33919. *Learning From Students' Errors-College Algebra and Calculus Examples.* Preliminary report.

Learning mathematics is a spiral process where students use what they already know to develop further understanding of concepts and ideas. New ideas of methods for solving mathematical problems are not easily discovered. Instructors engage students with conventional methods and procedures or algorithms that help solve these problems. In the process, students make a lot of mistakes. Interestingly, some of the mistakes students make, if closely reviewed, can lead to new way of solving these problems. In this article we look at a few examples on how students' errors lead to the desired solutions. (Received August 16, 2018)

1145-VJ-266 **Mary A Nelson*** (mnelso15@gmu.edu), 4400 University Drive, Fairfax, VA 22030, and **Stephen Liddle**, Mathematics Department, George Mason University, 4400 University Drive, Fairfax, VA 22030. *Facilitating Calculus I for Diverse Students.* Preliminary report.

Because students enter Calculus I with dramatically different preparation, we have created multiple entry points to ensure every student's ability to succeed. In addition to the regular one-semester Calculus I class, we have created an active learning two-semester course and have accommodated students earning a 3 on the AP test. In the two-semester course, students earn 3 credits each semester. Four credits count as the equivalent of Calculus I, and the other two credits are math elective credits. Students earning AP3 are given credit for the first semester of the two semester course and take the second semester. Students who have completed the two-semester course have been shown to succeed at rates equivalent to those students who take the regular course. Many of the two semester students who have a high probability of failing in the regular course, now have over an 80% probability of success. We will discuss the supports for this course: learning assistants, active learning classrooms and oral reviews. (Received August 27, 2018)

1145-VJ-300 **William Corson***, william.corson@usma.edu, and **Andrew F. Plucker**, andrew.plucker@usma.edu. *Striving for Gains: Implementing Growth Mindset in a Calculus Classroom.*

For the average college student, taking a calculus course may seem like an insurmountable task. Here at West Point, where every Cadet takes single variable calculus, breaking down that barrier is an integral part to success. Getting students to believe they can succeed when presented with quantitative problems is just as important as having them arrive at a correct solution. We want them to embrace challenges and struggles in an effort to change their mindset to one where they value the work put forth. Outside of the typical tests that can be seen in most calculus classrooms we have implemented a growth mindset project. This project asks the student to engage in mathematics in some way not normally done as a class requirement. Some examples include becoming a tutor, teaching a Science Technology Engineering Mathematics (STEM) workshop to middle school students, a historical project, or a modelling competition. The goal of the project is to challenge the student and allow them to overcome that challenge. The student will then be rewarded not for obtaining some result but rather for putting forth an effort. This study aims to evaluate the outcomes of making this growth mindset project a mandatory assignment for one semester and making it optional for another. (Received August 29, 2018)

1145-VJ-550 **Mark Bly*** (mbly@coastal.edu), 109 Chanticleer Drive East, SCI 218F, Conway, SC 29528. *Implementing Mastery Grading in Coordinated Calculus.* Preliminary report.

Since mastery grading places incentive on student perseverance and since calculus demands that students overcome a wide array of technical and conceptual challenges, pairing mastery grading and calculus is natural. However, given that university calculus courses are a common candidate for coordination, calculus instructors may be offered too little wiggle room in their grading scheme to feel comfortable implementing a non-traditional grading method.

This fall, two coordinated sections of Calculus I were assigned to me. In spite of having discretion over only 10% of the overall grade, I decided to implement mastery grading. I did so in one of my sections, using a traditional points-based system in the other. Data regarding student progress, from pre-tests to weekly homework to chapter tests to the final exam, was collected. The results and my experiences provide the content for this talk. (Received September 09, 2018)

1145-VJ-613 **Benjamin V.C. Collins*** (collinbe@uwplatt.edu). *Partially Flipping Calc 1: Using Instructor-Created Videos to Introduce, Inspire, and Motivate.* Preliminary report.

In this project, I created 10 to 20 minutes of videos for each content section of Calculus 1. Thus, rather than being a full-fledged flipped classroom, my course was only partially flipped. The videos served as an introduction to the material, provided a common basis for discussion, and freed up class time for in-class activities. I will discuss some of the advantages of this approach, as well as some of the difficulties. (Received September 11, 2018)

1145-VJ-663 **Daniel L McGee*** (mcgeed4@nku.edu). *Extending physical Manipulatives to Visualize Multivariable Calculus Topics into Virtual Reality.*

With help from the NSF, a set of physical manipulatives has been invented that allow students to create 3D representations that help understand the differential and integral calculus. Using student-centered classroom activities to create effective contexts for learning, these physical manipulatives have been used in multivariable calculus classrooms where they have proved very effective with students coming from weaker mathematics backgrounds. This presentation will discuss the underlying semiotic theory behind the manipulatives and activities. It will present samples of the classroom activities that were used and the support that was needed for classroom implementation. It will discuss studies of their effectiveness. And will conclude with an overview of supplemental virtual reality materials that are being used to enhance and broaden the capacity of the physical manipulatives and their associated activities. (Received September 12, 2018)

1145-VJ-679 **Zengxiang Tong***, Department of Mathematics, Otterbein University, Westerville, OH 43081, **Jingzhong Zhang** (zjz2271@163.com), School of Computer Science and Educational So, Guangzhou University, Guangzhou, Guangdong 510006, Peoples Rep of China, and **Hongguang Fu** (fu_hongguang@hotmail.com), University of Electronic Science of China, Chengdu, Sichuan , Peoples Rep of China. *Calculus without Limit Theory.*

This paper establishes calculus upon two physical facts: (1) an average velocity is always between two instantaneous velocities, and (2) the motion of an object is determined once its velocity has been determined. It directly defines derivative and definite integral on an ordered field, proves the fundamental theorem of calculus with no auxiliary conditions, easily reveals the common properties of derivatives, and obtains derivative formulas for elementary functions. Further discussion shows that for continuously differentiable functions, the new definitions are in accord with the traditional concepts. This is a result of the authors' research in the field of educational mathematics, which hopes to provide a more elementary and effective way to teach calculus. (Received September 12, 2018)

1145-VJ-1136 **Tanvir Prince*** (tprince@hostos.cuny.edu), Associate Professor of Mathematics, Hostos Community College, City University of New York, NY 10451. *Use of "Mathematica" as a classroom demonstration for Calculus and Differential Equation.*

Use of "Mathematica" software in STEM related disciplines is not new. But in this presentation, we showed how we use this software for classroom demonstration, in particular, for Calculus and Differential Equation. We involve students to learn, innovate and apply various knowledge of "Mathematica" from very basic to advance and also teach them how to explore various concepts learn in theory by using this software. Anybody who is interested to bring computer aided tools in teaching (does not matter in which disciplines) will be interested in the paper. This can also be used as a side tool to develop an online course, especially in STEM related subjects. Although the particular method is presented for the college level mathematics class, it can be easily elaborated and presented in a regular, hybrid and/or online classes. As a side note, the "Mathematica" software is free for students of City University of New York. (Received September 19, 2018)

1145-VJ-1407 **Alexander Halperin*** (adhalperin@salisbury.edu), 1101 Camden Ave., Salsibury, MD 21801. *When has a Student Mastered Calculus? Mastery-Based Grading with a Final Exam in Calculus I.*

This Mastery-Based Grading system designed for Calculus I combines Mastery-Based Testing with short, frequent quizzes and assignments that may be redone. Each assignment, quiz, and exam question is graded using the options Mastery/Progressing/Needs Improvement, while final grades are determined by cumulative totals of Mastered exam questions, online homework completion, written homework Mastery, quiz mastery, and a sufficiently high final exam score.

The purpose for such a system is for students to understand the high standards being asked of them, give objective feedback, and require students to demonstrate proficiency in calculus at the end of the semester.

Drs. John Foster and Tom Clark significantly influenced this presenter's approach to Mastery-Based Grading. (Received September 21, 2018)

1145-VJ-1437 **John A. Rock***, Mathematics and Statistics, Cal Poly Pomona, 3801 W Temple Ave, Pomona, CA 91768. *RIP: The Best Approach to Integration by Parts.*

Many of us have heard of the tabular method for integration by parts. However, it's a misunderstood trick which is not as limited as its reputation suggests. By constructing a table with the emphasis placed on each row—and therefore, placed on each new integral—the tabular method becomes an efficient bookkeeping technique for {any} application of integration by parts. This talk features several examples showcasing the utility of the technique, referred to as 'row integration by parts' or simply 'RIP', and includes the tic-tac-toe example made famous by the film "Stand and Deliver". Additionally, the RIP method allows for an elegant derivation of Taylor's Formula with integral remainder and other major results in analysis. RIP is both easy use and easy to learn. Give it a shot. Your students will thank you. (Received September 21, 2018)

1145-VJ-1498 **Diane C Lussier*** (diane.lussier@pima.edu), 1255 North Stone Avenue, Tucson, AZ 85709, and **Mary Minke** (maminke@pima.edu), 7600 North Shannon Road, Tucson, AZ 85709. *Practical Applications in Data Analysis for College Algebra.*

Mathematics higher education is moving away from theoretical algebraic manipulation and toward real life applications in the social sciences and careers. New trends in college algebra reflect a practical approach and emphasis on data analysis. A student group project that incorporates internet data search, the application of Microsoft Excel, and linear regression analysis is presented.

The learning outcomes for students working the project is to use their mined data to develop a linear regression model, and then use the model to predict data. The attendees of this workshop will be able to take the project back to their own college algebra students. (Received September 22, 2018)

1145-VJ-1846 **Christopher R. Cornwell**, **Kristin M. Frank** (kfrank@towson.edu) and **Nathan G. McNew*** (nmcnew@towson.edu). *Using computing software in Calculus I: Replacing coding with dynamic visualizations.*

Many Calculus courses introduce a computer algebra system such as Mathematica, Maple, or MATLAB as a way to simultaneously develop students' understanding of calculus while also learning some basics of computer programming. Our institution has been using a sequence of labs written in Mathematica that were designed to teach both calculus and computer programming throughout our calculus sequence. After many years and many frustrated students, we learned that the programming aspects of these activities often hindered students' learning of the calculus concepts they were designed to explore. This led us to reconceptualize how to use software to help students understand these concepts while deemphasizing the coding aspects of the activities. In this talk, we will discuss our goals for using computing software in Calculus and why this led us to create a new sequence of web-based activities that leverage embedded dynamic visualizations created with SageMath. We describe the design and implementation of these activities. We report how these web-based activities supported students' learning about graphical representations of concepts like derivatives and Riemann sums and we compare student feedback on the old Mathematica labs to the new web-based activities and dynamic visualizations. (Received September 25, 2018)

1145-VJ-1982 **Daniel L Kern*** (dkern@fgcu.edu), 10501 FGCU Blvd. S., Fort Myers, FL 33965, and **Menaka B Navaratna** (mnavarat@fgcu.edu), 10501 FGCU Blvd. S., Fort Myers, FL 33965. *Consistent Intervention Model in Calculus Classes.*

Historically calculus classes seem to be viewed as one of the most challenging classes in STEM disciples. There are many reasons behind this statement; lack of prerequisite knowledge, difficulty of content, poor learning styles, lack of accountability, and absence of support. Like many other universities, our institution is negatively affected by the high DFW rates in calculus classes. As an effort to remediate this problem, we have introduced a series of new testing modules and interventions which are intended to increase student learning while improving retention. Early on we test students' knowledge of prerequisite material and give multiple assignments to strengthen their understanding of basic concepts. In the event that a student displays a poor performance on assignments or a test, we have introduced a series of interventions to improve student learning. A variety of teaching mechanisms were adopted to maintain students' interest in the subject. The data is statistically compared with control groups. (Received September 24, 2018)

1145-VJ-1988 **Vincent J. Matsko*** (vince.matsko@gmail.com). *Making Sequences and Series Accessible.*

Students tend to have difficulty with sequences and series in a typical Calculus II course. One reason for this difficulty is that the organization of sections in widely-used calculus textbooks does little to motivate the need for Maclaurin and Taylor series until the end of the chapter. By briefly motivating the uesfulness of series, rearranging the order in which sections are presented, and emphasizing key conceptual points along the way, this usually challenging topic may be made more accessible to calculus students. (Received September 24, 2018)

1145-VJ-2277 **Yun Lu*** (lu@kutztown.edu), Kutztown, PA 19530. *Teaching Calculus Using Mathematica.*

In this talk, I will investigate the students engagement in calculus II courses and share my experience about the implementation of Mathematica to promote student learning results and engagement. I will share some of my approaches, as well as students' feedback and performance if time allows. (Received September 25, 2018)

1145-VJ-2355 **Andrew Kercher*** (andrew.kercher@mavs.uta.edu) and **James A. Mendoza Álvarez**. *Linking the understanding of derivatives of inverse functions to the teaching of inverse functions in high school mathematics for preservice secondary mathematics teachers in first-semester calculus.*

Making explicit mathematical connections for preservice secondary mathematics teachers to aspects of secondary school mathematics teaching or mathematical knowledge for teaching addresses a key element of the recommendations in the Mathematical Education of Teachers II report. Understanding how to represent and manipulate functions as practical mathematical objects is an important cornerstone in mathematics, both in college and secondary school curricula. In particular, mathematics learners should be cognizant of the relationship between a function and its inverse, whether its inverse is itself a function, and the properties which tie the two together. However, it is the case in many secondary school mathematics classrooms that the inverse function is presented as the result of an algorithm for its computation. In this session, we present an annotated lesson for a Calculus 1 classroom that leverages the properties of inverse functions to arrive at meaningful calculus results such as the derivative of inverse trigonometric functions. By highlighting the connection between these properties and advanced mathematics content, we hope to influence preservice teachers to treat inverse functions as an important holistic concept when teaching in their own future classrooms. (Received September 25, 2018)

1145-VJ-2356 **Cassie Williams*** (willi5cl@jmu.edu), James Madison University, Harrisonburg, VA. *A first approach to undergraduate learning assistants.* Preliminary report.

In active classrooms, sometimes it feels like you need to be in five places at once during class to answer a question, clarify a problem, or address an emerging misunderstanding. I used undergraduate learning assistants in my flipped calculus classes during 2018 to help better respond to student questions during and outside of class. In this talk, I will discuss the successes and failures, and my plans to expand the program beyond my own classroom. (Received September 25, 2018)

1145-VJ-2374 **Amine Benkiran**, azb165@psu.edu, and **Eric Simring**, **Andrew M Baxter**, **Russ deForest** and **Matthew Willyard*** (willyard@math.psu.edu). *Learning Assistants in the first-year biocalculus sequence at Penn State University.* Preliminary report.

At Penn State, Learning Assistants (LAs) are undergraduate students who support students in science courses, both inside and outside the classroom. Their involvement has become an instrumental part to the instructional practices for the first-year calculus sequence for life-science majors at Penn State University, University Park. We began with 12 LAs in Fall 2017 and have rapidly expanded to 69 applicants for LA positions in Fall 2018. In Fall 2018 we have had 39 Learning Assistants serving in a total of 15 different sections with roughly 600 students total. This talk will outline who Learning Assistants are, the model we have adopted at Penn State University, how classroom practices accommodate LA involvement, and what we have found to be best practices in working as part of an instructional team. (Received September 25, 2018)

1145-VJ-2381 **Cody Kearse*** (jrvalles@pvamu.edu) and **James R Valles, Jr.** (jrvalles@pvamu.edu). *The PVAMU Mathematics Summer Bridge Program: Examining Student Attitudes Toward the Establishment of a Learning Community.* Preliminary report.

Prairie View A&M University (PVAMU) held its first mathematics summer bridge program during the 2018 summer term, offering currently-enrolled students the opportunity to take Calculus with Analytic Geometry I with an intensive focus on student retention.

In this talk, I will look at responses, gathered from a student exit survey, with regards to various aspects of the program, especially with regards to the development of a learning community. I will discuss aspects of the program that were successful as well as aspects that need to be reevaluated for future summer bridge programs. (Received September 25, 2018)

1145-VJ-2604 **Jacquelyn L Rische*** (jrische@marymount.edu). *Standards-based grading in Calculus with Precalculus.* Preliminary report.

In this talk, I will discuss the implementation of a standards-based grading system into Calculus with Precalculus (a two semester course that is equivalent to Calculus I). In the system, I determine the "skills" that I want my students to master by the end of the semester. The mastery of these skills is 60% of a student's grade (with the rest of a student's grade determined by homework and a final exam). 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 stops appearing on the quizzes, students can still master it by coming to my office for a "retake." Given my students' diverse backgrounds, the system works well for them. They 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. (Received September 25, 2018)

1145-VJ-2821 **Anna Aboud*** (acseitz@iastate.edu), **Heather Bolles** and **Amanda Baker**. *Team-Based Learning Calculus.* Preliminary report.

Team-Based Learning (TBL) is a specific form of active learning designed to collaboratively engage students in significant problem-solving tasks. By means of a flipped classroom, students are able to spend class time working in heterogeneous groups, applying fundamental concepts to a rich applied context. In recent years, the Team-Based Learning structure has been applied with much success to select calculus sections at Iowa State University. Quantitative data has shown that the TBL students performed better on the midterm and final calculus exams, and gave higher quality explanations. A key component of the success of the TBL method is student attitudes. To this end, a qualitative study was performed in the spring of 2018, examining the mathematical mindsets which influence the experiences and attitudes of students in a TBL classroom. In this talk we will explain how the TBL structure was applied to the calculus curriculum at Iowa State University, share samples of the mathematical tasks implemented, and present the results of quantitative and qualitative studies on the efficacy of this method. (Received September 25, 2018)

1145-VJ-2840 **Katherine Walsh Hall*** (katie.hall@uconn.edu), Department of Mathematics, 341 Mansfield Drive, Storrs, CT 06269, and **Amit Savkar**. *Homogeneous Discussion Sections for New Start Calculus Students.* Preliminary report.

Many students taking calculus 1 at the university level have already seen some calculus before. Through a preliminary survey, we found that in the Fall of 2018, approximately 80% of the students enrolled in calculus 1 had seen calculus before. Our focus is on the rest of the students, i.e. the group of students who have not seen calculus before. We will refer to these students as the "New Start" calculus students.

In the past, New Start calculus students have reported feeling uncomfortable asking questions during class and discussion section because they feel they are not able to grasp the material as quickly as their classmates. They often attribute this feeling to their lack of ability to do math instead of to the fact that their classmates have seen this material before. To help New Start calculus students feel more comfortable getting the help they need, we are piloting a program where we group students into discussion section based on previous calculus experience. We are hoping that this homogeneous classroom with create an environment where students are more comfortable getting their questions answered. The talk will focus on the implementation of the intervention, and the results for the pilot as well as future plans. (Received September 25, 2018)

1145-VJ-2852 **Jan Cannizzo*** (jcannizz@stevens.edu). *Reimagining the Curriculum: Making Radical Changes to Improve Learning in First-Year College Calculus.*

Acting in response to unacceptably high DFW rates in its first-year calculus courses, math faculty at Stevens Institute of Technology embarked upon a multiyear effort to radically change the way they teach calculus. Changes made to the curriculum include:

- Incorporating active learning methods into lectures
- Encouraging team-based problem solving
- Redesigning all course components, including exams, so that they place a focus on conceptual understanding
- Using free educational resources in place of a textbook
- Developing a novel educational software, which has replaced written homework, that allows students to solve calculus problems in a fully free-form manner and receive immediate feedback

In this talk, I will describe this system, which has seen the DFW rate in Stevens calculus courses drop from 35% to 10%, in detail and give practical advice for improving the teaching of calculus. I will also talk about challenges that remain, and offer a vision for the future of calculus education that includes the elimination of high-stakes exams. (Received September 25, 2018)

1145-VJ-2977 **Douglas B Meade*** (meade@math.sc.edu) and **Philip B Yasskin**. *MYMA Calculus: An Active and Interactive Approach to Learning and Doing Calculus.*

While many calculus textbooks are now available in an electronic form, most are glorified PDF files. MYMA Calculus is a complete three-semester calculus book whose native format is purely electronic. The only pages are webpages; one dynamically-generated webpage for each theme. While definitions and statements of general rules and theorems are static, many of the accompanying figures involve a combination of active elements, including user control (via sliders) and animation.

The MYMA Calculus project replaces a sequence of figures showing secant lines through two points on the graph of a function approaching the tangent line through a single point on the graph of a single function with an interactive animation of this convergence. Users can control the animation, changing points and specific functions involved. Examples used to demonstrate an idea are not static either - different students see different examples of the same principle. To encourage students to work through the examples, and to develop a sound approach to applying the concepts, the steps in the solution process are presented one at a time.

This presentation showcases the current state of MYMA Calculus, discusses various technologies used, and outlines the remaining tasks to complete the project. (Received September 26, 2018)

Teaching and Learning Advanced Mathematics

1145-VK-140 **Aaron Carl Smith*** (smithaz12@scps.k12.fl.us), Seminole County Public Schools, Assessment and Accountability, 400 East Lake Mary Blvd, Sanford, FL 32773. *Using Directed Acyclic Graphs to Improve Classroom Instruction.*

What is the best order to present material in the classroom? Directed acyclic graphs (DAG) provide a method for answering this question using data instead of opinion. In such a model, parent nodes are prerequisite concepts for child nodes. DAG models can help teachers identify concepts that are choke points for many other concepts; such material must be mastered for success later in the course. The graphs show concepts that can be piggybacked onto other material so that it does not need to be presented on its own, thus improving classroom time usage. Furthermore, DAG models identify which material should be revisited when students struggle. The talk will present models learned on data from district wide standardized tests. (Received August 08, 2018)

1145-VK-145 **Andrew A. Cooper*** (andrew.cooper@math.ncsu.edu), Box 8205, North Carolina State University, Raleigh, NC 27695. *Content-Based Specifications Grading in a Proofs Course.*

Specifications grading is an approach to grading (popularized by Nilson's 2014 book) in which students are assigned term grades based on whether they meet binary (pass/fail) objectives, rather than accumulating points. One topic of frequent conversation has been how to implement specifications grading a proof-based major course, such as algebra, analysis, or linear algebra, which traditionally might have frequent homework assignments consisting mainly of proofs.

In this talk I will describe my experiences using a specifications system in a transition course and an undergraduate analysis course. The grading objectives are based on the learning objectives for the course; each relates to specific mathematical content. I will describe how I developed the grading objectives, how individual assignments are assessed, and the collation of each student's work into a final portfolio.

Throughout, I will provide evidence from student work and surveys, as well as anecdotes and my reflective impressions. I hope to convince you that, by adopting such a system, you can: improve the quality of student work; increase student satisfaction; greatly reduce grade-grubbing; instill mindfulness, good work practices, and pride; and (perhaps most critically) save yourself time and frustration. (Received September 25, 2018)

1145-VK-212 **Ahmad M Alhammouri*** (aalhammouri@jsu.edu), 64 Ashmaline Ln, Oxford, AL 36203. *Using Mathematical Modeling to Integrate Research into the Undergraduate Classroom.* Preliminary report.

The Mathematical Association of America's Committee on the Undergraduate Program in Mathematics recommended that students who study mathematical sciences need to enact mathematical modeling (MM) projects that relate to the real-world (SIAM & COMAP, 2015). Yet, what is the kind mathematical modeling that these students need to experience? To gain a deep understanding about how practitioners who enact modeling conceptualize modeling process, I interviewed professors from various departments: mathematics, civil engineering, physics, and geography. These interviews lasted between 20 to 60 minutes. The semi-structured interview protocol focused on the following aspects: How they use modeling in their professional works. How they understand and talk about MM. Which MM framework aligns their understanding of the MM process. What suggestions they offer high school teachers concerning MM. In this presentation, I will share the major findings from these interviews. (Received August 20, 2018)

1145-VK-248 **Irina Seceleanu*** (iseceleanu@bridgew.edu), Department of Mathematics, 24 Park Ave, Bridgewater, MA 02325. *Scaffolding Proofs in a First Course in Real Analysis.*

Teaching students to correctly develop and write proofs in a first course in Real Analysis is a daunting task. It is common for students at this introductory level to struggle with the basic structure of their proofs, confuse hypotheses and conclusions, and feel completely lost by the creative thought process required of constructing the argument of a proof. In this talk, I will introduce a method of scaffolding the writing of proofs both by parsing the conclusion statement and by using outlines for different proof structures. I will present specific examples using various proofs from discrete mathematics and introductory analysis. This method has helped many of my students gain the mathematical maturity needed to correctly set up a proof and overcome the anxiety of the creative process required of proving. This technique evolved over many years of teaching introductory analysis and has improved the learning of students in my Introduction to Real Analysis class. (Received August 24, 2018)

1145-VK-354 **Kevin Bombardier*** (kevin-bombardier@uiowa.edu). *Student Perceptions on an Expository Approach to Mathematics.* Preliminary report.

Incorporating mathematical journals into the classroom can be a useful tool for both the students and the instructor. A mathematical journal allows students to reflect on their thoughts and feelings in a given course. Possible benefits include giving students practice in explaining concepts they learned in the class, increasing motivation by reflecting on potential usefulness of the content they are learning, and allowing students to easily and consistently express any confusions or frustrations to the instructor. We will discuss students' perceptions of the addition of journals into an introductory abstract algebra course. In particular, we will evaluate the perceptions students have on incorporating mathematical journal writing into the classroom to determine the degree of which students find the process effective, motivational, and beneficial. (Received September 03, 2018)

1145-VK-694 **Jenna P Carpenter***, carpenter@campbell.edu. *Teaching "Proof": Helping Students Learn from Their Mistakes.*

Abstract algebra is among the suite of courses where students often first encounter rigorous proofs and the expectation to generate such proofs on exams. Teaching students "how to prove" is challenging, particularly when they are not mathematically mature enough to spot the gaps or errors in their logic. Showing students common proof types and structures can help, but they still often struggle with replicating logically adequate and complete proofs on exams. As a result, students can feel overwhelmed and frustrated. This talk will examine a strategy for converting students' mistakes on exam proofs into an opportunity to accelerate the development of their proving skills and, at the same time, build confidence and strengthen motivation. (Received September 13, 2018)

1145-VK-724 **Shangzhi Li*** (lisz@buaa.edu.cn), Department of Mathematics, Beihang University, Beijing, Beijing , Peoples Rep of China. *Mathematics Experiments — Learning and Investigating Mathematics with the Help of Computers.*

This talk presents several interesting examples on Taylor's series, Fourier's series, pi calculations, and composing music, showing how one can learn and investigate mathematics through experiments with the help of computers. Each example relates to a significant problem and each presentation shows the real research process: how to understand the problem, how to model the problem mathematically, how to design and invent a way to solve the problem, how to explore different and more effective strategies, and how the new strategy leads to a more satisfying solution. This talk shows that the wise application of computers has brought us to a new era of learning and researching mathematics. (Received September 13, 2018)

1145-VK-1361 **Nathan J Jewkes*** (njjewkes@ncsu.edu), 5105 Fort Sumter Rd Apt P, Raleigh, NC 27606. *Conditional Probability: Overcoming the Base Rate Fallacy.*

This paper reports the analysis and interpretations of undergraduate statistics students' work on a conditional probability task in an after-class setting. The purpose of this task is to help students avoid confusion of the inverse and the base rate fallacy when interpreting diagnostic results. The focus of the analysis was to see how the task did or did not help students overcome some of these common misconceptions related to conditional probability. The data analyzed consisted of student's written responses and technology-generated simulations. (Received September 21, 2018)

1145-VK-2015 **C. Bryan Dawson*** (bdawson@uu.edu). *Unicorns and Zombies and Other Analogies to Help Students with Proofs.*

Helping students avoid common errors while composing proofs can be a difficult task. Creatively-named analogies can help students better understand their errors. This talk will focus on three of these analogies, including what I call the "Unicorns and Zombies Rule." (Received September 24, 2018)

1145-VK-2101 **Marshall Gordon*** (mgordon417@aol.com), 5611 Mirrorlight Pl, Columbia, MD 21045. *Uncovering rationales behind mathematical techniques, algorithms, and proofs.*

Mathematical practices and presentations tend to respond to an aesthetic of concision. However, as Keith Devlin, author of "Devlin's Angle" in the American Mathematical Monthly has made clear that the way mathematics tends to be done is by making problems simpler. That essential means tends to be omitted from mathematics texts, keeping students memorizing rather than gaining understanding. This paper will demonstrate basic mathematical practices and proofs that because of their commitment to "austere beauty" keeps many students at a distance from learning and being successful in mathematics. Instead of making mathematics more available, students often experience stress and in such an emotional state lack the resilience and persistence essential for dealing productively with mathematics. (Received September 24, 2018)

1145-VK-2232 **Michael Renne*** (rennem@oregonstate.edu). *On Fun and Games: Designed for Learning.*

Interest in game-based learning is rapidly increasing, both in academia and the educational technology industry. This interest necessitates the formulation of principles for both designing learning games and using them within an existing curriculum. I consolidate and organize results from the domains of Psychology, Cognitive Science, Learning Science, Game-Based Learning, and Game Design into a short list of design principles that are presented and categorized with multiple research agendas in mind, and I offer guidance to educators who want to leverage the potential of learning games within the curriculum. (Received September 25, 2018)

1145-VK-2371 **Youssef Qranfal***, Wentworth Institute of Technology, 550 Huntington Ave, Boston, MA 02115, and **Steve Morrow**. *The Making of a Senior Design Course in Applied Mathematics.* Preliminary report.

Undergraduate research in our engineering university involves a student exploring, and perhaps obtaining on their own, results with faculty support. Ideally, this research is a common project with one or more of the engineering department capstone courses. Typical projects involve understanding or developing a mathematical model and applying it using tools such as from programming languages, statistics, and data science. Students are encouraged to come up with their project ideas, although they could choose from proposed ones by faculty. Their choices might be projects from their past or present coop or from courses of their own interest. Implementing this senior design course in our institute has evolved over time and is close to maturity, although there is always room for improvement. In this talk we will discuss the making of an applied mathematics capstone course within an engineering university and ways to improve it, grading schemes used, lessons we've learned, and students reactions. Examples of successful projects will be provided. (Received September 25, 2018)

1145-VK-2827 **Joseph E Hibdon*** (j-hibdonjr@neiu.edu), 5500 N. St. Louis Ave., Chicago, IL 60625. *Student Response to an Interdisciplinary Minor in Mathematics and the Effect of Inquiry Based Learning on Student Success.* Preliminary report.

Northeastern Illinois University (NEIU), a comprehensive public undergraduate university located in the city of Chicago, serves approximately 9,000 highly diverse commuter students. NEIU is the one of two, four-year public Hispanic Serving Institutions in the Midwest. Our students are predominantly minority and/or first generation college goers with the greatest challenge in entering the STEM career pipeline. To increase student interest in mathematics and to support other STEM initiatives at NEIU the Math Department has established a new minor in mathematical modeling and has modified the undergraduate curriculum to support more inquiry based learning. The minor is supported by an NIH MARC U*STAR grant. Through the support of NSF, the department has added inquiry based learning and peer lead team learning for a standard Calculus II (integration, series, and sequences) course and an applied statistics course. In this work we present the feedback from the first four years of the minor where we focus the analysis on student surveys and present the impact the minor has had on the students' current careers. We also look at the DFW numbers of those taking the inquiry based curriculum courses and the impact of being a peer leader that is supporting the courses. (Received September 25, 2018)

1145-VK-2883 **Cathy M Frey*** (frey@norwich.edu), Norwich University, Department of Mathematics, 150 Harmon Drive, Northfield, VT 05663. *Using Videos Created with an iPad Pro to Flip the Classroom in an Introductory course in Number Theory and Cryptology.* Preliminary report.

Mathematics 240 is an introduction to fundamental topics in number theory, including the real number system, prime numbers, modular arithmetic, the Euclidean Algorithm, Fermat's Theorem, Euler's Theorem, Euler's Phi Function. Topics will be applied to Caesar, affine and RSA ciphers and the Chinese Remainder Theorem.

During the fall semesters 2004 to 2012 this class was taught with a traditional lecture format with weekly quizzes, individual programming projects, three one-hour exams and a final examination. During the fall semester 2015 and 2016, I used a mixture of lecture and a flipped classroom. During the fall semesters 2017 & 2018 the classroom was completely flipped. Students watch video lectures created with an iPad Pro before coming to class, and we completed daily in class group projects. Students also were required to complete individual and group programming projects and had three one-hour exams as well as a final exam.

Preliminary analysis of the results flipped classroom format as compared to those with the traditional lecture format suggests significant improvement using the flipped format on both the final exam as well as the final course grade. (Received September 25, 2018)

1145-VK-2885 **Hong Yuan*** (hyuan@bmcc.cuny.edu), 199 Chambers Street, N583, New York, NY 10007. *Mathematics Education for Pre-service Elementary Teachers in Shanghai since 1985.*

China's mathematics education for pre-service elementary teachers has evolved since it began to borrow teacher education practices from the Soviet Union after 1949. The degree requirements for elementary teachers were increased because of influences from various developed countries in the 1980s. China retained, however, its tradition of teacher education emphasizing subject-matter knowledge. Most of Shanghai's elementary teachers did not have associate's degrees until 1989, and bachelor's degrees until 2003. Since 1985, Shanghai's elementary education program has been preparing teachers who specialize in teaching mathematics and science. Mathematics education requirements for pre-service elementary teachers have shown a strong orientation toward mathematics content knowledge. This presentation will review the mathematics content courses for the associate's and bachelor's degrees in the pre-service elementary education program, including topics in Calculus, Elementary Number Theory, Three-Dimensional Analytic Geometry, and Linear Algebra. (Received September 25, 2018)

1145-VK-2924 **Tuyin An*** (tan@georgiasouthern.edu). *Spotting "Fake" Theorems: Promoting Student Understanding of Disproof Using Dynamic Geometry Environments (DGEs).*

Proof and reasoning play an important role in both mathematics and mathematics education across content areas and grade levels. In my teaching of various levels of geometric proof and reasoning, I noticed students were challenged by the role of disproof and the use of counterexamples in disproving false statements. Their creativity in visualizing and creating counterexamples was also limited by using paper and pencil. I felt the need to incorporate dynamic geometry environments (DGEs) in my lesson design. The goal of this presentation is to show how my students in an undergraduate level geometry class explore the usage of counterexamples creatively using the dragging feature of DGEs and to discuss the potential positive influence of this activity on their understanding of the role of disproof and the meaning of counterexamples. The task was designed to promote the logical thinking that "direct proof, disproof by counterexample, and proof by contradiction are three aspects of the same whole. We arrive at one or another by a thoughtful examination of the statement" (Epp, 1998, p. 711). The specific principle of logic regarding counterexamples embodied in the task is that one counterexample is sufficient to disprove a statement. (Received September 25, 2018)

1145-VK-3006 **Shannon R Lockard*** (slockard@bridgew.edu). *Finding the Right Angle: Experiences in Teaching Geometry, Takes 2 and 3.*

Last year at the Joint Mathematics Meetings I shared my experiences in teaching an upper level geometry course for the first time after not thinking about geometry in over a decade. That first semester was quite a learning experience for me, with both successes and failures, but overall an exciting experience as I reacquainted myself with an area of mathematics and taught the course using Inquiry Based Learning (IBL).

During my first semester teaching geometry I learned a lot about the subject and about the type of students that take the course at my institution. For the past two semesters as I've continued to teach geometry, I've been able to focus more fully on pedagogy and content. In this talk I'll discuss my continued experience with IBL: what's worked well, what hasn't, and the changes I made since that first semester in order to help my students adapt to IBL more seamlessly. I'll also discuss how the content has changed in my course in an effort to help the course feel more applicable to my students, many of whom are future mathematics teachers. (Received September 26, 2018)

Algebra

1145-VL-64 **Chad Awtrey*** (cawtrey@elon.edu). *Galois groups of doubly even octic polynomials.*

Let $f(x) = x^8 + ax^4 + b$ be an irreducible polynomial with rational coefficients, $g(x) = x^4 + ax^2 + b$, G_f the Galois group of f and G_g the Galois group of g. We investigate the extent to which knowledge of G_g determines G_f. Our main result shows that, in general, knowledge of G_g does not automatically determine G_f, except when G_g is cyclic of order 4. We also show that G_f is completely determined when G_g is dihedral of order 8 and $4b - a^2$ is a perfect square. (Received July 18, 2018)

1145-VL-199 **Ian M Musson*** (musson@uwm.edu). *Twisting functors and generalized Verma modules.*

Let $\mathfrak{g}$ be a reductive Lie algebra over $\mathbb{C}$. Twisting functors are an important tool in the study of the BGG category $\mathcal{O}$ of $\mathfrak{g}$-modules. It is known that the character of a twisting functor applied to a Verma module is the same as the character of another Verma module. We give a condition that ensures that the character of a generalized Verma module is well-behaved under a twisting functor. We show that a similar result holds for basic classical simple Lie superalgebras. The result is used elsewhere to obtain a Jantzen sum formula for certain highest weight modules over type A Lie superalgebras. (Received August 18, 2018)

1145-VL-823 **Fei Yu Chen**, **Hannah Hagan** and **Allison Wang*** (aywang@caltech.edu). *On skew polynomial rings over locally nilpotent rings.*

In 2013, Kanwar, Leroy, and Matczuk proved that the idempotents in the Laurent polynomial ring arise from the idempotents in the ground ring. In their recent paper, Greenfeld, Smoktunowicz, and Ziembowski asked whether a skew Laurent polynomial ring over a locally nilpotent ring may contain a non-trivial idempotent. We will show that this is not possible for skew Laurent polynomial rings in several variables. (Received September 15, 2018)

1145-VL-931 **Samuel R. Carolus*** (carolus@bgsu.edu), 450 Mathematical Sciences Building, Bowling Green State University, Bowling Green, OH 43402, and **Mihai D. Staic**, 450 Mathematical Sciences Building, Bowling Green State University, Bowling Green, OH 43402. *G-Algebra Structure on the Higher Order Hochschild Cohomology over S^2.*

Gerstenhaber showed that the Hochschild cohomology of an algebra A has a G-algebra structure, namely a graded commutative cup product and a bracket that satisfies a graded Jacobi identity. Hochschild cohomology has a generalization called the higher order Hochschild cohomology. It is associated to a commutative algebra and to a simplicial set, and agrees with the usual Hochschild cohomology when the simplicial set is taken to be S^1. Following a paper of Gerstenhaber and Voronov, I will show the existence of an operad structure which induces a G-Algebra structure on the higher order Hochschild cohomology associated to S^2. (Received September 17, 2018)

1145-VL-1080 **Josh Hiller*** (johiller@adelphi.edu), Department of Mathematics and Computer Scienc, Adelphi University, Garden City, NY 11050, and **Tuval Foguel**, Department of Mathematics and Computer Scienc, Adelphi University, Garden City, 11050. *On n- abelian coverings of finite groups.*

For a finite group G, define the commutative graph of G, $C(G)$, as the simple, loopless, and undirected graph with vertex set the elements of G and an edge between $a, b \in G$ if $ab = ba$. For any graph Γ define an $n - clique$ partition of the vertices of Γ to be a partition of the vertices into exactly n complete induced subgraphs. We say a group G has an $n - abelian$ partition if $C(G)$ has an $n - clique$ partition where every clique contains at least two vertices. In this presentation we present some basic properties of $C(G)$ for various important families of groups. We also make strides towards a classification of of which groups admit an $n-$abelian covering for some n. We conclude with some open problems. (Received September 18, 2018)

1145-VL-1178 **Benjamin M. Bolker** (bolker@mcmaster.ca), **Eleanor J. B. Bolker** (ejbbolker@comcast.net) and **Ethan D. Bolker*** (ebolker@gmail.com). *A Curious Possible Prime Pattern.*

29 and $29_{29} = 67$ are both prime. We explore that curiosity and find connections to deep questions on the distribution of the primes: the prime number theorem, Dickson's conjecture, and Zhang's bounded prime gap theorem. (Received September 22, 2018)

1145-VL-1318 **Daniel A McGinnis*** (daniel.mcginnis15@ncf.edu), 5800 Bay Shore Road, Sarasota, FL 34243, and **Eirini Poimenidou**. *Construction of a 2n-Starter from a 2-Starter, and New Solutions to the Oberwolfach Problem.* Preliminary report.

We demonstrate a method of constructing a 1-rotational $2n$-factorization under $G \times \mathbb{Z}_n$ given a 1-rotational 2-factorization under a finite group G. This construction, given a 1-rotational solution to the Oberwolfach problem $OP(a_\infty, a_1, a_2 \cdots, a_n)$, allows us to find a solution to $OP(2a_\infty - 1,^2 a_1,^2 a_2 \cdots,^2 a_n)$ when the a_i's are even $(i \neq \infty)$, and $OP(p(a_\infty - 1) + 1,^p a_1,^p a_2 \cdots,^p a_n)$ when p is an odd prime, with no restrictions on the a_i's. (Received September 20, 2018)

1145-VL-1378 **Shahriyar Roshan Zamir*** (rosha013@d.umn.edu). *Subgroups of Groups of Units Modulo n.* Preliminary report.

The set of all positive integers less than n and relatively prime to n with multiplication mod n is a group denoted $U(n)$. These groups are useful in algebra, number theory and computer science. We are interested in subgroups of $U(n)$. As part of their 1980's paper titled *factoring groups of integers modulo n* Gallian and Rusin determined the structure of $U(n)$ and $U_s(n)$ for $n = st$ where $\gcd(s,t) = 1$ and $U_s(n) = \{x \in U(n) | \ x \pmod{s} = 1\}$. Inspired by their work and some exercises in Gallian's *Contemporary Abstract Algebra* we identified new families of subgroups of $U(n)$. For a subgroup H of $U(n)$ and an integer k we define:

$$U_{k,H}(n) = \{x \in U(n) | \ x \pmod{k} \ \in H\}.$$

We give a complete classification of these subgroups and their factor groups for the special cases of $H = \{1\}$ and $H = \{1, -1\}$. We also define $U^{(k)}(n) = \{x \in U(n) | \ x^k = e\}$ and $U(n)^{(k)} = \{x^k | \ x \in U(n)\}$. Our results completely classify the latter subgroups and their factor groups.
(Received September 21, 2018)

1145-VL-1613 **Parastoo Malakooti Rad** (pmalakoti@gmail.com), pmalakoti@gmail.com, and **Sara Shirinkam*** (shirinka@uiwtx.edu), shirinka@uiwtx.edu. *On the Properties of alpha-Skew Armendariz Modules.*

In this paper we investigate the properties of alpha-skew Armendariz modules and alpha reduced modules for a ring endomorphism alpha. Also, we study the relationship between the p.p. property of a module and skew polynomial modules. (Received September 25, 2018)

1145-VL-1755 **Erica R Bajo Calderon***, 100 N University Dr, Edmond, OK 73034. *Minimum Euclidean Function Over* $\mathbb{Z}[\omega]$. Preliminary report.

There are many ways of computing distance. This brings up the question, is there always one way which produces a smallest or minimal distance? In 1949 T. Motzkin discovered a recursive method for determining values of a function which computes the "minimal" Euclidean norm in a given Euclidean domain; however, this recursive method becomes computationally intensive. A closed form for this norm has been found over the integers. Our work is centered on the closed form over the Eisenstein integers, or $\mathbb{Z}[\omega]$ where $\omega = \frac{-1+\sqrt{-3}}{2}$. In this talk, we will discuss how we have analyzed the structure of the residue classes modulo $a + b\omega$, how this has allowed us to reduce the number of necessary computations to find the minimum distance and describe how these results can be applied to determine the closed form over $\mathbb{Z}[\omega]$. (Received September 24, 2018)

1145-VL-1950 **Michael Weselcouch*** (mweselc@ncsu.edu) and **Ricky Ini Liu**. *The combinatorics of the P-partition generating function and its irreducibility.*

The *P-partition generating function* of a (naturally labeled) poset P is a quasisymmetric function enumerating order-preserving maps from P to $\mathbb{Z}^+$. Using the Hopf algebra of posets, we give necessary conditions for two posets to have the same generating function. In particular, we show that they must have the same number of antichains of each size, as well as the same shape (as defined by Greene). We also show that the P-partition generating function of a connected poset is irreducible. (Received September 24, 2018)

1145-VL-1963 **D. Johnson*** (dylanjohnson777@yahoo.com). *Searching for Toric Rings with USTP.* Preliminary report.

A commutative Noetherian ring R has Uniform Symbolic Topology Property (USTP) if, for all integers $n > 0$, there exists some integer h such that $\mathfrak{p}^{(hn)} \subseteq \mathfrak{p}^n$ for all prime ideals $\mathfrak{p}$ in R. Using recent work from J. Carvajal-Rojas, J. Page, D. Smolkin, and K. Tucker, we identify toric rings which have USTP, as well as an upper bound on their h values. In particular, for k a field of positive characteristic, we show that $k[x_1, ..., x_n]$ has an h value bounded above by n and $k[w,x,y,z]/(wx - yz)$ has an h value bounded above by 3. Both of these results were already shown by Smolkin and Carvajal-Rojas, but we use a less technical method which we hope more readily generalizes to other rings. (Received September 24, 2018)

1145-VL-1978 **Min Soo Kim*** (min.soo.kim@vanderbilt.edu), 2301 Vanderbilt, Nashville, TN 37235. *Results in Leibniz n-algebras from the category $\mathbf{U}_n(\mathbf{Lb})$.*

We study the Leibniz n-algebra $\mathbf{U}_n(\mathfrak{L})$, whose multiplication is defined via the bracket of a Leibniz algebra $\mathfrak{L}$ as $[x_1, \ldots, x_n] = [x_1, [\ldots, [x_{n-2}, [x_{n-1}, x_n]] \ldots]]$. We the simplicity of $\mathbf{U}_n(\mathfrak{L})$ when $\mathfrak{L}$ corresponds to a simple Lie algebra. An analogue of Levi's theorem for Leibniz algebras in $\mathbf{U}_n(\mathbf{Lb})$ is established and it is proven that the Leibniz n-kernel of $\mathbf{U}_n(\mathfrak{L})$ for any semisimple Leibniz algebra $\mathfrak{L}$ is the n-algebra $\mathbf{U}_n(\mathfrak{L})$. (Received September 24, 2018)

1145-VL-2042 **Everett Sullivan*** (esullivan@lclark.edu). *Systems of Linear Recurrences with Non-Constant Coefficients.*

When creating a linear recurrence for a sequence it can be useful to think of it not as a single sequence, but a system of sequences which relate to each other. This gives rise to a system of linear recurrences which can be used to find the specific linear recurrence that describes the sequence. If every linear recurrence is homogeneous and has only constant coefficients then there is a process to extract the recurrence for the original sequence. We show that that the requirement that all coefficients be constant can be dropped while still being able to explicitly find the desired recurrence. (Received September 24, 2018)

1145-VL-2049 **Kaitlyn A Perry*** (k.perry@wingate.edu), 220 N Camden Rd, Wingate, NC 28174. *The Polydegree Conjecture.*

The group of polynomial automorphisms has two structures in which the interaction is not well understood: an amalgamated free product of the triangular and affine subgroups and an infinite dimensional algebraic variety. When looking at the amalgamated free product structure, we are able to define the polydegree: the unique sequence of degrees of the triangular automorphisms in the amalgamated free product decomposition of the automorphism. We will discuss the Polydegree Conjecture and new results that follow. (Received September 24, 2018)

1145-VL-2334 **Jamie Peabody*** (jpeabody@ksu.edu). *GIT Fan for Mori Dream Spaces.* Preliminary report.

A Mori Dream Space is naturally a GIT quotient of an affine variety by an algebraic torus. Such a GIT quotient naturally carries a combinatorial structure called the GIT fan. In the case of Mori Dream Spaces, this coincides with the Mori chamber decomposition which describes the birational contractions of the space. I will present my approach to describing the GIT fan using tropical geometry. As a result of this approach, I prove that this fan is the normal fan to an explicitly computable polytope which generalizes the result of toric geometry. (Received September 25, 2018)

1145-VL-2344 **Alison Becker*** (aebecker@uwm.edu). *Finding Relations Between Invariants of Representations Using a Monte Carlo Method.*

Invariant theory looks at the polynomial functions that remain unchanged as a result of actions of linear groups. The Second Fundamental Theorem of Invariant Theory (SFT) states what the relations are between the generating invariants. In many cases, these relations are unknown. This talk provides an overview of a Monte Carlo method of finding the relations between invariants given by the SFT, and will give several examples from actions of Gl_k, O_k, and Sp_{2k} on algebraic varieties. (Received September 25, 2018)

1145-VL-2614 **Orieta Liriano*** (oryl20@yahoo.com), Universidad Autónoma de Santo Domingo, 10105 Santo domingo, Dominican Rep, and **Ramon Esteban-Romero**. *A Note on Solitary Subgroups of Finite Groups.*

We say that a subgroup H of a finite group G is solitary (respectively, normal solitary) when it is a subgroup (respectively, normal subgroup) of G such that no other subgroup (respectively, normal subgroup) of G is isomorphic to H. A normal subgroup N of a group G is said to be quotient solitary when no other normal subgroup K of G gives a quotient isomorphic to G/N. We show some new results about lattice properties of these subgroups and their relation with classes of groups and present examples showing a negative answer to some questions about these subgroups. (Received September 25, 2018)

1145-VL-2780 **Cailin Foster*** (cailin.foster@dixie.edu), UT. *On a software accessible database of faithful representations of Lie algebras.*

The vital role of Lie theory and representation theory in modern sciences such as gravitational and quantum physics is well established. More applications of these theories can be found in recent developments in quantum computing, nonlinear network problems, robotics, radar design, spectroscopy, and many other areas. The classification of low-dimensional Lie algebras and their representations will therefore remain important for modern innovations well into the future. The paper *Representations of Codimension One Non-Abelian Nilradical Lie Algebras* by Gerard Thompson and Mahmoud Rawashdeh gives faithful representations for indecomposable six-dimensional Lie algebras. We briefly review these results and discuss our creation of a Maple database of Lie algebras, their representations, and right-invariant vector fields. The database will be distributed as part of a popular Maple package called *DifferentialGeometry* for the use of researchers in various fields. (Received September 25, 2018)

1145-VL-2820 **Houssein El Turkey** and **Salam Turki*** (sturk@ric.edu). *Critical Groups.* Preliminary report.

The critical group of a faithful complex representation of a finite group is the cokernal of the transpose of the McKay-Cartan matrix. In this talk, I will show our computations for the critical group of a faithful irreducible representation of the dihedral group. (Received September 25, 2018)

1145-VL-2834 **Felix Gotti***, Department of Mathematics, UC Berkeley, Berkeley, CA 94720. *Factorizations in Puiseux algebras.*

Let M be an additive submonoid of the positive cone of rational numbers, and let $F[M]$ be the monoid algebra of M over a field F. In this paper, we study some algebraic properties that can be transferred between M and $F[M]$. We start by studying the irreducible polynomial expressions in $F[M]$; in particular, we generalize Gauss's Lemma and Eisenstein's Criterion so we can use them both in $F[M]$. Then we prove that M is a BF-monoid (resp., an FF-monoid) if and only if $F[M]$ is a BFD (resp., FFD). Finally, we illustrate that the property of having finitely many irreducible divisors cannot be transferred from M to $F[M]$. (Received September 25, 2018)

1145-VL-2837 **Marly Cormar*** (marlycormar@ufl.edu), Department of Mathematics, University of Florida, Gainesville, FL 32611. *The elasticity and union of sets of lengths of Puiseux monoids.*

If M is an atomic monoid and x is a nonzero non-unit element of M, then the set of lengths $\mathsf{L}(x)$ of x is the set of all possible lengths of factorizations of x, where the length of a factorization is the number of irreducible factors (counting repetitions). In a recent paper, F. Gotti and C. O'Neil studied the sets of elasticities $\mathcal{R}(P) := \{\sup \mathsf{L}(x)/\inf \mathsf{L}(x) : x \in P\}$ of Puiseux monoids P. Here we take this study a step further and explore the local k-elasticities of the same class of monoids. We find conditions under which Puiseux monoids have all their local elasticities finite as well as conditions under which they have infinite local k-elasticities for sufficiently large k. Finally, we focus our study of the k-elasticities on the class of primary Puiseux monoids, proving that they have finite local k-elasticities if either they are boundedly generated and do not have any stable atoms or if they do not contain 0 as a limit point. (Received September 25, 2018)

1145-VL-2996 **Leo Herr*** (leo.herr@colorado.edu). *Product Formulas in Log Gromov-Witten Theory.*

After a discussion of the product formula in ordinary Gromov-Witten Theory and Y.P. Lee- F. Qu's attempt to prove the product formula, we introduce a new perspective on Log Gromov-Witten Invariants which allows us to obtain new theorems. Using the original argument of K. Behrend for the product formula, we adapt the tools and methods to the logarithmic setting to compare logarithmic invariants. (Received September 26, 2018)

Analysis

1145-VM-105 **J. Diego Ramirez*** (ramirezd@savannahstate.edu), 3219 College St., Department of Mathematics, Savannah, GA 31404. *Existence of minimal and maximal solutions for Caputo fractional differential equations with bounded delay.*

In this presentation we consider a fractional differential with bounded delay with Caputo derivative or order q, 0<q¡1. After defining different sets of coupled lower and upper solutions we prove that there exist two sequences of iterates that converge uniformly and monotonically to minimal and maximal solutions of the problem. Furthermore, we state conditions that guarantee that both sequences converge to a unique solution. (Received July 30, 2018)

1145-VM-129 **Kari E. Fowler*** (kfowler@ut.edu), 401 W. Kennedy Blvd., Tampa, FL 33606. *Families of Complex Linear Differential Equations in the Unit Disk.*

The interaction between coefficient and solution conditions for homogeneous complex linear differential equations in the unit disk has been widely studied, including within the context of normality. Instead of studying this interaction within the context of one differential equation as in previous studies, we introduce a new perspective for studying normality by investigating this interaction within the context of normal families and corresponding families of differential equations. Consequently, we obtain sharper results than were found in previous studies involving normal functions within the setting of one differential equation. (Received August 06, 2018)

1145-VM-375 **Gerardo R Chacon*** (gerardo.chacon@gallaudet.edu) and **Gerardo A Chacon** (gerardoachg@uan.edu.co), , Colombia. *Examples of spaces of analytic functions with variable exponents.*

We present some examples of spaces of analytic functions related to variable exponent Lebesgue spaces $L^{p(\cdot)}$. We exhibit some properties of the spaces and study the influence of the exponent $p(\cdot)$ on the behavior of functions on the space. (Received September 04, 2018)

1145-VM-524 **Isabelle Chalendar** and **George R. Exner*** (exner@bucknell.edu), Department of Mathematics, Bucknell University, One Dent Drive, Lewisburg, PA 17837. *Weighted shifts associated with composition operators: fixed points and iteration points.*

Let φ be a linear fractional transformation mapping the open unit disk $\mathbb{D}$ to itself with Denjoy-Wolff point 1 and a distinct fixed point w in $\mathbb{C} \setminus \mathbb{D}$. Consider the composition operator C_φ on the Hardy space $H^2(\mathbb{D})$. If z is a point of $\mathbb{D}$, the restriction of C_φ^* to an invariant subspace arising from the reproducing kernels $(k_{\varphi^n(z)})_{n=1}^\infty$ is similar to a weighted shift W. We show that hyponormality (equivalently, and surprisingly, subnormality) of W, or its lack, reflects information about the locations of w and z in pleasing geometrical ways. (Received September 08, 2018)

1145-VM-857 **Hieu D Nguyen*** (nguyen@rowan.edu), Rowan University, Department of Mathematics, 201 Mullica Hill Rd., Glassboro, NJ 08028, and **James Rosado** (james.rosado@temple.edu), Temple University, Department of Mathematics, Philadelphia, PA 19122. *Partitions of Steiner Equiangular Tight Frames.*

We present new results on partitions of Steiner equiangular tight frames (ETFs) that satisfy the operator norm bound established by a theorem of Marcus, Spielman, and Srivastava (MSS), which they proved as a corollary yields a positive solution to the Kadison-Singer problem. In particular, we prove that partitions derived from blocks defined by incidence matrices in the construction of ETFs based on $(2, k, v)$-Steiner systems (due to Fickus, Mixon, and Tremain) satisfy the MSS bound and explicitly determine the spectrum of their sum of outer products. (Received September 16, 2018)

1145-VM-1328 **Thomas J Osler*** (osler@rowan.edu) and **Marcus Wright**. *An unexpected random walk.* Preliminary report.

Consider tossing a fair coin yielding heads H or tails T, equally likely . You toss the coin 100 times. Suppose you get H 55 times and thus T 45. The difference 55– 45 is 10. We will say that the head-tail difference (HTD) for this toss is 10. The HTD will always be considered non-negative, regardless if the toss yields more heads or more tails. Now reflect on the possible values of the HTD in 100 tosses of the coin. It could be 0 if H = D, (although this is unlikely), or it could even be 100 if either D or T is zero, (again even more unlikely). So it seems to be more likely that 0 < HTD < 100. In fact on closer reflection, we expect the HTD to be closer to 0 than 100. The answer is 8! We show how this arrives. Now we ask the question, after tossing the coin N times again and again, many times, what is the expected HTD? The answer is surprising (Received September 21, 2018)

1145-VM-1417 **Jakob Hofstad** and **David Walmsley*** (walmsl1@stolaf.edu). *Iteration of Differentiation.*

Take your favorite infinitely differentiable function and repeatedly differentiate it. The successive derivatives of this function form a sequence. What kinds of sequences can you see? Sometimes, the sequence of successive derivatives is periodic, and other times, it is eventually zero. It is a surprising fact that in most cases, the sequence is actually dense! In this talk, we'll discuss how to construct such a *hypercyclic function* for the derivative operator on the Fréchet space of entire functions $H(\mathbb{C})$. We will also discuss our recent work on constructing such a hypercyclic function for a given differential operator as an infinite product. (Received September 21, 2018)

1145-VM-1587 **Gabriel Prajitura***, 350 New Campus Drive, Brockport, 14420. *Extending the Gauss - Lucas Theorem.* Preliminary report.

Gauss - Lucas Theorem states that the roots of the derivative of a polynomial lie within the convex hull of the roots of the polynomial. We will discuss what can happen when we divide the convex hull into polygons. (Received September 23, 2018)

1145-VM-1768 **Peter Nandori*** (pnandori@math.umd.edu). *Mixing and local central limit theorem for hyperbolic dynamical systems.*

We present a convenient joint generalization of mixing and the local version of the central limit theorem (MLLT) for an abstract class of probability preserving dynamical systems. By a result a Gouezel, MLLT holds for maps modeled by Young towers: in particular for many important examples of hyperbolic maps. We show that MLLT also holds for several hyperbolic flows (such as Axiom A flows, Sinai billiards flows, suspensions over Pomeau-Manneville maps). We apply these results to verify various mixing properties of infinite measure preserving systems (such as Krickeberg-Hopf mixing or global mixing). Joint work with Dmitry Dolgopyat. (Received September 24, 2018)

1145-VM-1807 **Timothy D Ferdinands*** (timothy.ferdinands@bethelcollege.edu), 1001 Bethel Circle, Mishawaka, IN 46545, and **John Ferdinands**. *Series where the set of Selective Sums is a Cantorval.*

Given an infinite series that is absolutely convergent we consider the summation of a subset of the series. A value that a subsum of a series converges to is called a selective sum of that series. It is known that the set of selective sums can be described in one of three ways: (i) a finite union of closed and bounded intervals, (ii) a cantor set, or (iii) a cantroval. We discuss conditions for the series which result in case (iii) and provide some specific examples of series whose set of selective sums is in fact a cantorval. (Received September 24, 2018)

1145-VM-2001 **Mark Medwid*** (mmedwid@ric.edu), Mathematics and Computer Science Department, Rhode Island College, Providence, RI 02908, and **Xiangdong Xie**. *Rigidity of Local Quasisymmetric Maps on Fibered Spaces.*

In this talk we will discuss the notion of a fibered metric space and its analogue in the Carnot group setting. We shall also discuss quasiconformal and quasisymmetric mappings. Often, if quasiconformal (or quasisymmetric) mappings preserve some additional structure, they are forced to be biLipschitz. We will give conditions under which a fiber-preserving quasisymmetry between open subsets of fibered metric spaces is locally biLipschitz. (Received September 24, 2018)

1145-VM-2412 **Timothy I Myers*** (timyers@howard.edu), 2400 Sixth Street NW, Washington, DC 20059. *Lebesgue Integration on a Banach Space with a Schauder Basis.*

This talk will feature the construction of a Lebesgue measure and integral on any Banach space $\mathcal{B}$ with a Schauder basis. This theory has the advantage that the integral is computable from below as a limit of Lebesgue integrals on Euclidean space as the dimension $n \to \infty$, so that we may evaluate infinite dimensional quantities by means of finite dimensional approximation. Applications to Gaussian measure will be discussed. (Received September 25, 2018)

1145-VM-2564 **Alberto A. Condori*** (acondori@fgcu.edu), 10501 FGCU Blvd., Fort Myers, FL 33965. *Maximum Principles for Matrix-Valued Analytic Functions.* Preliminary report.

To what extent is the maximum modulus principle for scalar-valued analytic functions valid for matrix-valued analytic functions? In this talk, we discuss some maximum *norm* principles for such functions that do not appear to be widely known, deduce maximum and minimum principles for their singular values, and make some observations concerning resolvents and matrix exponentials. (Received September 25, 2018)

1145-VM-2748 **Terrence Adams*** (terry@ganita.org) and **Joseph Rosenblatt**. *Existence of Coboundaries.*

We consider the fundamental coboundary equation: $f = g - g \circ T$. Suppose $(X, \mathcal{B}, \mu)$ is a separable probability space. We show that given $f \in L_p$, $p \geq 1$, there exists $g \in L_{p-1}$ and an ergodic measure preserving invertible transformation T on $(X, \mathcal{B}, \mu)$ such that $f(x) = g(x) - g(T(x))$ for almost every $x \in X$. On the other hand, we disprove a conjecture of Isaac Kornfeld by showing that it is not always possible to choose a transfer function $g \in L_p$. In particular, we show for every $p \geq 1$, there exists $f \in L_p$ such that for any ergodic measure preserving invertible T on $(X, \mathcal{B}, \mu)$ that satisfies the equation $f = g - g \circ T$, then $g \notin L_q$ for $q > p - 1$. We also consider moving averages and its connections with coboundaries. (Received September 25, 2018)

1145-VM-2822 **R Alexander Glickfield***, 4600 Sunset Ave, Indianapolis, IN 46208, and **Scott Kaschner**. *Uniform Convergence and Boundary Denjoy-Wolff Points.* Preliminary report.

When an analytic function (not the identity or an elliptic automorphism) from the complex unit disk to itself is iterated (i.e. composed with itself), the sequences of iterates will converge to a point in the closed unit disk. This point is known as the Denjoy-Wolff point. In this talk, we examine the necessary and sufficient conditions for

which an analytic functions converges uniformly on the whole disk to a boundary Denjoy-Wolff point. (Received September 25, 2018)

1145-VM-2862 **Michael P Cohen***, mcohen@carleton.edu. *Maximal metrics and distortion of circle diffeomorphisms.* Preliminary report.

I'll discuss a new notion of distortion of circle diffeomorphisms: a diffeomorphism of the circle f is called C^k-distorted if the distance of the n-th iterate from the identity grows sublinearly with n, where the distance in question is the Cayley distance associated to a sufficiently small open neighborhood of identity in the topological group of all orientation-preserving C^k circle diffeomorphisms. I will give a simple classification of exactly which diffeomorphisms are C^1-distorted. A classification of C^k-distortion appears very challenging for $k \geq 2$, but I will discuss methods for identifying examples of diffeomorphisms which are C^1-distorted but C^2-undistorted. (Received September 25, 2018)

1145-VM-3004 **Ishwari J Kunwar*** (kunwari@fvsu.edu). *Sparse Domination of Multilinear Dyadic Operators.*

We show that the multilinear dyadic paraproducts and Haar multipliers can be pointwise dominated by multilinear sparse operators. As a consequence, we obtain various quantitative weighted norm inequalities for these operators. (Received September 26, 2018)

Applied Mathematics

1145-VN-247 **Forest Mannan*** (fmannan@mines.edu) and **Karin Leiderman**. *Numerical Calculation of Weak Inertial Lift on Arbitrarily Shaped Objects Near a Plane.* Preliminary report.

The Navier-Stokes equations are a nonlinear set of equations that describe the motion of viscous fluids. They become the linear Stokes equations in situations when the Reynolds number (*Re*), a nondimensional parameter that relates inertial to viscous forces on the fluid, tends to zero. Many relevant real world flows occur at small but non-zero *Re* but these flows are generally well approximated with the Stokes equations. Nevertheless, the simplification to Stokes means that potentially important qualitative features that are inertial in origin will be lost. One approach to capture so-called weak inertial effects for small *Re* without wholly having to revert to the nonlinear Navier-Stokes equations is to formulate a new problem using lower-order terms from a series approximation in *Re*. Work in this direction has generally focused on analytic solutions and thus has been restricted to fairly simple geometries. We consider a numerical approach using the Method of Regularized Stokeslets to calculate the weak inertial lift on an arbitrarily shaped object with any prescribed movement near a plane wall. (Received August 24, 2018)

1145-VN-475 **Hossein Behforooz*** (hbehforooz@utica.edu). *New Methods on Approximation by Spline Functions.*

Recently I have edited a math book together with few articles on Approximation by Integro Spline Functions. For the first time in the history of the study of spline function, I have introduced few brand new types of spline functions and I have called them Integro Splines and Differentio Splines. In this short presentation I will review the progress of these types of spline functions from beginning all the way up to now. We will compare traditional splines with these new splines and present some numerical results and graphs. Keywords: Differentio Splines, Integro Splines, End conditions. (Received September 07, 2018)

1145-VN-518 **Bombina Polina*** (pbombina@crimson.ua.edu), 3914 Watermelon Rd Apt 320C, Northport, AL 35473, and **Brendan Ames**. *The Dense Submatrix discovery.* Preliminary report.

We consider the problem of identifying the densest mn-submatrix in the given binary matrix. We write this problem as rank- constrained cardinality minimization and then relax it using nuclear and trace norms. Then we show that the densest mn-submatrix can be recovered from the solution of our convex relaxation for matrices containing a single dense submatrix. Results of numerical simulations for randomly generated matrices demonstrate the efficiency of our algorithm. (Received September 08, 2018)

1145-VN-589 **Basiru Usman*** (bzu0005@auburn.edu), Auburn, AL 36830, **Xiaoying Maggie Han**, AL , and **Peter Kloeden**. *Long term behavior of a random hopfield neural lattice model.*

In this talk I will introduce the so-called Hopfield neural model introduce by John Hopfield in 1984, then present some modifications of the model and their respective applications, then I will introduce the Hopfield neural lattice model with random input in a space of square summable bi-infinite sequence. Existence and uniqueness of solution will be investigated, then it will be shown that the solution generate a random dynamical system. Finally long term behavior will be investigated. (Received September 10, 2018)

1145-VN-704 **Michael McAsey*** (mcasey@bradley.edu), 1501 W Bradley Ave, Bradley University, Peoria, IL 61625, and **Libin Mou**. *Tax Policy to Minimize the 20:20 Index.* Preliminary report.

The 20:20 index is a simple measure of inequity in the distribution of income (or other attributes) in a society. The index is the ratio of the total income of the 20% of the population with the highest incomes versus the total income of the 20% of the population with the lowest incomes. Thus the index is a number larger than 1. The goal is to find a tax scheme to minimize this index (i.e., get closest to 1). The re-distribution function $q(x)$ of incomes gives the after-tax income; it satisfies (1) $Bx \leq q(x) \leq Ax$, and (2) $q'(x) \geq r \geq 0$, and (3) $q'(x)$ is decreasing. In the discrete case, the index is represented by a quotient of affine functions. In the continuous version, the optimal q is a piecewise linear function with three pieces that allows lower incomes to be most preserved ($q(x) = Ax$ for x small), higher incomes to be least preserved ($q(x) = Bx$ for x large) and has a linear transition between the two. Thus there are at most 3 tax rates in an optimal tax policy. In the discrete case, the middle tax rate can be chosen to apply to only one income class while the other two rates are maximal and minimal. (Received September 13, 2018)

1145-VN-851 **KC Patidar*** (kpatidar@uwc.ac.za), Department of Mathematics, University of the Western Cape, Private Bag X17, Bellville, 7535, South Africa, and **A Ramanantoanina**. *Comparison of non-standard finite difference methods for cross-diffusion models.*

Cross-diffusion models describe a variety of problems in mathematical ecology. In particular, the dynamics of interacting species are classically modelled by using Lotka-Volterra differential equations. However, when investigating spatial dynamics, one usually considers individual movements which in turn lead to reaction-diffusion equations some of which yield cross-diffusion models. Standard numerical methods often fail in providing dynamically consistent numerical solutions for strongly-coupled equations that arise from cross-diffusion. To this end, we aim to design a class on nonstandard finite difference method that can cope with the requirements of the dynamics of the solution. We then analyse some of these schemes for relevant properties and present comparative numerical results. (Received September 16, 2018)

1145-VN-1018 **Nasim Eshghi*** (neshghi@kent.edu), 6800 Alpha Dr, Apt 362, Kent, OH 44240, and **Lothar Reichel** (reichel@math.kent.edu), 233 MSB, 1300 Lefton Esplanade, kent, OH 44242. *Estimating Error Of Matrix Function Approximation.*

The evaluation of matrix functions f(A)v, where A is a large symmetric matrix, f is a function, and v is a vector, may be prohibitively expensive. It is well known that the Lanczos algorithm can be used to determine inexpensive approximations of f(A)v. This talk is concerned with estimating the error in the computed approximations (Received September 18, 2018)

1145-VN-1256 **Kathryn A. Boddie*** (klokken@uwm.edu). *A Minimal Time Solution to the Firing Squad Synchronization Problem with Von Neumann Neighborhood with Radius of Extent 2.*

Cellular automata provide a simple environment in which to study global behaviors. One example of a problem that utilizes cellular automata is the Firing Squad Synchronization Problem, first proposed in 1957. This talk provides an overview of a new extension of the standard Firing Squad Synchronization Problem to a Von Neumann neighborhood with radius of extent 2. A minimal time solution to this extended problem will be presented and demonstrated through computer simulation. (Received September 20, 2018)

1145-VN-1263 **Thomas G Stojsavljevic*** (tgs@uwm.edu), 1428 E Captiol Drive #1, Shorewood, WI 53211. *Mathematical Modeling and Analysis of a Phytoplankton Competition Model Incorporating Preferential Nutrient Uptake.*

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 from other sources. Nutrients in turn are typically supplied from below. In poorly mixed water columns, phytoplankton can be heterogeneously distributed forming various layering patterns. In this talk we present a model of two phytoplankton species competing for two nutrients, one of which is assumed to be preferred. The parameter space of the model is 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 model is then analyzed to study how these parameters influence the outcome of population competition. In particular, conditions for population coexistence are developed. (Received September 20, 2018)

1145-VN-1325 **Vinicio R. Ríos*** (vrios@demat-fecluz.org), Universidad del Zulia, Facultad Experimental de Ciencias, Departamento de Matemáticas, Maracaibo, Edo. Zulia 526, Venezuela. *Time-delayed differential inclusions and contractibility of their solution sets.*

Topological properties of the set of trajectories play a central role in the understanding of the qualitative behavior of deterministic dynamical systems. Among such properties, contractibility is one of the strongest and most useful due to the simplicity that it provides to the structure of the solution set. In this talk we announce contractibility in the case of a time-delayed dynamical system that is parametrized by a differential inclusion under very mild hypotheses. We sketch the proof of the aforementioned fact, which improves Haddad's result within this talk's context (see [1]).

[1] Haddad G., Topological properties of the sets of solutions for functional differential inclusions, Nonlinear Analysis, Theory, Methods & Apps., 5, 1349-1366 (1981). (Received September 21, 2018)

1145-VN-1551 **Tania Hazra*** (thazra@misericordia.edu) and **Shan Zhao**. *A super-Gaussian Poisson-Boltzmann model for electrostatic solvation energy calculation: EDC Analysis and Application on Protein Cavities.* Preliminary report.

Understanding the mechanism of many biological systems requires the calculations of electrostatic potential and solvation energy of macromolecules. In the classical implicit solvent Poisson-Boltzmann (PB) model, the macromolecule and water are modeled as two-dielectric media with a sharp border. However, the dielectric property of interior cavities and ion-channels is difficult to model realistically in a two-dielectric setting. In fact, whether there are water molecules or cavity-fluid inside a protein cavity remains to be an experimental challenge. Physically, this uncertainty affects the subsequent solvation free energy calculation. In order to compensate this uncertainty, a novel super-Gaussian dielectric PB model is introduced in this work, which devices an inhomogeneous dielectric distribution to represent the compactness of atoms and characterizes empty cavities via a gap dielectric value.

Mathematically, an effective dielectric constant (EDC) analysis is introduced in this work to benchmark the dielectric model and select optimal parameter values. Computationally, a pseudo-time alternative direction implicit (ADI) algorithm is utilized for solving the super-Gaussian PB equation, which is found to be unconditionally stable in a smooth dielectric setting. (Received September 23, 2018)

1145-VN-1553 **Kathleen Storey*** (storeyk@umich.edu) and **Trachette Jackson**. *Modeling oncolytic viral therapy and the complex dynamics of innate and adaptive immunity.*

Oncolytic viral therapy is emerging as a promising strategy for treating cancer. The immune response to the oncolytic virus plays a critical role in treatment effectiveness, but uncertainty remains regarding the circumstances under which the immune system assists in eliminating tumor cells or inhibits treatment by clearing infected cells. In this work, we develop an ODE model that incorporates an innate immune response with a transition to an adaptive immune response to oncolytic viral therapy using the Herpes Simplex Virus. We compare the efficacy of treatment in this setting with models that incorporate the adaptive immune response alone in order to gain insight into the complex interactions between oncolytic viruses and the immune system. We explore various OV dosing strategies alone and also investigate the impact of combining oncolytic viral therapy with other types of immunotherapies. (Received September 23, 2018)

1145-VN-1560 **Trevor A. Leach*** (trevor.leach@louisville.edu), 328 Natural Scence Building, University of Louisville, Louisville, KY 40292. *An axiomatic approach to aggregating individual preferences into a collective preference.*

In any social structure, there is often a need to reach decisions, not only within a group but between groups as well, sometimes even urgently so. Take for example emergency situations involving Police, Fire, EMS, and other first responders. Each of the individuals constituting these groups has their own preference for the decision to be made. We will discuss the problem of aggregating individual preferences into a collective preference and under what conditions we are required to select a collective majority. (Received September 23, 2018)

1145-VN-1618 **Zicong Zhou*** (zicong.zhou@mavs.uta.edu), 411 South Nedderman, Box 19408, Arlington, TX 76019-0408, and **Guojun Liao**. *Averaging images through averaging Diffeomorphisms.*

Given some similar images, apply our method for Image Registration [New Development of Non-rigid Registration, Hsiao, et al, 2013], then same number of diffeomorphic transformations can be constructed between the given similar images. A geometrical connection from constructed diffeomorphic transformations, in terms of the Jacobian determinant (which reflects local changes in cell size) and curl-vector (which reflects local rotation), to the given images has been computationally realized, which allows us to average images by averaging the constructed diffeomorphic transformations [New method of averaging diffeomorphisms based on Jacobian determinant and curl-vector, Chen, et al, 2016]. Also, a uniqueness problem has been theoretically discussed in [Uniqueness of Transformation based on Jacobian Determinant and curl-Vector, Zhou, et al, 2017], which indicates the averaged diffeomorphic transformation is unique. In this work, we integrate the above components to build a novel approach to average the given similar images. An algorithm is provided for demonstrating the proposed approach. Numerical examples are displayed in 2D case. (Received September 25, 2018)

1145-VN-1626 **Matthew Jacob Roberts*** (majrober@mtu.edu), 1400 Townsend Dr., Houghton, MI 49931. *Approximating the Generalized Singular Value Expansion.*

The singular value expansion (SVE) of a compact operator is invaluable for analyzing Tikhonov regularization. For semi-norm regularization, where a regularization operator such as the gradient is also involved, the generalized singular value expansion (GSVE) can be used in place of the SVE. In this talk, we discuss the approximation of the GSVE of a pair of operators and present sufficient conditions for the convergence of a sequence of discretizations. (Received September 23, 2018)

1145-VN-1717 **Alrazi Abdeljabbar*** (alrazi.abdeljabbar@ku.ac.ae), P.O box 2533, Abu Dhabi, United Arab Emirates, Abu Dhabi, United Arab Emirates. *Exact solutions of nonlinear partial differential equations.*

It is significantly important to search for exact soliton solutions to nonlinear partial differential equations (PDEs) of mathematical physics. Transforming nonlinear PDEs into bilinear forms using Hirota differential operators enables us to apply the Wronskian and Pfaffian techniques to search for exact solutions for a (3+1)-dimensional generalized evolution equations. In our presentation we are going to use this technique to develop new solutions to a new generalized systems. (Received September 24, 2018)

1145-VN-2029 **Nawa Raj Pokhrel*** (npokhrel@xula.edu), 2511 South Carrollton Ave. Apt 205, New Orleans, LA 70118, and **Netra khanal** and **Chris P. Tsokos**. *A Predictive Analytical Model for Stomach Cancer Data.*

The recent study [1] exclusively focused on statistical analysis and modeling of stomach cancer data. More specifically, extensive parametric analysis was performed on race and sex of patients with malignant tumors. The overall conclusion of the study was malignant stomach tumor sizes significantly different on gender and races. Similarly, quantile regression and decision tree analysis techniques were implemented to find the probabilistic behavior of the given phenomenon. Quantile regression model explored the fact that patient age was the most significant variable to determine the size of the malignant tumor. When age of the patient increases, so does the tumor size. Thus we developed analytical model to predict the malignant tumor size of stomach cancer as a function of age based on the given historical data taken from Surveillance Epidemiology and End Results (SEER) program of the United States.

[1] Chao Gao (2017), Statistical analysis and modeling of stomach cancer data, Ph.D Dissertation, University of South Florida (Received September 24, 2018)

1145-VN-2153 **Matthew Young***, Penn State University Mathematics Dept., 104 McAllister Building, State College, PA 16802, and **Andrew Belmonte**. *Fair Contributions in a Nonlinear Stochastic Public Goods Game.*

Much research has focused on how cooperation arises in public goods games, in which players either contribute to a shared good (cooperate) or do not (free-ride). Equilibrium solutions include the coexistence of cooperators and free-riders, or total extinction. We construct a population model around a nonlinear public goods game, with variable contributions and a subrational learning algorithm for players. We find the emergence of a fair solution, an equilibrium in which all players contribute the same amount, when players play in proper subsets of the population, rather than all playing together. (Received September 24, 2018)

1145-VN-2322 **Mehmet Emin Aktas*** (maktas@uco.edu), 100 N University Drive, Box 129, Edmond, OK 73034. *Using Network Topology in Fingerprint Identification.* Preliminary report.

Classical fingerprint identification methods utilize three different levels of features: Level 1 features (pattern), Level 2 features (minutiae points) and Level 3 features (pores and ridge shape). In this paper, we report an on-going work concerning a new method of identification which uses network topology. We represent fingerprint as weighted networks and employ the network topology, that takes all these three level features into consideration, for fingerprint identification. (Received September 25, 2018)

1145-VN-2337 **Warren Keil*** (wkeil@uco.edu), 100 N University Dr, Box 129, Edmond, OK 73034, and **Mehmet Emin Aktas** (maktas@uco.edu), 100 N University Dr, Box 129, Edmond, OK 73034. *Attributed Network Clustering: A Topological Data Analysis Approach.* Preliminary report.

In this paper, we study the attributed networks using topological data analysis. We first extract the ego network of each node. We then define the diffusion Frechet function over ego networks, which takes both network topology and attribute information into consideration, to extract the topological features. Next, we encode this information in persistent diagrams using functional filtrations and finally reach our goal by combining the distances within the persistence diagrams with machine learning algorithms. Our experiment shows that our method can be promising in clustering the attributed networks. (Received September 25, 2018)

1145-VN-2588 **Michael Natole Jr.*** (mnatole@albany.edu), **Yiming Ying** and **Siwei Lyu**. *Fast Algorithms for AUC Maximization.*

Quantifying machine learning performance is an important issue to consider when designing learning algorithms for binary classification. Most algorithms maximize accuracy, however, this can be a misleading performance metric when the data is imbalanced. In this talk, we will give a general overview of other metrics to measure performance and then discuss the Receiver Operating Characteristic (ROC) Curve and the AUC score. We will then introduce two novel algorithms that I have developed for optimizing the AUC score: stochastic proximal AUC maximization (SPAM) and stochastic primal-dual AUC maximization (SPDAM). I will briefly discuss the $O(\log t/t)$ convergence rate for SPAM and the linear convergence rate for SPDAM. I will also validate the effectiveness of both algorithms on various data sets. (Received September 25, 2018)

1145-VN-2606 **Stephen H. Harnish*** (harnishs@bluffton.edu). *MD simulations of acoustically-controlled defect dynamics: An analog of Born's law in QM.* Preliminary report.

As a mentor for the 2018-19 National Computational Science Institute's Blue Waters Student Internship Program I am guiding code development for simulations on the University of Illinois' Blue Waters supercomputer system. These molecular dynamics simulations track vacancies and interstitials in face-centered cubic and diamond cubic Lennard-Jones lattices. By simulating induced acoustic standing waves in these solids, we test the prediction that defects are more likely at acoustic wave antinodes than nodes and that the long-term PDF for defects are proportional to the square of the amplitudes of the acoustic standing waves. A kinetic Monte Carlo model and its associated eigenvalue/eigenvector analysis supports this hypothesis, which offers close analogies to Born's law in quantum mechanics. The goal of this year-long project is to further test this hypothesis via MD simulations. Aspects of code development and benefits of parallelization will be presented along with the preliminary report of these simulations. (Received September 25, 2018)

1145-VN-2616 **Erin E. Tripp*** (eetripp@syr.edu). *Structured Sparsity Promoting Functions.*

Motivated by the minimax concave penalty, we introduce a simple scheme to construct structured semiconvex sparsity promoting functions from convex sparsity promoting functions and their Moreau envelopes. We provide sparsity guarantees for the general family of functions and further study the thresholding behavior of the proximity operators of piecewise quadratic functions, indicator functions, and their sums. (Received September 25, 2018)

1145-VN-2721 **Adam T Wilander*** (wilandat@jmu.edu) and **Scott G McCalla** (scott.mccalla@montana.edu). *The Metastable Dynamics of an Aggregation Model.*

Aggregation is a natural phenomenon that occurs in a variety of contexts: schooling of fish, flocking of birds, and the formation of bacterial colonies. This behavior can often result from simple rules of interaction across each pair of agents. In this talk, we examine a particular aggregation model with a random network (featuring the property of community structure) underlying its individual-based interactions. We explore a specific aspect of the system's metastable dynamics as the system's parameters vary. Finally, we leverage this system's behavior to establish and assess an associated dynamics-based algorithm for recovering community structure, given a known graph. (Received September 25, 2018)

1145-VN-2730 **Darleen Perez-Lavin*** (darleenpl@uky.edu), Lexington, KY, and **James B Kowalkowski**, **Stephen Mrenna** and **Sven Leyffer**. *Traveling Circus Particle Model.* Preliminary report.

The strong interaction of particle physics is understood in terms of color. The transition from colored partons to the observed colorless particles (protons, pions, etc.) is currently described by the Lund string model. One aspect of this phenomenon is color reconnections (CR), when long-distance interactions between colored partons force an exchange of color. The CR model posits that these exchanges occur to minimize a free energy called the λ measure. Understanding CR models is important for a precise measurement of the top quark mass.

The CR phenomenon is similar to the traveling salesman problem, but with multiple salesmen; i.e. a traveling circus. . We construct a graph where our quarks are origins, gluons are intermediate cities and antiquarks are destinations with weighted edges. Then we find a set of paths that start at a quark and end at an antiquark, traveling through the gluons. The sum of the weights on each edge in our paths is the λ measure we are minimizing.

We begin by defining our model classically and use standard tools to find solutions. However, our ultimate goal is to map this problem onto a quantum computer. To this end, we map the free energy into an Ising model appropriate for a quantum annealing machine, such as the D-wave. (Received September 25, 2018)

1145-VN-2791 **Cara D. Brooks*** (cbrooks@fgcu.edu), 10501 FGCU Blvd., South, Fort Myers, FL 33965, and **Patricia K. Lamm** (lamm@math.msu.edu). *An improved first order local regularization method for ill-posed Volterra equations.* Preliminary report.

We present a first order local regularization method for solving ill-posed Volterra equations with ν-smoothing kernels. Based upon a previous method that performs well only for one-, two-, and three-smoothing kernels, our method is shown to be convergent for *all* values of $\nu \in \mathbb{N}$. We describe numerical implementation of the method and provide a new scheme to approximate the initial condition. Numerical examples illustrate the newly achieved stability in the cases $\nu = 4$ and higher. (Received September 25, 2018)

1145-VN-2926 **Yinqi Chen*** (yinqi.chen@uconn.edu), 40 Wilbur cross way, apt 7506, Storrs, CT 06268, and **Hieu Nguyen** (hiue@msu.edu), **Srihita Mediboina** (srihitamediboina@gmail.com), **Mingyang Zhang** (zhangbruin24@g.ucla.edu) and **Xiaodi Wang** (wangx@wcsu.edu). *Option Pricing by Wavelet filtering and Machine learning Based Monte Carlo Method.*

Researchers have developed so many accepted models for predicting the option price. The Black Scholes model is the earliest and most popular model both in theory and in practice. As researchers concentrate more on the stochastic volatility as a factor of option pricing, Binomial Tree Model, Monte Carlo Simulation, Support Vector Regression, Neural Networks are used as methods to predict the option price, as well. However, there are some disadvantages in old models. For example, the exercise date is assumed to be the last day, while American options could be exercised before the exercise day. Furthermore, the old models based on limited factors. To gain more accurate results, we need to consider more and weight these factors differently. In this article, we provide a new model by integrating old models such as Monte Carlo simulation using wavelet filtering, support vector regression, and recurrent neural network that can predict the dynamic option price more accurately and compare the results from different models. We selected Apple, Facebook, Netflix, Tesla, and Google as database and focused on the first quarter of 2018. (Received September 25, 2018)

1145-VN-2940 **Ryan M Evans*** (ryan.evans@nist.gov), 100 Bureau Drive, Gaithersburg, MD 20899, **Arvind Balijepalli**, 100 Bureau Drive, Gaithersburg, MD 20899, and **Anthony Kearsley**, 100 Bureau Drive, Gaithersburg, MD 20899. *Transport Phenomena in Biological Field Effect Transistors.*

Biological field effect transistors (Bio-FETs) are novel nanoscale electronics instruments that are designed for biomarker detection. Well-suited for biomarker measurement due to high charge sensitivity and direct signal transduction, these instruments have the potential to provide physicians with rapid, accurate, and portable measurements of biomarkers. A mathematical model for Bio-FET experiments will be presented that takes the form of a diffusion equation coupled to a nonlinear equation that described the evolution of the reacting species concentration. (Received September 25, 2018)

1145-VN-2979 **Qing Wang***, Shepherd University, Shepherdstown, WV 25443, and **Zhijun Wang** and **David J Klinke**. *Analysis of A Calibrated Tumor Growth Model in Response to a Combination Therapy Involving 4-1BB & IL-12.*

Recent preclinical studies have demonstrated synergistic therapeutic benefit by combining 4-1BB agonists with multiple antitumor therapies including IL-12. In this work, we developed a multi-scale model using a system of impulsive ordinary differential equations (IODE) to describe the interaction between the immune system and tumor in response to the combination therapy involving 4-1BB and IL-12. Model parameters are calibrated to experimental data using a genetic algorithm. Results of stability and sensitivity analysis, optimal treatment strategies will be discussed. This research was supported by NIH Grant P20GM103434 to the West Virginia INBRE. (Received September 26, 2018)

1145-VN-2993 **Kevin Li*** (likevin6688@gmail.com), **Mingyang Zhang** (zhangbruin24@g.ucla.edu) and **Xiaodi Wang** (wangx@wcsu.edu). *Privacy-preserving support vector regression and deep learning.*

Today, every moment huge amount of personal information is collected, stored, used in digital form or otherwise. Improper or non-existent disclosure control can be the root cause for privacy issues. These issues may arise from a wide range of sources such as in healthcare records, criminal investigations and proceedings, web surfing behavior using persistent cookies, academic research, and financial transactions. Data analysis with privacy-preserving can be regarded as statistical disclosure control, private data analysis, and privacy-preserving data-mining. To achieve the goal, some robust concepts of privacy-preserving such as k-anonymity and l-diversity have been proposed. However, even these methods cannot prevent private information leaking from attacks. In an extreme case, the attacker might know the contents of all but one of the rows in the set . To combat such background attacks, Dwork proposed concept of Differential privacy. In this research, we'll private an algorithm that will allow multiple parties to jointly apply support vector regression and deep learning models for a given objective without sharing their input datasets so that differential privacy will be achieved. (Received September 26, 2018)

1145-VN-3014 **Gurcharan Singh Buttar*** (gurcharanbuttar@gmail.com), Village Churian Po Makhu, Makhu, India, and **Vikramjeet Singh** (vikramjeet31782@gmail.com), PTU Batala Campus, Batala, India. *Solution Of Multiple Travelling Salesmen Problem Using Non Probabilistic Distribution Algorithm.* Preliminary report.

Fuzzy entropy is applied in the fields of Statistics, Computer Science, Bio- Technology to find the optimal solution of multifaceted problems. MTSP(Multiple travelling salesmen problem) is a generalised optimization problem with numerous combinatorial. The MTSP cannot be effectively handled by classical methods of optimization. Genetic Algorithms (GA), ant colony optimization (ACO), simulated annealing (SA) and partial swarm optimization (PSO) algorithms can be good option for MSTP. This paper is an attempt to apply non probabilistic distribution to MSTP, with some restrictions for the optimal solution. (Received September 26, 2018)

1145-VN-3020 **Terry F Cox*** (tfcox1703@gmail.com), 1500 Bishop Carroll Dr. apt. 223, Helena, MT 59625. *Math in the Mountains- Undergraduate Consulting.*

Math in the Mountain is a consulting class offered at Carroll College in Helena, MT. Over the last 3 years, I have worked with three different non-profits to show their impacts on the community.

- Montana No Kid Hungry- Analyze the newly implemented "Alternative Breakfast Model" across Montana school to see how participation numbers have changed
- United Way of the Lewis and Clark Area- Find a way to quantify individual and family resiliency to measure impace
- Habitat for Humanity ReStore- Tracking environmental impact by estimating weight kept out of landfills, as well as, optimizing donations

(Received September 26, 2018)

Geometry

1145-VO-99 **Hemangi Shah*** (hemangimshah@hri.res.in), Chhatnag Road, Jhunsi, Allahabad, UP 211019, India. *Geometry of Asymptotically harmonic manifolds with minimal horospheres.*

(M^n, g) be a complete Riemannian manifold without conjugate points. We show that if M is also simply connected, then M is flat, provided that M is also asymptotically harmonic manifold with minimal horospheres (AHM). The (first order) flatness of M is shown by using the strongest criterion: $\{e_i\}$ be an orthonormal basis of T_pM and $\{b_{e_i}\}$ be the corresponding Busemann functions on M. Then, (1) The vector space $V = span\{b_v | v \in T_pM\}$ is finite dimensional and dim V = dim $M = n$. (2) $\{\nabla b_{e_i}(p)\}$ is a global parallel orthonormal basis of T_pM for any $p \in M$. Thus, M is a parallizable manifold. And (3)$F : M \to R^n$ defined by $F(x) = (b_{e_1}(x), b_{e_2}(x), \cdots, b_{e_n}(x))$, is an isometry and therefore, M is flat. Consequently, AH manifolds can have either polynomial or exponential volume growth, generalizing the corresponding result for harmonic manifolds. In case of harmonic manifold with minimal horospheres (HM), the (second order) flatness was proved by Ranjan and Shah by showing that $span\{b_v^2 | v \in T_pM\}$ is finite dimensional. (Received July 29, 2018)

1145-VO-431 **Yuhang Liu*** (liuyuhang.fudan@gmail.com), 321 N 40th St., Philadelphia, PA 19104. *On positively curved manifolds of dimension 6.*

Understanding the structure of Riemannian manifolds with strictly positive sectional curvature remains a fundamental problem in Riemannian geometry. In this talk, I will briefly go over the history of the classification of positively curved manifolds in low dimensions under certain symmetry assumptions on the isometry group. Then I will focus on dimension 6 and discuss positively curved 6-manifolds whose isometry groups are non-Abelian Lie groups. Examples of such manifolds will be given together with the isometric group actions, and if time permits I will present some results I got in this direction. This is ongoing work on my thesis problem. (Received September 06, 2018)

1145-VO-713 **Oliver Thakar*** (olliet19@parkschool.net) and **Katherine Socha** (ksocha@parkschool.net). *Enchanting Geometry.* Preliminary report.

Mathematicians know that developing and proving theorems both require creative thinking, but many of our peers in other lines of work have not experienced mathematics as creative thinking about beautiful ideas. In this talk, we present one beautiful geometric result and coax the audience into developing a particularly elegant argument. The result: that the lune of Hippocrates, a shape bounded by two circular arcs, is quadrable — equal in area to a constructible square. Join us in the talk to develop the argument! This exploration is one example from a guided journey through geometry: a book in progress, intended to enchant the general reader into discovering elegance and creativity through geometry. (Note: this is a student-led presentation.) (Received September 13, 2018)

1145-VO-718 **Hongguang Fu*** (fu_hongguang@hotmail.com), University of Electronic Science of China, Chengdu, Sichuan 610000, Peoples Rep of China, **Jingzhong Zhang** (zjz2271@163.com), School of Computer Science and Educational So, Guangzhou University, Guangzhou, Guangdong 510006, Peoples Rep of China, **Zengxiang Tong** (ztong@otterbein.edu), Department of Mathematical Sciences, Otterbein University, Westerville, OH 43081, and **Xicheng Peng** (pxc417@126.com), National Engineering Research Center, Central China Normal University, Wuhan, Hubei 430000, Peoples Rep of China. *Outline of Point-Geometry.*

This paper outlines the Point-Geometry, a new geometric-algebraic system. It introduces the concepts of point, addition of two points, product of a real number and a point, product of a complex number and a point, inner product of two points, and external products of two points and of three points. This paper explains the geometric meanings of the above concepts and operations, and presents important rules and theorems in the point-geometry. All points constitute an Abelian group, and the operations reflect important Euclidean transformations. The point-geometry possesses the merits of coordinate and vector methods, but avoids many intrinsic shortcomings (e.g., tedious calculation) in these traditional methods. The point-geometry is a powerful method in solving geometric problems. The authors have solved more than 600 nontrivial geometric problems, with most solutions simpler, easier, more understandable, and more beautiful than those using traditional methods. (Received September 13, 2018)

1145-VO-1264 **Barry Minemyer*** (bminemyer@bloomu.edu), 400 E. Second St., 212 Ben Franklin Hall, Bloomsburg, PA 17815. *Real hyperbolic hyperplane complements in the complex hyperbolic plane.*

In this talk we will discuss Riemannian manifolds of the form $M \setminus S$, where M^4 is a complete four dimensional Riemannian manifold with finite volume whose metric is modeled on the complex hyperbolic plane $\mathbb{CH}^2$, and S is a compact totally geodesic codimension two submanifold whose induced Riemannian metric is modeled on the real hyperbolic plane $\mathbb{H}^2$. The main results in the paper to be presented are as follows. We will discuss how to write the metric on $\mathbb{CH}^2$ in polar coordinates about $\mathbb{H}^2$, compute formulas for the components of the curvature tensor in terms of arbitrary warping functions, and prove that there exist warping functions that yield a complete finite volume Riemannian metric on $M \setminus S$ whose sectional curvature is bounded above by a negative constant. The cases of $M \setminus S$ modeled on $\mathbb{H}^n \setminus \mathbb{H}^{n-2}$ and $\mathbb{CH}^n \setminus \mathbb{CH}^{n-1}$ were previously studied by Belegradek. (Received September 20, 2018)

1145-VO-1302 **Richard G Ligo*** (ligo001@gannon.edu). *Curves, Pointwise Curvature, and Conformal Transformations.*

The pointwise absolute curvature of a curve provides a measurement of how tightly a curve is "turning" at any point. The maximum pointwise absolute curvature of any curve can be made arbitrarily large through dilation in a trivial way. In this talk it is shown that for any non-circular closed curve, there exists a length-preserving inversion such that the maximum pointwise absolute curvature can be made arbitrarily large. This is accomplished via an elementary argument involving basic analysis, topology, and geometry. (Received September 23, 2018)

1145-VO-2226 **Rishi Raj Subedi*** (rishi.subedi@famu.edu), 1767 Hermitage Blvd, Apt 9304, Tallahassee, FL 32308. *Five-dimensional Lie-Einstein metrics.*

The question of the existence Einstein metrics on five-dimensional solvable Lie groups are partially solved. Several classical results pertaining to the existence of such "Lie-Einstein" are presented and their relevance to the fi ve-dimensional case is explained. Index formulas for the curvature tensors of an invariant metric on a Lie group are supplied. The case where the nilradical is of dimension four is solved completely and in the case when the nilradical is of dimension three and the single non-solvable case, the problem is solved when the metric is assumed to be of diagonal form. The five cases where an Einstein space is known to exist are given. (Received September 25, 2018)

1145-VO-2354 **Yun Myung Oh** and **Devin German Garcia*** (gdevin@andrews.edu), 4260 Administration Dr, Berrien Springs, MI 49104. *A Curve Satisfying $\frac{\tau}{\kappa}=\frac{1}{s}$ With Constant $\kappa > 0$.*

According to the Fundamental Theorem of Curves, any regular curve with a smooth positive curvature and smooth torsion can be completely determined up to its position. Helices have the property that the ratio of torsion to curvature is a constant. For rectifying curves, the ratio of torsion to curvature is a linear function. In this paper, we study a space curve whose ratio of torsion to curvature is given by $\frac{1}{s}$, where s is an arc length. For this problem, we consider the curvature is constant. After reparametrization, we use a series solution to solve a third-order differential equation and obtain the general equation of the curve. (Received September 25, 2018)

1145-VO-2581 **Tom Edgar** (edgartj@plu.edu) and **David Richeson*** (richesod@dickinson.edu). *Gregory's theorem for inscribed and circumscribed regular polygons.*

Archimedes famously used the perimeters of inscribed and circumscribed regular polygons to approximate the circumference of a circle and thus to obtain bounds for π. In 1667, James Gregory did the same, but for areas. Let I_k and C_k denote the areas of inscribed and circumscribed regular k-gons, respectively. Gregory proved that for all n, I_{2n} is the geometric mean of C_n and I_n, and C_{2n} is the harmonic mean of C_n and I_{2n}. In this talk we give a brief history of Gregory's work and we present a short proof of his theorem. (Received September 25, 2018)

1145-VO-2726 **Oliver T.B. Meldrum*** (ooliveair@gmail.com). *Maximizing the number of vertices of the d-cube that can be covered by a ball of given radius.* Preliminary report.

We consider the problem of finding the maximum number of vertices of a unit $d-$dimensional hypercube that can be covered by a hypersphere of radius r. We give solutions for $(d \leq 6)$ and $\left(r^2 < \frac{45}{44}\right)$ and provide some bounds on the solution in general. Finally, we disprove many natural conjectures, showing that this problem, despite it's elementary statement, appears to have a surprisingly complicated solution. (Received September 25, 2018)

1145-VO-2745 **Bradley Lewis Burdick*** (bburdick@uoregon.edu). *Ricci-positive metrics on arbitrary connected sums of products of spheres.* Preliminary report.

Sha and Yang gave a sufficient condition on a Ricci-positive manifold to perform surgery while preserving Ricci-positivity, which applied to $S^{n-1} \times S^{m+1}$ with the product of round metrics yielded a Ricci-positive metric on $\#_k(S^n \times S^m)$. Using a technical constructions of Perelman, we give a sufficient condition to perform a modified surgery, which in particular allows us to replace the attaching handle $D^n \times S^m$ with $(N^n \setminus D^n) \times S^m$ given the existence of a Ricci-positive metric on $N^n \setminus D^n$ with round, convex boundary. Applied to $S^{n-1} \times S^{m+1}$ with a particular choice of metric yields a Ricci-positive metric on $\#_i(N_i^n \times S^m)$.

Going further, by making a careful local analysis of the metric constructed on $\#_k(N^n \times S^m)$ on a neighborhood of $(N^n \times S^m) \setminus D^{n+m}$, one finds that this metric almost satisfies the hypotheses originally imposed on the metric for $N^n \setminus D^n$, except the boundary is not round. We will discuss whether it is possible to correct this defect. Assuming one could, the conclusion would be that it is possible to find a Ricci-positive metric on on arbitrary connected sums of arbitrary products of spheres. (Received September 25, 2018)

1145-VO-2886 **James Dibble*** (james-dibble@uiowa.edu). *Central splitting of manifolds with no conjugate points.*

An unresolved question in Riemannian geometry is the extent to which rigidity results for nonpositively curved manifolds extend to the case of no conjugate points. It will be shown that each compact manifold with no conjugate points admits a family of functions whose integrals vanish exactly when central Busemann functions split linearly. These functions vanish when central Busemann functions are sub- or superharmonic. A consequence is that splitting theorems for nonpositively curved manifolds with nontrivial center generalize to those with no conjugate points and convex or concave central Busemann functions. (Received September 25, 2018)

Graph Theory

1145-VP-106 **Cesar O. Aguilar*** (aguilar@geneseo.edu), Department of Mathematics, SUNY Geneseo, Geneseo, NY 14454, **Joon-yeob Lee** (jl56@geneseo.edu), Department of Mathematics, SUNY Geneseo, Geneseo, NY 14454, **Eric Piato** (esp6@geneseo.edu), Department of Mathematics, SUNY Geneseo, Geneseo, NY 14454, and **Barbara J. Schweitzer** (bjs22@geneseo.edu), Department of Mathematics, SUNY Geneseo, Geneseo, NY 14454. *Spectral characterizations of anti-regular graphs.*

In this talk, we present recent results on the eigenvalues of the unique connected anti-regular graph A_n. Using Chebyshev polynomials of the second kind, we obtain a trigonometric equation whose roots are the eigenvalues and perform elementary analysis to obtain an almost complete characterization of the eigenvalues. In particular, we show that the interval $\Omega = [\frac{-1-\sqrt{2}}{2}, \frac{-1+\sqrt{2}}{2}]$ contains only the trivial eigenvalues $\lambda = -1$ or $\lambda = 0$, and any closed interval strictly larger than Ω will contain eigenvalues of A_n for all n sufficiently large. We also obtain bounds for the maximum and minimum eigenvalues, and for all other eigenvalues we obtain interval bounds that improve as n increases. Moreover, our approach reveals a more complete picture of the bipartite character of the eigenvalues of A_n, namely, as n increases the eigenvalues are (approximately) symmetric about the number $-\frac{1}{2}$. We also obtain an asymptotic distribution of the eigenvalues as $n \to \infty$. Finally, the relationship between the eigenvalues of A_n and the eigenvalues of a general threshold graph is discussed. (Received July 30, 2018)

1145-VP-132 **Joshua J Steier*** (joshua.steier@student.shu.edu), **Kristi Luttrell** and **John T Saccoman**. *Limit Characterizations of Graphs: An Extension to Multigraphs.*

Limit characterizations through spanning trees in multigraphs: an exploration By Joshua Steier Advisors: Dr. Kristi Luttrell and Dr. John T. Saccoman

Nikolopolous et. al., using Cayley's Theorem and Kirchhoff's Matrix Theorem, established limiting results for the number of spanning trees of certain families of graphs. Focusing as they did on edge deletions, we applied similar techniques to similar families of multigraphs. We examined existing results involving threshold graphs and split graphs. Utilizing various matrix properties and a general formula for the number of spanning trees on complete multigraphs, we conjecture limit characterization for underlying complete multigraphs with fixed multiplicity. Keywords: multigraphs, split graphs, spanning trees, Laplacian Matrix, Kirchhoff's Theorem (Received August 07, 2018)

1145-VP-207 **Emily A Hynds*** (eahynds@samford.edu) and **Ronald J Gould**. *A Generalization of a Result of Catlin: 2-Factors in Line Graphs.*

A 2-factor of a graph G consists of a spanning collection of vertex disjoint cycles. In particular, a hamiltonian cycle is an example of a 2-factor consisting of precisely one cycle. Harary and Nash-Williams described graphs with hamiltonian line graphs. Gould and Hynds generalized this result, describing those graphs whose line graphs contain a 2-factor with exactly k ($k \geq 1$) cycles. With this tool, we show that certain properties of a graph G, that were formerly shown to imply the hamiltonicity of the line graph, $L(G)$, are actually strong enough to imply that $L(G)$ has a 2-factor with k cycles for $1 \leq k \leq f(n)$, where n is the order of the graph G. (Received August 19, 2018)

1145-VP-233 **Monsikarn Jansrang*** (jansr1m@cmich.edu). *Graph Complement Conjecture for the Minimum Semidefinite Rank.* Preliminary report.

Given an $n \times n$ Hermitian matrix $A = [a_{ij}]$ we associate a graph $G(A)$ to the matrix A such that the set of vertices is $\{v_1, \ldots, v_n\}$ and the set of edges is $E = \{\{v_i, v_j\} : a_{ij} \neq 0, i \neq j\}$. The diagonal entries of A do not have an effect on $G(A)$. Let $P(G) = \{A \in M_n(\mathbb{C}) : A^* = A,\ A \text{ is positive semidefinite},\ G(A) = G\}$. The *minimum semidefinite rank* of G is defined to be $mr_+^{\mathbb{C}}(G) = \min\{rank(A) :\ A \in P(G)\}$. If we restrict to real symmetric positive semidefinite matrices, the real minimum semidefinite rank is denoted by $mr_+^{\mathbb{R}}(G)$.

It has been conjectured that $mr_+^{\mathbb{R}}(G) + mr_+^{\mathbb{R}}(\overline{G}) \leq |G| + 2$ where $\overline{G}$ is the complement of the graph G and $|G|$ is the number of vertices in G. This conjecture is called "Graph Complement Conjecture" and is denoted GCC_+. Given a graph G, the *shadow graph* $S(G)$ is obtained from G by adding for each vertex u of G, a new vertex v called the shadow vertex of u, and joining v to the neighbors of u in G. In this talk we will present some new results about classes of shadow graphs that satisfy GCC_+. (Received August 23, 2018)

1145-VP-462 **Shannon Dillman*** (2sdillman@gmail.com) and **Franklin Kenter** (kenter@usna.edu). *Bounding the Cop Number in the Game of Cops and Robbers on Graphs.* Preliminary report.

The game of Cops and Robbers on graphs was first introduced in the early 1980s, and one of the deepest problems in the game is finding a good upper bound for the cop number of a graph. We will describe our strategy based on a breadth-first search method used to estimate an upper bound for the cop number on any graph. For this strategy, we also discuss the algorithm and integer program used. We then explore this idea on the proven cop number of an n-dimensional cube graph. (Received September 06, 2018)

1145-VP-478 **Hays W. Whitlatch*** (hww@math.sc.edu) and **Joshua N. Cooper**. *Pressing Sequences in Genome Graphs.*

In the 1930's, two biologists, Dobzhansky and Sturtevant, introduced the idea that the degree of disorder between the genes in two genomes is an indicator of the evolutionary distance between two organisms. This has inspired extensive work in the fields of computational biology, bio-informatics and phylogenetics. In particular, researchers have pursued the question of how a common ancestral genome may have been transformed by evolutionary events into distinct, yet homologous, genomes. In mathematics, we often represent genomes as signed permutations, and evolutionary events are encoded as operations on signed permutations. Hannenhalli and Pevzner famously showed that sorting such sequences can be done in polynomial time and that they are essentially equivalent to a certain sequences of operations - "vertex pressing" - on bicolored graphs. In this talk we examine the combinatorial matrix algebra over GF(2) that arises from the theory of such sequences, providing a collection of equivalent conditions for their existence and showing how linear algebra, poset theory, and group theory can be used to study them. We also discuss enumeration, characterization, and recognition of uniquely pressable graphs (those with exactly one pressing sequence). (Received September 07, 2018)

1145-VP-500 **Zhongyuan Che*** (zxc10@psu.edu). *A characterization of the resonance graph of an outer plane bipartite graph.* Preliminary report.

Let G be a 2-connected outer plane bipartite graph. The resonance graph of G, denoted by $Z(G)$, is a graph whose vertex set is the set of all perfect matchings of G and two vertices are adjacent in $Z(G)$ if their symmetric difference is the boundary of a finite face of G. Assume that s is a reducible face of G and H is the subgraph of G obtained by removing all internal vertices (if exist) and edges on the common periphery of s and G. We show that $Z(G)$ can be obtained from $Z(H)$ by a peripheral convex expansion. It follows that $Z(G)$ can be obtained from an edge by a sequence of peripheral convex expansions with respect to a reducible face decomposition of G. As an application, we prove that $\Theta(Z(G))$ is a tree and isomorphic to the inner dual of G, where $\Theta(Z(G))$ is the induced graph on the Djoković-Winkler relation Θ-classes of $Z(G)$. Our results generalize the corresponding ones given by Klavžar et al. for resonance graphs of catacondenesed hexagonal systems and catacondensed even ring systems. (Received September 07, 2018)

1145-VP-552 **Allison Ganger**, **Shannon Golden**, **Brian Kronenthal*** (kronenthal@kutztown.edu), **Felix Lazebnik**, **Carter Lyons** and **Jason Williford**. *Cycles in algebraically defined bipartite graphs.*

For a field $\mathbb{F}$ and a bivariate polynomial $f \in \mathbb{F}[x,y]$, the partite sets P and L of a two-dimensional algebraically defined bipartite graph are each copies of $\mathbb{F}^2$, and $(p_1,p_2) \in P$ and $[\ell_1,\ell_2] \in L$ are adjacent if and only if $p_2+\ell_2 = f(p_1,\ell_1)$. This definition can be generalized to three or more dimensions. In this talk, we will discuss how different choices of f impact the graph's girth (i.e. the length of the smallest cycle it contains). (Received September 09, 2018)

1145-VP-866 **Michael R Yatauro*** (mry3@psu.edu), Penn State - Brandywine, 25 Yearsley Mill Rd., Media, PA 19063. *The Current State of Best Monotone Theorems in Graph Theory.*

In 2015 Bauer et al. published the article Best Monotone Degree Conditions for Graph Properties: A Survey in the journal Graphs and Combinatorics. Since this time, a few more best monotone degree condition theorems have be derived. In addition, various authors have produced new results by utilizing best monotone degree theorems found in this survey. The purpose of this talk is two-fold. First, we will introduce the concept of a best monotone degree theorem for those who are unfamiliar. Then, we will discuss recent related results and open conjectures. (Received September 16, 2018)

1145-VP-894 **Desmond Cummins*** (dcummins@wells.edu) and **Jocelyn Bell** (bell@hws.edu). *Constructing Arbitrarily Large Ordered Graceful Labelings.*

We define graceful labelings and ordered graceful labelings of graphs. We then describe a technique for constructing ordered graceful labelings of arbitrarily large size. (Received September 17, 2018)

1145-VP-995 **Jason J Molitierno*** (molitiernoj@sacredheart.edu), Department of Mathematics, Sacred Heart University, 5151 Park Avenue, Fairfield, CT 06825-1000. *A tight upper bound on the spectral radius of bottleneck matrices of graphs.*

The Laplacian matrix, $L = [\ell_{i,j}]$, of a graph G on n vertices labeled $1, \ldots, n$ is the $n \times n$ matrix in which $\ell_{i,i}$ 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. The eigenvalues of L are $0 = \lambda_1 \leq \lambda_2 \leq \ldots \leq \lambda_n$. The eigenvalue λ_2 is known as the algebraic connectivity of G because it gives a measure of how connected G is. In this talk, we will investigate the spectral radius ρ of the bottleneck matrix $M_i = (L\overline{\{i\}})^{-1}$ where $L\overline{\{i\}}$ is the matrix created from L by deleting the row and column corresponding to vertex i. It is known that $1/\rho(M_i)$ is a lower bound for λ_2. We will find tight upper bounds on $\rho(M_i)$ which will, in turn, give tight lower bounds on λ_2. (Received September 18, 2018)

1145-VP-1013 **Drake P Olejniczak*** (drake.p.olejniczak@wmich.edu). *An Application of Ramsey Numbers.*

The mathematician Theodore Motzkin said, describing Ramsey theory, that “complete disorder is impossible”. While this should be taken with a grain of salt, Ramsey theory offers a glimpse at the relationship between order and chaos. In certain circumstances, it is found that in any sufficiently large structure, some prescribed sub-structure must exist. The most well known area of Ramsey theory is the study of Ramsey numbers. The Ramsey number of two graphs F and H, denoted $R(F, H)$, is defined to be the smallest positive integer n such that if every edge of the complete graph K_n is colored either red or blue then there exists a subgraph isomorphic to F all of whose edges are red or a subgraph isomorphic to H all of whose edges are blue. A version of Ramsey's theorem guarantees that such an n exists. Ramsey theory is not limited to graphs, and there are a number of exciting and useful applications of Ramsey theory to number theory, algebra, topology, and geometry. In this talk, we show how a version of Ramsey's theorem can be used to prove Schur's theorem, and, in turn, prove a result about the status of Fermat's last theorem in $\mathbb{Z}_p$. (Received September 18, 2018)

1145-VP-1021 **Manuel A Davila***, mdavila9@calstatela.edu, and **Cynthia M Ramirez** and **Gwen Ostergren**. *The Chromatic Number of a Two Dimensional Lattice.*

This work is based on the open problem, "The Chromatic Number of the Plane." This problem asks for the minimal number of colors needed to color the Euclidean Plane so that no two points that are one unit distance apart are of the same color. In our variation of this problem we focus on a discrete approximation of the Euclidean plane. We use the set of points of the form $(\frac{p}{n}, \frac{q}{n})$ where p, q are integers and n is a fixed positive integer. As n approaches infinity, these sets approximate the plane. We also introduce a small positive number, ϵ, and we require two points in the Euclidean plane to be of different colors if their distance is between $1 - \epsilon$ and $1 + \epsilon$. For $n = 3$, we prove that a lower bound for the chromatic number is 5 when $\epsilon = \frac{\sqrt{13}}{3} - 1$. (Received September 18, 2018)

1145-VP-1265 **Ethan Berkove*** (berkovee@lafayette.edu) and **Mike Brilleslyper**. *Graph labeling and social intervals.*

In a coprime labeling of a graph, two labeled vertices are connected precisely when their labels are coprime. In this talk we will discuss, given a consecutive set of labels starting at some positive integer k, which bipartite graphs admit a coprime labeling. We have found (to our surprise) that there are intervals which admit no coprime labeling of any bipartite graph at all. We call these collections of labels “social intervals”; they have interpretations both in terms of a construction based on modular arithmetic as well as in terms of the coprime graph associated to the collection. (Received September 20, 2018)

1145-VP-1345 **Emily N Hoard*** (ehoard1@murraystate.edu). *A Graphical Game, Southwesterly Snakes.*

We consider a single player combinatorial game, “Southwesterly Snakes,” played on a pair of partitions, each with the same fixed maximum part size and fixed maximum number of parts. The objective of the game is to find the least number of “snake moves” to move from one partition to another, where a snake move is an addition or removal of a series of adjacent boxes in the partition with the middle box lying on the main diagonal of the partition. We evaluate a strategy for completing the game by building a lattice based on partitions that summarizes the possible moves from each partition. Using this, we are able to determine, for any two partitions, which moves are necessary to move from one partition to the other. (Received September 21, 2018)

1145-VP-1396 **Gregory J Clark*** (gjclark@email.sc.edu) and **Joshua Cooper**. *A Generalization of the Harary-Sachs Theorem for Hypergraphs.*

The Harary-Sachs theorem equates the coefficients of the characteristic polynomial of a graph to a weighted sum of a specific set of graphs called elementary graphs. We extend this theorem by equating the coefficients of the characteristic polynomial of a hypergraph to a weighted sum of a specific set of hypergraphs called Veblen graphs. We provide a characterization of Veblen graphs and present a combinatorial formula for their associated coefficient. Using our theorem, we provide a numerically stable algorithm for computing the characteristic polynomial of a hypergraph. We conclude by demonstrating this algorithm by presenting the characteristic polynomial of various hypergraphs which are not computable using conventional methods. This is joint work with Joshua Cooper. (Received September 21, 2018)

1145-VP-1447 **Samuel C Gutekunst*** (scg94@cornell.edu) and **David P Williamson**. *Semidefinite Programming Relaxations of the Traveling Salesman Problem.*

We study a semidefinite programming relaxation of the traveling salesman problem introduced by de Klerk, Pasechnik, and Sotirov [SIAM J. Optim., 19 (2008), pp. 1559–1573] and based on methods from algebraic graph theory. We begin by motivating this relaxation with a new, direct proof of its validity and discussing its relationship to association schemes. We then sketch our main result: the integrality gap of this relaxation is unbounded. Our proof involves searching for highly symmetric feasible solutions; the problem of finding such solutions reduces to finding feasible solutions for a related linear program which we can do analytically. These solutions imply several corollaries that help us better understand the semidefinite program and its relationship to other relaxations of the traveling salesman problem. (Received September 21, 2018)

1145-VP-1448 **Hong-Jian Lai**, **Mingquan Zhan** and **Taoye Zhang*** (tuz3@psu.edu), Penn State Scranton, 120 Ridge View Dr, Dunmore, PA 18512, and **Ju Zhou**. *s-hamiltonian and s-hamiltonian connected line graphs of claw-free graphs.*

For an integer $s \geq 0$, a graph G is s-hamiltonian if for any vertex subset $S \subseteq V(G)$ with $|S| \leq s$, $G - S$ is hamiltonian; and G is s-hamiltonian-connected if for any vertex subset $S \subseteq V(G)$ with $|S| \leq s$, $G - S$ is hamiltonian-connected. Thomassen in 1984 conjectured that every 4-connected line graph is hamiltonian. Lai and Shao [J. GraphTheory, 74 (2013), 344-358] proved that for a connected graph G and an integer $s \geq 5$, the line graph $L(G)$ is s-hamiltonian if and only if $L(G)$ is $(s+2)$-connected. The results presented in this talk are:

(i). For an integer $s \geq 2$, the line graph $L(G)$ of a claw-free graph G is s-hamiltonian if and only if $L(G)$ is $(s+2)$-connected.

(ii). The line graph $L(G)$ of a claw-free graph G is 1-hamiltonian-connected if and only if $L(G)$ is 4-connected.
(Received September 21, 2018)

1145-VP-1463 **Michael Kerckhove*** (mkerckho@richmond.edu) and **Hassan Naveed**. *Diffusion of Innovations on Strongly Regular Graphs.*

For many innovations, potential users choose between an objectively better product and the product currently prevalent within their local social network. Two-colored graphs provide a structure by which to investigate this problem. We use the following adoption rule: if a weak majority of its neighbors are using the innovation, a vertex will switch to the innovation. A dynamic majority is a subset of vertices such that if these vertices adopt the innovation initially, then eventually all vertices will share their color. We establish a lower bound in terms of the graph parameters for the minimum size of a dynamic majority in any strongly regular graph and illustrate patterns of dynamic majorities in graphs that achieve this lower bound. (Received September 22, 2018)

1145-VP-1576 **Kathleen Ryan***, 2755 Station Avenue, Center Valley, PA 18034, and **Nicholas Speranza** and **Henry Wickus**. *Colorful Cacti.* Preliminary report.

A cactus graph is a connected graph in which every block is either a cycle or an edge, and a partial cactus graph is simply a spanning subgraph of a cactus graph. We classify which sequences are realizable as partial cactus graphs. We furthermore address how our search for the degree sequences of partial cactus graphs originates from a related edge-coloring problem. (Received September 23, 2018)

1145-VP-2004 **Max Lind*** (mlind314@icloud.com) and **Eugene Fiorini** (eugenefiorini@muhlenberg.edu). *On Some Properties of Pebbling Configuration Graphs.*

Consider a configuration S_G of pebbles on a simple, connected graph G. For $m, k \in \mathbb{N}$, $k < m$, an (m, k) pebbling move removes m pebbles from a vertex in $V(G)$ and adds k pebbles to an adjacent vertex. A context $\Sigma = \{(m, k) \,|\, m, k \in \mathbb{N} \text{ and } k < m\}$ is the set of allowable pebbling moves on a graph with given configuration. A configuration graph $[S_G]_\Sigma$ associated with a configuration S_G is a Hasse diagram whose vertices represent subsequent configurations that can be reached from S_G, and whose edges correspond to a single pebbling move in Σ. We show that $[S_G]_\Sigma$ is bipartite with girth 4 for all Σ and prove under what conditions $[S_G]_\Sigma \cong [S_H]_\Sigma$ for simple, connected graphs G and H. Furthermore, we prove for which configurations $[S_G]_\Sigma$ is a symmetrical

Hasse diagram and which sub-configurations are associated with subgraphs of $[S_G]_\Sigma$. Finally, we address the question: When is $[S_G]_\Sigma$ pebblable? (Received September 24, 2018)

1145-VP-2250 **Mitch Phillipson***, mphilli2@stedwards.edu. *Non-Crossing Matchings on Words with Restricted Bonding Conditions.*

Let G be a graph and w be a word on the vertex set of G. We consider all non-crossing matchings on w where each arc in the matching is an edge in G. Additionally, we define an operation to transform on matching to another, called a move. The move graph of a word is the directed graph of all non-crossing matchings with edges given by the moves. In this talk we work to classify graphs based on their possible move graphs. We give a sufficient condition when two graphs are equivalent and detail several open problems in the area. (Received September 25, 2018)

1145-VP-2292 **Matthew A Hawks*** (mhawks@usna.edu), 572-C Holloway Rd, MS 9E, Annapolis, MD 21402. *Multivariate Change Detection and Localization Using Degree-K Nearest Neighbors.*

We explore the topic of detecting and localizing change in a series of multivariate data using graph-theoretic statistical criteria. Change-detection methods based on graph theory are emerging due to their ability to detect change of a general nature with desirable power properties. The graph-theoretic structure of nearest neighbors according to distances between observations forms the basis of our statistical procedures. We consider the detection power of the derived statistics. In a simulation study, we evaluate the power of our proposed statistical tests in a series of vignettes in which the sampling distribution, dimensionality, change parameter (location or scale), change type (abrupt or gradual), and change magnitude each are allowed to vary. We compare detection power with contemporary parametric and graph-theoretic approaches. Although our tests alone do not provide the information needed to localize a change point, we develop a follow-on procedure that satisfies this objective. (Received September 25, 2018)

1145-VP-2385 **Joshua Fenton*** (jfenton@syr.edu), 805 Broad Street, Syracuse, NY 13210. *Calculating Fries Deficit in Large Fullerenes.*

A fullerene is a trivalent graph, representing a large carbon molecule, the faces of which are hexagons and 12 pentagons. A perfect matching of the edges in a fullerene is called a Kekulé structure. In this structure, a face which has 3 of its incident edges contained in the matching is called a benzene ring. The Fries number is the maximum number of benzene rings over all Kekulé structures. It is clear that for any vertex, at most 2 of the 3 incident faces could be benzene rings and so there is an upper bound on the Fries number of $\frac{2}{3}$ of the faces. Since the actual Fries number for any given fullerene may not reach this $\frac{2}{3}$ mark exactly, the difference between the true Fries number and $\frac{2}{3}$ of the faces is called the Fries deficit. I am developing tools to calculate the Fries deficit through the grouping of pentagons and measuring deficit generated in these groups. (Received September 25, 2018)

1145-VP-2405 **Megan Cream*** (megan.cream@cedarcrest.edu). *Extending Vertex and Edge Pancyclicity.*

A graph G of order n is chorded pancyclic if it contains a chorded cycle of every possible length from 4 to n. In this talk, we consider extensions of the property of chorded pancyclicity to graph properties called chorded vertex pancyclicity and chorded edge pancyclicity. We will discuss results on graphs having these newly defined properties. (Received September 25, 2018)

1145-VP-2417 **Ju Zhou*** (zhou@kutztown). *PM-compact graphs and cycle-forced graphs.*

A graph G is *perfect matching compact*, or *PM-compact* for short, if for each even cycle C of G, $G-V(C)$ has at most one perfect matching. A graph G is a *cycle-forced graph* if for every cycle C in G, $G-V(C)$ has a unique perfect matching. In this talk, we talk about results related to PM-compact graphs and cycle-forced graphs. (Received September 25, 2018)

1145-VP-2504 **Mike Krebs*** (mkrebs@calstatela.edu), CSULA Dept. of Mathematics, 5151 State University Drive, Los Angeles, CA 91711. *The closure chromatic number of the plane, and of Euclidean space.*

We say a subset A of the Euclidean plane avoids distance 1 if no two points in A are of distance 1 from one another. The classical "chromatic number of the plane" problem asks for the smallest number of sets in a partition of the plane such that each set avoids distance 1. The sets in the partition can be thought of as color classes for some coloring of the plane. For over half a century, it has been known that this number is at least 4 and at most 7. In 2018, de Grey improved the lower bound to 5. In this expository talk, we discuss the "closure chromatic number of the plane," that is, the smallest number of sets in a partition of the plane such that the closure of each set avoids distance 1. We show how the results of Grytczuk et al., drawing on the work of Nielsen, immediately imply a slightly weaker result than de Grey's, namely that the closure chromatic number of the plane is at least 5. We then extend these results to higher dimensions. Finally, we note the relationship between the closure chromatic number and the measurable chromatic number (that is, the smallest number of sets in a partition of the plane such that each set is measurable and avoids distance 1). (Received September 25, 2018)

1145-VP-2573 **Daniel McGinnis** (daniel.mcginnis15@ncf.edu), 5800 Bay Shore Road, Sarasota, FL 34243, **Peter Gardner*** (psgardner1@wcu.edu), 157 Altaview Dr, Apt# 1D, Cullowhee, NC 28723, and **Tess Baren**, **Michael Corey**, **Mia Friedberg**, **Riley Waechter**, **James Hammer**, **Joshua Harrington** and **Tony Wong**. *On the Domination Number of Permutation Graphs and an Application to Strong Fixed Points.* Preliminary report.

A *permutation graph* G_π is a simple graph with vertices corresponding to the elements of π and an edge between i and j when i and j are inverted in π. A set of vertices D is said to *dominate* a graph G when every vertex in G is either an element of D, or adjacent to an element of D. The *domination number* $\gamma(G)$ is defined as the cardinality of a minimum dominating set of G. A *strong fixed point* of a permutation π of order n is an element k such that $\pi^{-1}(j) < \pi^{-1}(k)$ for all $j < k$, and $\pi^{-1}(i) > \pi^{-1}(k)$ for all $i > k$. In this article, we count the number of connected permutation graphs on n vertices with domination number 1 and domination number $\frac{n}{2}$. We further show that for a natural number $k \leq \frac{n}{2}$, there exists a connected permutation graph on n vertices with domination number k. We find a closed expression for the number of permutation graphs dominated by a set with two elements, and we find a closed expression for the number of permutation graphs efficiently dominated by any set of vertices. We conclude by providing an application of these results to strong fixed points, proving some conjectures posed on the OEIS. (Received September 25, 2018)

1145-VP-2653 **Jamie L. Shive***, shivejl@vcu.edu. *Cartesian Product of Palindromic Graphs.*

Palindromic graphs are a class of graphs inspired by the concept of palindromes in words and sequences. A graph G on n vertices is a *palindromic graph* if it has a vertex-labeling bijection $f : V(G) \to \{1, 2, ..., n\}$ with the property that $uv \in E(G)$ if and only if there is an edge $xy \in E(G)$ such that $f(x) = n - f(u) + 1$ and $f(y) = n - f(v) + 1$. This concept was introduced by Robert Beeler who presented sufficient conditions on G and H that guarantee that the Cartesian product $G \square H$ is palindromic. We prove that these sufficient conditions are also necessary. (Received September 25, 2018)

1145-VP-2664 **Sean Rainville*** (ser1008@plymouth.edu), **Eugene Fiorini** (eugenefiorini@muhlenberg.edu), **Tony H. W. Wong** (wong@kutztown.edu), **Sierra Brown** (sierrabrown@creighton.edu), **Spencer Daugherty** (daugh22s@mtholyoke.edu), **Barbara Maldonado** (barbara.maldonado23230@gmail.com) and **Riley Waechter** (rsw66@nau.edu). *Nimbers of Node-kayles on Certain Families of Graphs.*

This talk investigates the outcome of Node-Kayles games played on several families of graphs, which resulted in several new sequences published in the On-Line Encyclopedia of Integer Sequences. Using the Sprague-Grundy theorem, we are able to obtain sequences of "nimber" values for lattices (A316632), linked complete graphs (A316781), linked cycles (A316629), and other families such as generalized Petersen graphs (A316533). Furthermore, we define and prove recursion relations for these nimber sequences. Finally, we prove that Node-Kayles is equivalent to an octal game for some of these families. (Received September 25, 2018)

1145-VP-2776 **Curtis Clark*** (curtis.clark@morehouse.edu), 830 Westview Drive, Atlanta, GA 30314. *Ultimately Economical Multigraphs.* Preliminary report.

For positive integers λ and v, λK_v denotes the complete multigraph with λ parallel edges between each pair of v distinct vertices. For vertices x and y in a multigraph F, the multiplicity of the edge xy is the number of edges that have x and y as their endpoints, denoted $\mu_F(xy)$. Let F be a multigraph with $v(F)$ vertices and $e(F)$ edges such that $v(F) \leqq v$ and $\mu_F(xy) \leqq \lambda$ for each pair of vertices x and y in F. In the F-achievement game on λK_v, two players alternately color different edges of λK_v so as to make a copy of F in his color. The multigraph F is achievable on λK_v if a player can make a copy of F in his color. The least number of moves it takes for this player to win is the move number of F on λK_v. The multigraph F is economical on λK_v if the move number of F is equal to $e(F)$. The multigraph F is ultimately economical if there exists a t such that F is economical on λK_t. Some families of ultimately economical multigraphs are determined, and it is shown that there are no forbidden subgraphs for ultimately economical multigraphs.

(Received September 25, 2018)

1145-VP-2778 **Ronald J Gould** and **Warren E Shull*** (wshull@emory.edu), Warren Shull, 1519 North Decatur Rd, Apt 1, Atlanta, GA 30307. *On Spanning Trees with few Branch Vertices.*

Hamiltonian paths, which are a special kind of spanning tree, have long been of interest in graph theory and are notoriously hard to compute. One notable feature of a Hamiltonian path is that all its vertices have degree at most two in the path. In a tree, we call vertices of degree at least three *branch vertices*. If a connected graph has no Hamiltonian path, we can still look for spanning trees that come "close," in particular by having few branch vertices (since a Hamiltonian path would have none).

A conjecture of Matsuda, Ozeki, and Yamashita posits that, for any positive integer k, a connected claw-free n-vertex graph G must contain either a spanning tree with at most k branch vertices or an independent set of $2k+3$ vertices whose degrees add up to at most $n-3$. In other words, G has this spanning tree whenever $\sigma_{2k+3}(G) \geq n-2$, where $\sigma_k(G)$ is defined as the smallest sum of degrees of any k-vertex independent set in G. We prove this conjecture, which was known to be sharp. (Received September 25, 2018)

1145-VP-2785 **L Bookman***, 600 District Ave, Burlington, MA 01803, and **J Ubnoske** and **D Zwillinger**. *Classifying the difficulty of the k-clique problem.*

Not all instances of NP-complete problems are equally difficult to solve. For example, the knapsack problem for a superadditive sequence of values (each value exceeds the sum of all preceding values) is solved in linear time using a greedy algorithm; the difficulty of solving an NP-complete problem is dependent on underlying structure in a given problem instance. In 2012, Ercsey-Ravasz and Toroczkai used a dynamical system to exactly solve NP-complete problems. Their difficulty metric (essentially, the log of convergence time) applied to Sudoku puzzles showed strong agreement with human difficulty ratings. Leveraging their approach, we apply machine learning to identify features that contribute to the computational difficultly of a certain NP-complete problem: k-clique. We analyzed nonisomorphic 6-node graphs and found specific graph spectral properties predicting clique problem difficulty; we are studying larger graphs to determine if the characterizations persist. Our goal is to identify features of a given NP-complete problem which are strong indicators of problem difficulty, guiding the appropriate choice of algorithm in each instance. (Received September 25, 2018)

1145-VP-2880 **Caitlin M Owens*** (owensc@rowan.edu), Rowan University, Robinson Hall, Suite 228, 201 Mullica Hill Road, Glassboro, NJ 08028, and **Garth Isaak**. *Forbidden subgraphs for Hamiltonian problems on 2-trees.* Preliminary report.

It is known that 2-trees are Hamiltonian if and only if they are 1-tough. However, the analogous statement for Hamiltonian paths does not hold. We will define a family of 2-trees such that a 2-tree has a Hamiltonian path if and only if it does not contain any graph from that family as an induced graph. To define this family, we will examine a variation of the Hamiltonian path problem, 2HP, which is to determine whether or not it is possible to find a Hamiltonian path in a graph when both endpoints of the path are fixed. These results will be extended to the Hamiltonian path problem on 2-trees. (Received September 25, 2018)

1145-VP-2888 **Allan E Bickle*** (aub742@psu.edu). *Independence Number of Maximal Planar Graphs.*

We show that for a maximal planar graph G with order $n \geq 4$, the independence number satisfies $\frac{n}{4} \leq \alpha(G) \leq \frac{2}{3}n - \frac{4}{3}$. We show the lower bound is sharp and characterize the extremal graphs for the upper bound. (Received September 25, 2018)

1145-VP-2891 **Gregory Churchill***, gregory.churchill@oswego.edu. *An Extension of Hansel's Theorem to Hypergraphs.*

For integers $n \geq k \geq 2$, let V be an n-element set, and let $\binom{V}{k}$ denote the set of all k-element subsets of V. Let $\mathcal{C}$ be a collection of pairs $\{A, B\} \in \mathcal{C}$ of disjoint subsets $A, B \subset V$. We say that $\mathcal{C}$ covers $\binom{V}{k}$ if, for every $K \in \binom{V}{k}$, there exists $\{A, B\} \in \mathcal{C}$ so that $K \subset A \dot\cup B$ and $K \cap A \neq \emptyset \neq K \cap B$. When $k = 2$, such a family $\mathcal{C}$ is called a separating system of V, where this concept was introduced by Rényi, and studied by many authors.

Let $h(n,k)$ denote the minimum value of $\sum_{\{A,B\}\in\mathcal{C}}(|A|+|B|)$ over all covers $\mathcal{C}$ of $\binom{V}{k}$.Hansel determined the sharp bounds $\lceil n\log_2 n\rceil \leq h(n,2) \leq n\lceil \log_2 n\rceil$, and Bollobás and Scott sharpened these bounds to an exact formula for $h(n,2)$, for all integers $n \geq 2$. Here, we extend these results by determining an exact formula for $h(n,k)$, for all integers $n \geq k \geq 2$. (Received September 25, 2018)

1145-VP-2906 **Katie Anders**, **Alissa Crans**, **Briana Foster-Greenwood*** (brianaf@cpp.edu), **Blake Mellor** and **Julianna Tymoczko**. *Decomposing Rings of Generalized Graph Splines.*

Splines arise in many areas of mathematics as a way to interpolate and fit given data. Generalized graph splines are a combinatorial version of this idea. Given a graph with edges labeled by ideals in a ring, a spline on the graph is a vertex-labeling such that the endpoints of each edge are congruent modulo the edge label. The set of splines on a graph forms a ring, and in this talk, we discuss how to use certain subgraphs to decompose the ring of splines into a direct sum of splines on smaller graphs. We then apply these techniques recursively to find the ring of splines for graphs whose edge labels can be linearly ordered by inclusion. (Received September 25, 2018)

1145-VP-2921 **Billy M Duckworth*** (`billy@iduck.org`). *The Randić Index and Average Path Length.*
In graph theory the Randić Index is a number that gives information about the degree of branching within a particular graph. We examined the relationship between the Randić Index and other well known graph properties such as radius, diameter, and average path length. We attempt to bound the Randić Index for families of graphs such as paths, cycles and "methylated" paths and cycles. (Received September 25, 2018)

1145-VP-2935 **Tucker L Dowell*** (`td4h@mtmail.mtsu.edu`) and **Xiaoya Zha** (`xiaoya.zha@mtsu.edu`). *Counting Vertices in Tessellations of the Hyperbolic Plane.*
Let $T(d,f)$ be some planar, d-regular graph such that every face has f sides. For every face of $T(d,f)$ to be a regular polygon, it must tessellate a sphere, the plane, or the hyperbolic plane. We focus on counting vertices in tessellations of the hyperbolic plane. When $T(d,f)$ induces a tessellation of the hyperbolic plane, we can draw the graph starting with some vertex v and go out in rings of faces away from v. We offer a proof for a closed form solution for the number of vertices in the n-th ring from v when $d \geq 3$, $f \geq 4$, and $T(d,f)$ induces a tessellation of the hyperbolic plane, and we offer a proof for a different closed form solution when $d \geq 7$, $f = 3$, and $T(d,f)$ induces a tessellation of the hyperbolic plane. (Received September 25, 2018)

1145-VP-2960 **Janet Fierson*** (`fierson@lasalle.edu`), Dept. of Mathematics and Computer Science, La Salle University, 1900 W. Olney Ave., Philadelphia, PA 19141, and **Yitbarek Demesie**. *Reconfiguration graphs under constraints and variations.* Preliminary report.
In reconfiguration, one feasible solution of a problem is transformed into another through a series of applications of a reconfiguration rule, with each application of the rule producing an intermediate feasible solution. The reconfiguration graph has as its vertices all feasible solutions to the underlying problem. If the solution represented by one vertex may be transformed into the solution represented by another vertex through a single application of the reconfiguration rule, an edge exists between the vertices.

We consider graph problems to which reconfiguration has been applied and implement two types of changes: constraints on solutions to the underlying problem and variations on the reconfiguration rule. The first type of change necessarily leads to a vertex set for the reconfiguration graph that is a subset of the original vertex set. The second type of change affects the edges of the reconfiguration graph. When considered in isolation and in combination, these changes can greatly affect the characteristics of the resulting reconfiguration graphs. In particular, we examine differences in properties such as order, girth, and connectedness, as well as which graphs may appear as reconfiguration graphs themselves or as subgraphs of such graphs. (Received September 25, 2018)

1145-VP-2984 **Bernd Sing*** (`dr.bernd.sing@gmail.com`), Department of Mathematics, University of the West Indies, Cave Hill, Bridgetown, St Michael BB11000, Barbados. *Kolakoski sequences and Chvatals sequence of graphs.* Preliminary report.
An infinite sequence z over the alphabet $\{1,2\}$ that equals its own run-length sequence, is called a Kolakoski-sequence (OEIS #`A000002`):

$$z = \underbrace{1}_{1}\ \underbrace{22}_{2}\ \underbrace{11}_{2}\ \underbrace{2}_{1}\ \underbrace{1}_{1}\ \underbrace{22}_{2}\ \underset{\ldots}{\ldots} = z.$$

Although it is conjectured that the letter frequencies are equal in the infinite sequence (i.e., half the letters are 1s and half of them 2s), it is not even know if the frequencies actually exist.

Seeking to understand this mysterious sequences better, one can consider sequences that equal their own run-length sequence over other alphabets with two letters: For alphabets consisting of two even or two odd numbers, one can easily calculate the limiting frequencies; in the case of one even and one odd number, one arrives at the same conjecture about the letter frequencies as for the alphabet $\{1,2\}$.

In order to find bounds on the letter frequencies, Vašek Chvátal considered a certain recursively defined sequence of digraphs $(G_d)_d$ obtained from the Kolakoski sequence under consideration. We study the structure and adjacency matrices of these graphs over various alphabets. (Received September 26, 2018)

1145-VP-3009 **Peng Zhao***, Indiana State University, Terre Haute, IN 04807, and **Cheng Zhao** (peng.zhao@indstate.edu), Department of Mathematics and Computer Scienc, Indiana State University, Terre Haute, IN 04807. *Optimal cluster detection of a certain directed edge-weighted bipartite graph.* Preliminary report.

We study the cluster detection of a certain edge-weighted bipartite graph. Using Markov matrix and random walks, we obtain the optimal clustering in polynomial time. (Received September 26, 2018)

Linear Algebra

1145-VQ-326 **Sara M. Motlaghian*** (smotlaghian1@student.gsu.edu), 1307 Gettysburg Place, Atlanta, GA 30350, and **Ali Armandnejad** and **Frank J. Hall**. *Topological Properties of J-Orthogonal Matrices.*

In this paper, the set of all $n \times n$ J-orthogonal matrices is considered and some interesting properties of these matrices are obtained. The main topic is a straightforward proof of the known topological result that for $J \neq \pm I$, the set of all $n \times n$ J-orthogonal matrices has four connected components. An important tool in this analysis is Proposition **??** on the characterization of J-orthogonal matrices in the paper "J-orthogonal matrices: properties and generation", SIAM Review 45 (3) (2003), 504–519, by Higham. The expression of the four components allows formulation of some further noteworthy properties. For example, it is shown that the four components are homeomorphic and group isomorphic and that each component has exactly 2^{n-2} signature matrices.

Keywords: Signature matrix, J-orthogonal matrix, Connected component.
MSC(2010): Primary: 15B10; Secondary:15A30.
(Received September 01, 2018)

1145-VQ-629 **Mehmet Gumus*** (mzg0083@auburn.edu), 221 Parker Hall, Auburn, AL 36849. *Positive Diagonal Solutions to the Lyapunov Matrix Inequalities.*

A square real matrix A is said to be Lyapunov diagonally stable if there exists a positive diagonal matrix D such that $AD + DA^T$ is positive definite. This type of matrix stability plays an important role in various applied areas such as population dynamics, systems theory, complex networks, and mathematical economics. In this talk, we examine a result of Redheffer that reduces Lyapunov diagonal stability of a matrix to common diagonal Lyapunov solutions on two matrices of order one less. An enhanced statement of this result based on the Schur complement formulation is presented here along with a shorter and purely matrix-theoretic proof. We develop a number of extensions to this result, and formulate the range of feasible common diagonal Lyapunov solutions. In particular, we derive explicit algebraic conditions for a set of 2×2 matrices to share a common diagonal Lyapunov solution. (Received September 11, 2018)

1145-VQ-1390 **Rafael Bru**, **María T Gassó**, **Isabel Giménez** and **Máximo Santana*** (msantana22@uasd.edu.do), Instituto de Matemática, Universidad Autónoma de Santo Domingo, 10105 Santo Domingo, Dominican Rep. *Diagonal entries of the combined matrix of a totally negative matrix.*

The combined matrix of a nonsingular matrix A is the Hadamard (entrywise) product $A \circ \left(A^{-1}\right)^T$. This paper deals with the characterization of the diagonal entries of a combined matrix $C(A)$ of a given nonsingular real matrix A. A partial answer describing the diagonal entries of $C(A)$ in the positive definite case was given by Fiedler in 1964. Recently in 2011, Fiedler and Markham characterized the sequence of diagonal entries of the combined matrix $C(A)$ for any totally positive matrix A when the size is 3. For this case, we characterize totally negative matrices and we find necessary and sufficient conditions for the sequence of diagonal entries of $C(A)$, in both cases, symmetric and nonsymmetric. (Received September 21, 2018)

1145-VQ-1475 **Thomas R Cameron*** (thcameron@davidson.edu). *Householder Sets and their Application to the Polynomial Eigenvalue Problem.* Preliminary report.

In 1964, Alston S. Householder presented an elegant norm derivation of the Gershgorin set of a matrix. Then, in his book titled *Geršgorin and His Circles*, Richard S. Varga reviewed this derivation and dubbed the normed defined sets used as Householder sets.

In this talk, we present a generalization of Householder sets for matrix polynomials. These sets have many wonderful properties, including being inclusion sets for the eigenvalues of a matrix polynomial. With the aid of beautiful pictures, we outline our systematic study of the properties of these sets and their connection to the Geršgorin set of a matrix polynomial. (Received September 22, 2018)

1145-VQ-1589 **Rachid Marsli*** (rmarsliz@kfupm.edu.sa). *New sights on the location theory of matrix eigenvalues.*

A new concept, called "Gershgorin disc of the second type", has been recently introduced by Frank J. Hall and Rachid Marsli in their article titled "On the Location of Eigenvalues of Real Matrices". (Electronic Journal of Linear Algebra, 2017). The author gives the definition of the concept and discusses how it was obtained and how it can be used to improve the location of eigenvalues of some important type of matrices such as real stochastic and Laplacian matrices. (Received September 23, 2018)

1145-VQ-1889 **Laney Bowden*** (lbowden1@rams.colostate.edu), **Julia Balukonis**, **Fatme Hourani**, **Ellie Lochner** and **John Clifford**. *The Numerical Range of a Composition Operator on the Hardy Space.*

For a bounded operator T on a Hilbert Space $\mathbb{H}$, the numerical range of T is the subset $W(T)$ of $\mathbb{C}$ given by $W(T) = \{< Tx, x > \, : \, ||x|| = 1\}$. We study the numerical range of the composition operator, C_A, on the Hardy space $H^2(\mathbb{B}_n)$ where A is an $n \times n$ matrix that is a self-map of the unit ball. We show the set of homogeneous holomorphic polynomials of degree k is a reducing subspace for C_A; it follows that $W(A) \subseteq W(C_A)$. In the special case where A is a weighted shift, $W(C_A) = \text{convex hull}(W(A) \cup \{1\})$. We completely characterize the numerical range of the operator when A is unitarily similar to a Jordan-normal form that maps the ball to the ball by decomposing our operator into the direct sum of shifts and normal operators. (Received September 24, 2018)

1145-VQ-1896 **Samir Raouafi*** (szr0067@auburn.edu), Department of Mathematics and Statistics, Auburn University, 221 Parker Hall, Auburn, AL 36849. *Some Extension of the Kreiss Matrix Theorem.*

Let A be a matrix with spectrum $\sigma(A)$. The Kreiss Matrix Theorem, a well-known fact in applied matrix analysis, gives estimates of upper bounds for $\|A^n\|$ if $\sigma(A)$ is in the unit disc, or for $\|e^{tA}\|$ if $\sigma(A)$ is in the left-half plane based on the resolvent norm. In this talk, we shall discuss some extension of this celebrated theorem to arbitrary analytic functions on general complex domains. (Received September 24, 2018)

1145-VQ-2180 **Ivko M Dimitric*** (ivko@psu.edu), 2201 University Drive, Lemont Furnace, PA 15456. *Multivariable n-step maps.* Preliminary report.

An n-step map is a map f whose nth iterative power is the identity, $f^{\circ n}(x) = x$, hence, such a map is an iterative nth root of the identity map. While there is an extensive literature on n-step maps of one (real) variable, the study of n-step maps of $\mathbb{R}^k$ is not as well developed, outside the framework of matrix theory. We provide some examples of and results on n-step maps of 2 and more variables. In particular, n-step affinely linear maps of $\mathbb{R}^2$ are classified for $n = 2, 3$, and 4. Also, some classification of n-step Cremona transformations of the plane are obtained. (Received September 25, 2018)

1145-VQ-2816 **Ghanshyam Bhatt*** (gbhatt@tnstate.edu), 3500 John B Boulvard, Nashville, TN 37221. *The incoherent matrices and their applications.*

The matrices with low mutual column coherence have application in signal processing. The frames are linearly dependent spanning set, that for a fat matrix. These fat matrices with low coherence have applications but are difficult to construct. We provide a simple construction and talk about their application in compressed sesing. (Received September 25, 2018)

1145-VQ-2858 **Christina Pospisil*** (pospisil.christina@gmx.de), Department of Mathematics, University of Massachusetts Boston, 100 William T. Morrissey Boulevard, Boston, MA 02125, and **Eric L Grinberg**. *Generalization Theory of Linear Algebra.*

We present an algorithm for multiplying and adding matrices regardless of dimensions via an embedding. We also investigate an equivalent embedding for a general determinant theory. In future work we will explore applications to physics and other natural sciences. (Received September 25, 2018)

1145-VQ-2994 **Olivia R. Vasquez*** (vasquezol@cwu.edu), **Amadou Y. Bah** and **Jackson Abascal**. *A Non-iterative Parallelizable Eigenbasis Algorithm for Johnson Graphs.* Preliminary report.

We present a new $O\left(k^2\binom{n}{k}^2\right)$ method for generating an orthonormal basis of eigenvectors for the Johnson graph $J(n,k)$. Unlike standard methods for computing a full eigenbasis of sparse symmetric matrices, the algorithm presented here is non-iterative, and produces exact results under an infinite-precision computation model. In addition, our method is highly parallelizable; given access to unlimited parallel processors, the eigenbasis can be constructed in only $O(n)$ time given n and k. We also present a highly parallelizable algorithm for computing projections onto the eigenspaces of $J(n,k)$. Such an algorithm is useful for spectral analysis, in which these eigenspaces serve as spaces of ordered effects for data modeled on subsets of $\{1, \ldots, n\}$ of a fixed size k. (Received September 26, 2018)

Logic and Foundations

1145-VR-939 **Lavinia Corina Ciungu*** (lavinia-ciungu@uiowa.edu), 1575 Foster Rd, Iowa City, IA 52245. *On involutive filters of pseudo-hoops.* Preliminary report.

The aim of this presentation is to introduce the notion of involutive filters of pseudo-hoops, and to emphasize their role in the probability theory on these structures. A characterization of involutive pseudo-hoops is given and their properties are investigated. We also give characterizations of involutive filters of a bounded pseudo-hoop and we prove that in the case of bounded Wajsberg pseudo-hoops the notions of commutative and involutive filters coincide. One of main results consists of proving that a normal filter F of a bounded pseudo-hoop A is involutive if and only if A/F is an involutive pseudo-hoop. It is also proved that any Boolean filter of a bounded Wajsberg pseudo-hoop is involutive. The notions of state operators and state-morphism operators on pseudo-hoops are introduced and the relationship between these operators are investigated. For a bounded Wajsberg pseudo-hoop we prove that the kernel of any state operator is an involutive filter.

Keywords: Pseudo-hoop, Wajsberg pseudo-hoop, Archimedean pseudo-hoop, involutive filter, commutative filter, state operator, state-morphism

AMS Mathematics Subject Classification (2000): 03G25, 06F05, 06F35
(Received September 17, 2018)

1145-VR-1678 **Phillip Michael Bressie*** (pmbressie@ksu.edu). *On Tautological Globular Operads.*

A nonstandard description of the construction of the classical tautological, or endomorphism, operad $taut(X)$ on a set X will first be given. Then a description of how globular operads are a strict generalization of classical operads will be provided. From this perspective a description will be given of the analogous construction for the tautological globular operad $Taut(\mathcal{X})$ on a globular set $\mathcal{X}$ by way of describing the internal hom functor for the monoidal category **Coll**, of collections and collection homomorphisms, with respect to the monoidal composition tensor product used to define globular operads. (Received September 23, 2018)

1145-VR-2907 **Timothy Trujillo*** (trujillo@shsu.edu), 1905 University Ave, Huntsville, TX 77340. *Condorcet's paradox and ultrafilters.* Preliminary report.

Two of the most iconic results of voting theory are Condorcet's paradox and Arrow's impossibility theorem. The purpose of this talk is to place these results in the context of Ramsey theory - the study of collections of sets that are partition regular. We give a new short proof of Arrow's theorem which uses Condorcet's paradox. Along the way the notion of an ultrafilter plays a prominent role. (Received September 25, 2018)

1145-VR-2909 **Mojtaba Moniri*** (mojtaba.moniri@normandale.edu). *On definable completeness for ordered fields.*

Regarding definable Dedekind completeness for ordered fields, it is known to be successively weakened if we just required nonexistence of definable *regular* gaps (of zero distance to their complement) and then disallowing parameters. Reducing in the opposite order, at least one side is sharp: there are 0-definably complete ordered fields which are not real closed. The proof uses a lemma by L. van den Dries. (Received September 25, 2018)

Number Theory

1145-VS-55 **Jay L Schiffman*** (schiffman@rowan.edu). *Exploring Rudolph Ordrejka's Prime Magic Square of Order Three.* Preliminary report.

Rudolph Ordrejka (1928-2001) discovered a prime magic square of order three consisting of nine prime entries. The entries in row one are respectively 17, 89 and 71. In row two, the respective entries are 113, 59 and 5 while in row three, the entries are respectively 47, 29 and 101. In this paper, we will determine the smallest constant required to add to each of the entries to obtain a new magic square consisting of 0-8 primes respectively and show the impossibility of obtaining a magic square consisting of all nine entries being prime in this manner. In addition, we determine the case where constants are added to obtain no prime entries. This latter problem takes on two flavors which will be discussed. (Received July 11, 2018)

1145-VS-96 **Satvik U Kaushik*** (`satvik.u.kaushik@gmail.com`), Flat No 1266, Anantha Buildings,4th Main, 1st block, Bangalore, 560097, India. *A note on Armstrong numbers.*

In this note we provide a new method of proof for identifying the Armstrong numbers and also we discuss the patterns in their generalizations. (Received July 29, 2018)

1145-VS-113 **Juan G Orozco*** (`jgorozco@gmail.com`), 4101 Aplomado Falcon Cove, Austin, TX 78738. *Algorithmic approach to Goldbach and Twin Primes Conjectures.*

We present a greedy elimination algorithm that generates lower bounds on Twin Prime and Goldbach pair counts.

By incorporating Mertens' third theorem and the twin prime constant, we generate a lower-bound closed formula on pair counts for both conjectures. The algorithm can also be applied to Germain primes, Cousin Primes, and other prime related conjectures that result in an Euler product like $\prod\left(1-\frac{a}{p}\right)$. (Received August 02, 2018)

1145-VS-251 **Alfred S Beebe*** (`axbeebe@salisbury.edu`), Department of Mathematics & Computer Science, Salisbury University, Salisbury, MD 21801. *Pythagorean Triples.* Preliminary report.

New formulas for all reduced Pythagorean triples are derived in the spirit of Dickson's Method, using the differences between the hypotenuse and the legs. Every pair of relatively prime natural numbers F, G, with G odd, corresponds to a unique reduced Pythagorean triple a, b, c, $(a^2 + b^2 = c^2)$ given by $a = G^2 + 2FG, b = 2F^2 + 2FG, c = G^2 + F^2 + 2FG$. Classical $3, 4, 5$ divisibility properties of the sides are examined and an alternate proof of Hall's generation of all reduced Pythagorean triples from $(3, 4, 5)$ is given using these formulas. (Received August 24, 2018)

1145-VS-280 **Philip K Hotchkiss*** (`photchkiss@westfield.ma.edu`), Department of Mathematics, Westfield State University, Westfield, MA 01085. *Generalized Rascal Triangles.*

In 2010, three middle school students, Alif Anggaro, Eddy, Liu and Angus, Tulloch introduced the *Rascal Triangle*,

$$\begin{array}{ccccccccccc} & & & & & 1 & & & & & \\ & & & & 1 & & 1 & & & & \\ & & & 1 & & 2 & & 1 & & & \\ & & 1 & & 3 & & 3 & & 1 & & \\ & 1 & & 4 & & 5 & & 4 & & 1 & \\ 1 & & 5 & & 7 & & 7 & & 5 & & 1 \\ & & & & & \vdots & & & & & \end{array}$$

a variation of Pascal's Triangle. Adopting the notation from Anggaro, Liu and Tulloch, the entries in Pascal's Triangle can be determined by the well known formula, **South** = **East** + **West**. To construct the Rascal Triangle, Anggaro, Liu and Tulloch used the formula

$$\mathbf{South} = \frac{\mathbf{East} \times \mathbf{West} + \mathbf{1}}{\mathbf{North}}.$$

In 2015, students in a Mathematics for Liberal Arts (MLA) class taught by my colleague, Julian Fleron, discovered that the formula

$$\mathbf{South} = \mathbf{East} + \mathbf{West} + \mathbf{1} - \mathbf{North}$$

also generates the Rascal Triangle.

In this talk we will discuss examples and properties of number triangles (many of which were discovered by our MLA students) that can be generated by a variation of one of these formulas. (Received August 28, 2018)

1145-VS-283 **Maria Fox*** (`maria.fox@bc.edu`). *The* GL_4 *Rapoport-Zink Space.* Preliminary report.

The GL_{2n} Rapoport-Zink space is a moduli space of supersingular p-divisible groups of dimension n and height $2n$, with a quasi-isogeny to a fixed base point. After the GL_2 Rapoport-Zink space, which is zero-dimensional, the GL_4 Rapoport-Zink space has the most fundamental moduli description, yet relatively little of its specific geometry has been explored. We give a full description of the geometry of the GL_4 Rapoport-Zink space, including the connected components, irreducible components, and intersection behavior of the irreducible components. As an application of the main result, we also give a description of the supersingular locus of the Shimura variety for the group $\mathrm{GU}(2, 2)$ over a prime split in the corresponding imaginary quadratic field. (Received August 28, 2018)

1145-VS-341 **Borys Kadets*** (bkadets@mit.edu). *Large arboreal Galois representations.*

Given a field K, a polynomial $f \in K[x]$ of degree d, and a suitable element $t \in K$, the set of preimages of t under the iterates $f^{\circ n}$ carries a natural structure of a complete rooted d-ary tree T_∞. The Galois action on the roots of $f^{\circ n}(x) - t$ gives rise to a homomorhism $\phi : G_K \to \mathrm{Aut}(T_\infty)$ known as the *arboreal Galois representation* attached to f and t. Arboreal representation is an arithmetic dynamics analogue of the Tate module. We study conditions under which the representation ϕ is surjective. For d even we prove a criterion relating the surjectivity of ϕ with the arithmetic of the critical orbit of f. When $d \geqslant 20$ is even we use this criterion to exhibit examples of polynomials with maximal Galois action on the preimage tree, partially affirming a conjecture of Odoni (simultaneously and independently of our work two papers on Odoni's conjecture appeared; the full conjecture was proved by Joel Specter; Robert Benedetto and Jamie Juul proved the conjecture for most number fields). We also study the case of $K = F(t)$ and $f \in F[x]$ in which the corresponding Galois groups are the monodromy groups of ramified covers $f^{\circ n} : \mathbb{P}^1_F \to \mathbb{P}^1_F$. (Received September 02, 2018)

1145-VS-676 **Ralph P Grimaldi*** (grimaldi@rose-hulman.edu). *Ternary Sequences and the Pell Numbers.*

For $n \geq 1$ let a_n count the number of sequences $s_1, s_2, s_3, \ldots, s_n$ where (i) $s_1 = 0$; (ii) $s_i \in \{0, 1, 2\}$, for $2 \leq i \leq n$; and, (iii) $|s_i - s_{i-1}| \leq 1$, for $2 \leq i \leq n$. Then $a_1 = 1$, $a_2 = 2$, $a_3 = 5$, $a_4 = 12$, and $a_5 = 29$. In general, for $n \geq 3, a_n = 2a_{n-1} + a_{n-2}$, and a_n equals P_n, the nth Pell number.

For these P_n sequences of length n, we count (i) the number of occurrences of each of the symbols $0, 1, 2$; (ii) the number of times each of the symbols $0, 1, 2$ occur in a given position; (iii) the number of levels, rises and descents that occur within the sequences; (iv) the number of runs that occur within the sequences; (v) the sum of all the sequences considered as base 3 integers; (vi) the number of inversions and coinversions for the sequences; and, (vii) the sum of the major indices for the sequences.

Finally, from the numbers of occurrences of each symbol in each of the n possible locations for the sequences of length n, we find an example of the hexagonal property. (Received September 12, 2018)

1145-VS-973 **Joshua Zelinsky*** (zelinsky@gmail.com), 811 Clark Ave, Apt 6, Ames, IA 50010. *On the total number of prime factors of an odd perfect number.*

Let N be an odd perfect number. Ochem and Rao showed that if $\omega(N)$ is the number of distinct prime factors of N, and that $\Omega(N)$ is the number of prime factors of N counting multiplicity then $\Omega(N)$ is at least than $18\omega(N) - 31)/7$. We discuss improvements of this inequality, as well as related open problems concerning the behavior of cyclotomic polynomials. (Received September 17, 2018)

1145-VS-1230 **Timothy B Flowers*** (flowers@iup.edu). *Pondering a Putnam problem on partitions.*

Problem B2 of the 44th Putnam Exam in 1983 can be restated in terms of integer partitions as follows: find an expression to count the number of binary partitions of n wherein each part is used at most 3 times. It is natural to extend this question to partitions into powers of m, or m-ary partitions. We will show how generating functions motivate a generalization of the Putnam problem to enumerating a two-parameter family of m-ary integer partitions, $b^*_{m,j}(n)$. We then use the generating functions and a bijection to give an identity between $b^*_{m,j}(n)$ and another family of m-ary partitions. (Received September 20, 2018)

1145-VS-1334 **James Hammer** and **Joshua Harrington*** (joshua.harrington@cedarcrest.edu), 100 College Drive, Allentown, PA 18104, and **Kristina Marotta**. *Odd Coverings of Subsets of the Integers.*

Let S be a set of integers. A covering system of S is a finite collection of congruences such that every integer in the set satisfies at least one of the congruences in the collection. An odd covering of S is a covering system such that all moduli are distinct, odd, and greater than 1. Filaseta and Harvey recently investigated the existence of odd coverings of certain subsets of the integers. In this talk we extend this investigation and address a question of Filaseta and Harvey. (Received September 21, 2018)

1145-VS-1397 **Tom Koshy** (zhengaoo@yahoo.com) and **Zhenguang Gao***, 100 State Street, Framingham, MA 01772. *Polynomial Extensions of a Putnam Delight.*

Fibonacci, Lucas, Pell, and Pell-Lucas polynomials are a fertile ground for imagination and creativity. They offer boundless exploratory opportunities for Fibonacci and Lucas enthusiasts. This article features one such activity; it extends a delightful Fibonacci problem that appeared in the 68th William Putnam Mathematical Competition to Fibonacci, Lucas, Pell, and Pell-Lucas polynomials.

(Received September 21, 2018)

1145-VS-1637 **Lisa Kaylor*** (lkaylor@wesleyan.edu). *Quaternary Lattices of Discriminant 4p.*
Let L be a quaternary even positive definite integral lattice and p a prime. It was shown by Hsia and Hung that the degree two theta series of the classes of L with nontrivial root system are linearly independent when $dL = p$ and $p \equiv 1 \bmod 4$. We consider the situation $p > 13$ and $dL = 4p$ where $p \equiv 3 \bmod 4$. There are two genera of lattices in this case, which are considered separately. We show that the degree two theta series of the indecomposable classes with nontrivial orthogonal group within each genus are linearly independent. (Received September 25, 2018)

1145-VS-1921 **Justin Moccaldi*** (justinmoccaldi@gmail.com) and **Roman Wong**. *An Ancient Chinese Problem and Two Sequences.*
In their article that appears in the 2018 May issue of CMJ, Ezra Brown and Matthew Crawford showed that the solution to a generalization to the ancient Chinese problem *Five Families Around a Well* actually involves the derangement sequence $d(n) = n! \sum_{k=0}^{n} \frac{(-1)^k}{k!}$ and the sequence $w(n) = n! + (-1)^n$. They also observed that for all $n < 10^5, gcd(d(n), w(n)) = 1$ except when $n = 9$. We explore this oddity further and use Python to extend the coprime property beyond $n = 10^5$. (Received September 24, 2018)

1145-VS-2221 **Byungchul Cha**, **Adam Claman**, **Joshua Harrington**, **Ziyu Liu**, **Barbara Maldonado**, **Alexander Miller**, **Ann Palma**, **Tony W. H. Wong** and **Hongkwon Yi*** (321_vin@berkeley.edu), 2083 Delaware St, Berkeley, CA 94709. *Extensions on Conway's Wizard Problem.* Preliminary report.
Conway's Wizard Problem can be mathematically summarized in the following way. Given a sum s and a product p, do there exist two n-partitions of s into distinct multisets such that both multisets have the same product p? If there are, we call s sum-admissible and p product-admissible. From this context, we define the following two functions. (1) $f(s)$ = number of n values such that s is sum-admissible. (2) $g(s)$ = number of p values such that s is sum-admissible; the case $g(s) = 1$ is precisely what we need to solve Conway's problem. We derive and prove the formula for $f(s)$, and determine the value of s that gives $g(s) = 1$. We further tackle the question: What would happen if we fix p instead of s? Fixing the product as $p = m^j$, where m is a prime, we are led to study a special polynomial $f(x) = (x - m)(x - 1)^2 g(x)$ with $g(x) \in \mathbb{Z}[x]$. We subsequently prove that $p = m^j$ is product-admissible if and only if $j \geq 2m + 4$. (Received September 25, 2018)

1145-VS-2225 **Theresa Baren**, **James Hammer**, **Joshua Harrington**, **Ziyu Liu**, **Sean Rainville**, **Melea Roman*** (mrroman@cedarcrest.edu) and **Hongkwon Yi** (321_vin@berkeley.edu), 2083 Delaware St, Berkeley, CA 94709. *Sums of Two Polygonal Numbers in Rings.* Preliminary report.
In 1640, Fermat wrote a letter to Mersenne regarding a question about when a natural number can be expressed as a sum of two squares. Thanks to Euler, we fully understand the answer to this question in $\mathbb{Z}$. April 2nd 2014, Harrington, Jones, and Lamarche published a paper that explains sufficient and necessary set of conditions for when every element in the ring $\mathbb{Z}_n$ can be expressed as a sum of two squares. Our research motivates from the realization that square numbers are just a specific type of polygonal number; namely 4-gonal numbers. We carried out our research with the goal of finding the sufficient and necessary set of conditions for when every element in $\mathbb{Z}_{n \geq 2}$ can be expressed as a sum of two s-gonal numbers while (1) allowing and (2) not allowing zero as a summand. Most of the work was first done in $\mathbb{Z}_{p^\alpha}$, with prime p, using tools in algebraic number theory such as properties of quadratic residues; modular arithmetic; and also combinatorics. Then by applying the Chinese Remainder Theorem, we were able to geneate relevant conditions for $\mathbb{Z}_n$. (Received September 25, 2018)

1145-VS-2310 **Erhan Gürel*** (egurel@metu.edu.tr), Middle East Technical University, N.C.C., TZ-32, Güzelyurt, Mersin 10, Turkey. *Products of values of certain quadratics forms.*
We prove that for a fixed integer q, there exits an integer N such that the product $\Omega_q^2(n, D) = (1^2 + Dq^2)(2^2 + Dq^2) \ldots (n^2 + Dq^2)$ is never a square for $D = 2, 3$ and 7 when $n > N$.

In particular, we can ask that how often does the product of consecutive values of a polynomial become a power? In 2008, J. Cilleruelo proved that $\Omega_1^2(n, 1)$ is a square only for $n = 3$. After his work, many similar results were given for different polynomials as in [4],[5],[6],[7] and [8]. These type of products are studied for quadratic form $x^2 + y^2$ in [7] and for the cubic form $x^3 + y^3$ recently in [8]. In this work, we will study the product of consecutive values of the binary quadratic forms such as $x^2 + Dy^2$ for $D = 2$ and 3. (Received September 25, 2018)

1145-VS-2338 **David Petrie Moulton*** (dpmoulton@gmail.com). *An entropy-derived lower bound for the size of a set whose subset sums include the first n powers of 2.*

The *subset-sum rank* of a set S of numbers is the smallest size of a set B such that each element of S is the sum of some subset of B. The subset-sum rank of $\{1, 2, 4, 8, 16\}$, the set of the first 5 powers of 2, is 4, since each element is a sum of a subset of the 4-set $\{1, -5, 7, 9\}$.

I use results on entropies of discrete random variables to improve the known lower bound on the subset-sum rank of the set of the first n powers of 2 to

$$\frac{2n}{\log_2(\pi e n/2)}.$$

(Received September 25, 2018)

1145-VS-2415 **Jeremy Nathan Glasner*** (glasnerjn@jay.washjeff.edu). *Circles and Squares: A Look at Gauss's Circle Problem.*

Some natural numbers can be represented as the sum of two squares of the form $n = a^2 + b^2$ for $a, b \in \mathbb{Z}$. For example, $5 = 2^2 + 1^2$ whereas 3 cannot be represented as the sum of two squares. Let $r(n)$ be the number of ordered representations of n and let $N_2(n) = \sum_{k=0}^{n} r(k)$. Gauss showed that $\lim_{n\to\infty} \frac{N_2(n)}{n} = \pi$. This presentation will go over some properties of these representations in respect to number theory as well as a geometric proof of Gauss's problem. Additionally, we will see current research on reducing the error associated with this proof as well as extensions of this problem into three dimensions. (Received September 25, 2018)

1145-VS-2526 **Sam Kottler*** (sam.kottler@coloradocollege.edu). *Parameters of locally recoverable codes with multiple recovery sets.* Preliminary report.

A code is a set of vectors, called codewords. Usually we look at codes that actually form vector spaces. Codes can be used for redundancy and error correction, when storing or transferring data. One way to do this is with locally recoverable codes (LRCs) in which any position of a codeword can be recovered from a fixed subset of other positions, called a recovery set. An interesting problem is called the availability problem, which addresses constructing LRCs with multiple disjoint recovery sets for each position. This project studied minimum distance and other parameters of families of such codes constructed from curves over finite fields. (Received September 25, 2018)

1145-VS-2767 **David Chang Luo*** (david.luo@emory.edu), MSC 161201 Emory University Main, 1762 Clifton Road, Atlanta, GA 30322. *Generalizations of the Abundancy Index and Outlaws.*

The *abundancy index* of a positive integer n is the ratio of the sum of its divisors to itself; the abundancy index of n is two if and only if n is perfect. An *abundancy outlaw* is a rational number greater than one that fails to be the abundancy index of any positive integer. We generalize previous results about abundancy outlaws by defining a two variable abundancy index function as $I(x,n)\colon \mathbb{Z}^+ \times \mathbb{Z}^+ \to \mathbb{Q}$ where $I(x,n) = \frac{\sum_{d|n} d^x}{n^x}$. By exploring upper bound properties of the abundancy index, we construct sufficient conditions for rationals greater than one that fail to be in the image of $I(x,n)$. Finally, we apply these results to observe properties of *perfect* numbers under the two variable abundancy index. (Received September 25, 2018)

1145-VS-2854 **Alexander Carney*** (acarney@berkeley.edu). *The Hodge-index theorem for arithmetic intersections over function fields.*

The Hodge-index theorem states that the intersection pairing on an algebraic surface has signature $+1, -1, \ldots, -1$. This is generalized by Faltings and Hriljac to arithmetic surfaces using Arakelov Theory, and to higher dimensional arithmetic intersections over number fields by Moriwaki and Yuan–Zhang. In this paper, we extend these results to the context of function fields, proving the Hodge-index theorem for adelic metrized line bundles on projective varieties of arbitrary dimension over one-dimensional function fields. As an application, we also prove a rigidity theorem for preperiodic points of polarized algebraic dynamical systems over global function fields. (Received September 25, 2018)

Probability and Statistics

1145-VT-166 **Gerald Y. Agbegha*** (gagbegha@ggc.edu), Lawrenceville, GA 30043, **Anthony Thomas** (athomas1@ggc.edu), Lawrenceville, GA 30043, **Adrian Heinz** (aheinz@ggc.edu), Lawrenceville, GA 30043, and **Junkoo Park** (jpark15@ggc.edu), Lawrenceville, GA 30043. *A discrete Distribution on the Unit Interval and Its Application to Simulation of Sampling Distributions.* Preliminary report.

We introduce a discrete distribution on the unit interval. Under equiprobable assumptions, the distribution is asymptotically uniform. The remarkable thing about this distribution is that it enables us to develop fanned-out distributions of any desired shape over any interval on the real line. An immediate application of this distribution is its use in generating populations of desired shape on any interval of the real line for the purpose of simulating the sampling process. Such simulations help to elucidate concepts related to sampling distributions and in particular the central limit theorem. (Received August 14, 2018)

1145-VT-261 **Duha Hamed*** (math@winthrop.edu), Department of Mathematics, 142 Bancroft Hall, Rock Hill, SC 29733, and **Felix Famoye** and **Carl Lee**. *On Families of Generalized Pareto Distributions: Properties and Applications.* Preliminary report.

In this talk, we introduce some new families of generalized Pareto distributions using the T-$R\{Y\}$ framework. These families of distributions are named T-$Pareto\{Y\}$ families, and they arise from the quantile functions of exponential, log-logistic, logistic, extreme value, Cauchy and Weibull distributions. The shapes of these T-Pareto families can be unimodal or bimodal, skewed to the left or skewed to the right with heavy tail. Some general properties of the T-$Pareto\{Y\}$ family are investigated and these include the moments, modes, mean deviations from the mean and from the median, and Shannon entropy. Several new generalized Pareto distributions are also discussed. Four real data sets from engineering, biomedical and social science are analyzed to demonstrate the flexibility and usefulness of the T-$Pareto\{Y\}$ families of distributions. (Received August 26, 2018)

1145-VT-448 **Nathaniel Adjei Adu*** (nadu@knights.ucf.edu), Department of Mathematics, University of Central Florida, 4393 Andromeda Loop N, Orlando, FL 32816. *Unit Roots Test: Spatial Model With Long Memory Errors.*

A test for unit roots in the autoregressive model $Y_{ij} = \alpha Y_{i-1,j} + \beta Y_{i,j-1} - \alpha\beta Y_{i-1,j-1} + \epsilon_{ij}$ is developed whenever the error structure is assumed to have long range dependence. Whenever $\alpha = \beta = 1$, the limiting distribution of the sequence of normalized Fourier coefficients of the $Y-$ process is shown to be a function of a two parameter fractional Brownian motion process on $[0,1] \times [0,1]$. This result is used to to find the limiting distribution of the periodogram ordinate of the $Y-$ process under the null hypothesis that $\alpha = \beta = 1$ (Received September 06, 2018)

1145-VT-730 **Noah N. Williams*** (noah.williams@colorado.edu), Department of Mathematics, University of Colorado Boulder, 2300 Colorado Avenue, 395 UCB, Boulder, CO 80309-0395, and **Sean O'Rourke** (sean.d.orourke@colorado.edu). *Pairing between Zeros and Critical Points of Polynomials with Random Roots.*

We study the pairing between zeros and critical points of degree n random polynomials whose roots are independently chosen according to a distribution on the complex plane. In particular, we locate the nearest critical point to a given root and determine its limiting fluctuations. We also generalize to situations where the roots are not independent and use the Wasserstein metric to establish that the typical distance between a root-and-critical-point pair is on the order of $1/n$, up to logarithmic corrections. (Received September 13, 2018)

1145-VT-784 **Yan Dai*** (ydai@math.arizona.edu), Department of Mathematics, The University of Arizona, 617 N. Santa Rita Ave, Tucson, AZ 85721. *Mirror Model on the Square Lattice.*

We consider a random walk model on the two-dimensional square lattice, starts at the origin and only turns left and right at each step with equal probability. Going straight and revisiting a bound that has been visited before are not allowed. In this model, turning left or right at each step can be viewed as a walk deflecting by a left or right mirror on each vertex. Therefore, we refer to this random walk model as a mirror model. Here, we study the nature of the mirror model process on the square lattice and investigate its relation to percolation process. We believe that the scaling limit of the mirror model on the square lattice in a bounded domain between two boundary points is the chordal Schramm-Loewner evolution with $\kappa = 6$ (SLE_6). We test this conjecture and find a good agreement with predictions of chordal SLE_6. (Received September 14, 2018)

1145-VT-834 **Jenkin Tsui*** (jenkin.tsui@yale.edu), 73 Whitney Ave, Apt 1, New Haven, CT 06510.
Measuring Statistical Evidence Using Relative Belief.

Statistics is comprised of data collection and statistical inference. Given measurements based on a subset of a population, we believe this data contains evidence concerning questions we are interested in answering. Belief is measured by probability and when there is a change in belief, this is due to evidence. Relative belief is one of the few statistical inference theories that explicitly defines how we should measure statistical evidence. In my talk, I will discuss the reasons we need statistics, the ingredients we need to setup a statistical problem and the importance of checking the ingredients against the data. I will then introduce relative belief ratio as the measure of statistical evidence as well as measures of strength and accuracy. I will discuss the inferences based on Michael Evan (2016)'s relative belief ratios including hypothesis assessment, estimation, and prediction inferences. At last, I will talk about the issue of bias in statistical analyses as illustrated via the Jeffrey-Lindley's paradox. (Received September 15, 2018)

1145-VT-872 **Yujia Ding*** (yujia.ding@cgu.edu) and **Qidi Peng** (qidi.peng@cgu.edu). *Series Representation of Jointly $S\alpha S$ Distributions via Generalized Covariations.*

We introduce a new measure of dependency between coordinates of a symmetric α-stable random vector that we call the generalized covariation. We show that these covariations can be represented via a new type of fractional derivative and can be used to fully characterize the joint distribution of bi-variate symmetric α-stable variables. (Received September 16, 2018)

1145-VT-935 **Lida Ahmadi*** (lahmadi@purdue.edu). *Asymptotic Results on the k-th Subword Complexity of Strings.*

The Subword Complexity of a character string refers to the number of distinct substrings of any length that occur in the string. The k-th subword complexity in particular, is the number of distinct substrings of length k in the string . We evaluate the first and the second factorial moment of the k-th Subword Complexity over the binary alphabet. We first take a combinatorial approach to derive a probability generating function in the Bernoulli model for the number of occurrences of patterns in strings of finite length. We then investigate the asymptotic behavior of the expected value and the second factorial moment under a certain assumption for the length of substrings. The Methodology that we use involves complex analysis, analytic poissonization and depoissonization, the Mellin transform, and the saddle point analysis. (Received September 17, 2018)

1145-VT-1002 **Farida Parvez Barbhuiya*** (faridaparvezb@gmail.com), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, WestBengal 721302, India, and **Umesh Chandra Gupta**. *Discrete-time queue with batch renewal input and random serving capacity rule.*

We consider a discrete-time infinite buffer queue in which customers arrive in batches of random size such that the inter-arrival times are arbitrarily distributed. The customers are served in batches by a single server according to random serving capacity rule and the service times are geometrically distributed. We model the system via supplementary variable technique and further use displacement operator method to solve non-homogeneous difference equation. The analysis done using these methods results in an explicit expression of steady-state queue-length distribution at pre-arrival and arbitrary epochs simultaneously, in terms of roots of the underlying characteristic equation. Our approach enables one to estimate the asymptotic distribution at pre-arrival epoch by a unique largest root of the characteristic equation lying inside the unit circle. With the help of few numerical results, we demonstrate that the methodology developed throughout the work is computationally tractable and is suitable for light-tailed inter-arrival distributions and can also be extended to heavy-tailed inter-arrival distributions. The model considered here generalizes the previous work done in the literature in many ways. (Received September 18, 2018)

1145-VT-1048 **Joseph Anderson*** (jtanderson@salisbury.edu), Mathematics and Computer Science, 1101 Camden Ave., Salisbury, MD 21801. *Robust Signal Processing with the Convex Floating Body.* Preliminary report.

We present new algorithmic techniques for signal processing in the presence of heavy-tailed noise. Considering the problem of Independent Component Analysis, we consider the use of a geometric structure called the "Convex Floating Body" as an algorithmic surrogate for the distribution of a signal. This structure (defined for any non-degenerate distribution) is an approach to generalize statistical quantiles for higher dimensions, and enables one to capture important notions of data such as covariance, kurtosis, and higher-order moments. We provide provably efficient estimation techniques for the convex floating body in natural conditions, and show that we can solve the Independent Component Analysis (ICA) problem when the signals come from heavy-tailed distributions, even the Cauchy distribution. This extends the state-of-the-art which requires the source signals to have $1 + \epsilon$ finite moments.

We then discuss further applications for other robust-estimation settings, and how other notions of statistical depth functions can be used. (Received September 18, 2018)

1145-VT-1049 **Grant L Innerst*** (grant_innerst@baylor.edu), 1816B S 12th St., Waco, TX 76706, and **David J Kahle** (david_kahle@baylor.edu). *An Algebraic Approach to Minimum Chi-Square Estimation.* Preliminary report.

The field of algebraic statistics arose from the realization that many statistical questions exhibit an algebraic structure. Leveraging this algebraic structure allows for the use algebraic theory and powerful, often niche, software from the algebraic community to find solutions which were previous unattainable. Minimum chi-square estimation, a statistical estimation paradigm alternative to maximum likelihood estimation, exhibits such an algebraic structure. The computation of a minimum chi-square estimator involves an optimization problem with rich algebraic structure: a rational objective function over an algebraic feasibility region. This structure can be exploited with tools from the algebraic geometry community. Bertini, a highly specialized, state-of-the-art software package for nonlinear algebra, is designed to determine the solution sets of systems of nonlinear polynomial equations. Preliminary results show that the implementation of this estimation technique using algebraic methods yields expected results while providing enhanced reliability and adding the ability to solve more complicated problems. (Received September 18, 2018)

1145-VT-1075 **Xiaonan Zhu*** (xzhu@nmsu.edu), New Mexico State University, Department 3MB, PO Box 30001, Las Cruces, NM 88003-1274, and **Tonghui Wang** (twang@nmsu.edu), New Mexico State University, PO Box 30001, Las Cruces, NM 88003-1274. *Multivariate generalizations of F-G-M copulas.*

In this talk, several general methods to construct multivariate copulas are presented, which are multivariate generalizations of F-G-M copulas and some existing constructions of bivariate copulas. Dependence properties of new constructions are explored and examples are given for illustration of our results. (Received September 20, 2018)

1145-VT-1127 **Na Zhang*** (zhangn4@mail.uc.edu), 45220, and **Lucas Reding** and **Magda Peligrad**. *On the quenched CLT for stationary random fields under projective criteria.*

Motivated by random evolutions which do not start from equilibrium, in a recent work, Peligrad and Volný (2018) showed that the quenched CLT (central limit theorem) holds for ortho-martingale random fields. In this paper, we study the quenched CLT for a class of random fields larger than the ortho-martingales. To get the results, we impose sufficient conditions in terms of projective criteria under which the partial sums of a stationary random field admit an ortho-martingale approximation. More precisely, the sufficient conditions are of the Hannan projective type. As applications, we establish quenched CLT for linear and nonlinear random fields with independent innovations. (Received September 19, 2018)

1145-VT-1175 **David A Nash*** (nashd@lemoyne.edu), 1419 Salt Springs Rd, Syracuse, NY 13214, and **Shaun Ceci**. *Markov Plays Prime Climb.*

Markov Chains have been used previously to study probabilistic games which are deterministic in nature and whose players play effectively independently (games such as Chutes and Ladders, Hi-ho Cherry-o, etc.). The independence allows one to calculate the average length of a game by focusing on the play of a single player. Here we apply similar techniques to study the more complicated games Trouble and Prime Climb which are both non-deterministic and contain simple player interactions. For Prime Climb specifically, we iterate these techniques in an effort to determine an optimal strategy for a single player. (Received September 19, 2018)

1145-VT-1267 **Bhikhari Tharu*** (btharu@spelman.edu), 2209 Caneridge Ct, Marietta, GA 30064. *Spatiotemporal trend of extreme monthly precipitation of the USA.*

Changes in extreme precipitation are associated with changes in their probability distributions and the characteristics of quantiles derived from fitted distributions. In this study, the Bayesian linear quantile regression method is employed to analyze spatiotemporal trends of monthly extreme precipitation in the United States. Monthly total maximum precipitation over the period of 65 years (1950 -2014) for 1108 sites was used for the analysis. Our results show that changes in upper quantiles of the distributions of the extreme precipitation have occurred in the Southeastern United States and at a much higher rate. In addition, north west region seems to encounter extreme draught specially some part of California. Such results are particularly useful for water managers who are more concerned with extreme values rather than the averaged one. Our study has significant implication in environmental and infrastructural assessment as well as disaster risk management. (Received September 20, 2018)

1145-VT-1353 **Netra P Khanal*** (nkhanal@ut.edu), 401 W. Kennedy Blvd, Tampa, FL 33606.
Cybersecurity: A New Predictive Analytical Model for Software Vulnerability Discovery Process.

A software Vulnerability is defined as a flaw that exists in computer resources or control that can be exploited by one or more threats. In this presentation, we examine the existing models on the subject area and propose a new time-based differential equation model. We apply the proposed model in cumulative quarterly vulnerability data for three Operating Systems: Mac OS X, Windows 7, and Linux Kernel. Our model performs significantly better when compared with the existing models in terms of fitting and prediction capabilities. (Received September 21, 2018)

1145-VT-1440 **Myung Soon Song*** (song@kutztown.edu), 15200 Kutztown Rd, Kutztown, PA 19530. *A Numerical Likelihood-Based Approach to Synthesizing Correlation Matrices.*

Numerical approaches to developing accurate and efficient approximations to combined likelihoods of population correlation matrices in meta-analysis under normality assumptions for the data are studied. The likelihood is expressed as a multiple integral over the unit cube in (p − 1)-dimensional space, where p is the row and column dimensionality of the correlation matrix. Three types of computation are proposed as ways to calculate the likelihood for any population correlation matrix P. As an application, an inference is explored concerning intercorrelations among cognitive anxiety, somatic anxiety, and self-confidence from Competitive State Anxiety Inventory (CSAI-2). Comparisons are made with conventional methods. (Received September 21, 2018)

1145-VT-1450 **Tulika Rudra Gupta*** (tulika28893@gmail.com), Department of Mathematics, Indian Institute of Technology, Kharagpur, Kharagpur, Kharagpur, WestBengal 721302, India, and **Somesh Kumar** (smsh@maths.iitkgp.ac.in), Department of Mathematics, Indian Institute of Technology, Kharagpur, Kharagpur, Kharagpur, WestBengal 721302, India.
Estimation of a Stress-Strength Index for Exponential Populations.

Stress-strength reliability is widely used in manufacturing industry for producing good quality equipment. A new stress-strength index has been introduced recently. In this paper, we consider estimation of this index for exponential distributions. Various estimators such as the maximum likelihood, the uniformly minimum variance unbiased, the plug-in best scale equivariant and Bayes estimators have been derived. A generalized Bayes estimator is obtained which is shown to be a limit of Bayes estimators. A detailed simulation study is conducted to numerically compare the risk performance of various estimators. (Received September 22, 2018)

1145-VT-1477 **Robert W Vallin*** (robert.vallin@lamar.edu), Department of Mathematics, Box 10047, Beaumont, TX 77706. *Probabilities for Penney's Game with an Unfair Coin.*

Penney's Game is a two-player coin flipping game that serves as a real-life example of a non-transitive game. Players A and B each take turns announcing a choice of three outcomes of flipping a coin (e.g. HTH) with Player B going first. An umpire then tosses a coin recording the outcomes and the Player whose sequence appears first wins. Regardless of Player B's choice, Player A always has a choice that tilts the odds in his/her favor. In this talk we look at playing this game with an unfair coin. We will present formulas for the probability of winning for various sequences and see some surprising result. (Received September 22, 2018)

1145-VT-1674 **Mahmoud Aldeni*** (alden1ms@cmich.edu), Department of Mathematics, Central Michigan University, Mt. Pleasant, MI 48859. *A generalized family of lifetime distributions and survival models.*

In lifetime data, the hazard function is a common technique for describing the characteristics of lifetime distribution. Monotone increasing or decreasing, and unimodal are relatively simple hazard function shapes, which can be modeled by many parametric lifetime distributions. However, fewer distributions are capable of modeling diverse and more complicated shapes such as N-shaped, reflected N-shaped, W-shaped, and M-shaped hazard rate functions. In this work, we introduce a generalized family of lifetime distributions, namely, the uniform-R{generalized lambda} (U-R{GL}) and derive the corresponding survival models. Two members of this family are derived, and some general properties of these members are studied. The method of maximum likelihood (ML) for estimating the model's parameters are employed. The distribution is applied to fit two lifetime data sets. The survival model is applied to fit a right censored lifetime data set. (Received September 23, 2018)

1145-VT-1695 **Enrico Au-Yeung*** (eauyeun1@depaul.edu) and **Greg Zanotti** (gregzanotti1@gmail.com). *Recovery of Low-Coherence Dictionary Atoms under Restricted Signal Assumptions.*

In dictionary learning, a matrix comprised of signals Y is factorized into the product of two matrices: a matrix of prototypical "atoms" D, and a sparse matrix containing coefficients for atoms in D, called X. Dictionary learning finds applications in signal processing, image recognition, and a number of other fields. Many procedures for solving the dictionary learning problem follow the alternating minimization paradigm; that is, alternating between solving for D and X separately, until the procedure converges to a solution.

Suppose an initialization procedure is chosen carefully. Under certain assumptions, is it possible to eliminate the computationally intense task of using a subsequent alternating minimization procedure? In this work, we analyze a dictionary initialization algorithm and the assumption of a more nuanced data generating process. By decomposing and individually bounding sources of noise contributed by our model assumptions, we show that the algorithm achieves nearly complete atom recovery with overwhelmingly high probability. Our findings indicate that the costly step of alternating minimization can be avoided in certain cases, without affecting the performance of the signal recovery process. (Received September 23, 2018)

1145-VT-1708 **Shreyashi Basak*** (shreyashimathematics@gmail.com), Rani Laxmibai Hall of Residence, Kharagpur, WestBengal 721302, India, and **Somesh Kumar** (smsh@maths.iitkgp.ac.in), Department of Mathematics, Indian Institute of Technology, Kharagpur, Kharagpur, WestBengal 721302, India. *Estimating the mean direction in a wrapped Cauchy distribution.*

Directional data arises in various studies such as spread of disease vector, wind directions during a storm, seasonality of phenomena etc. Some distributions have been proposed in statistical literature to model directional data. In this paper, we consider estimation of parameters of a wrapped Cauchy distribution. For estimating the mean direction parameter we propose the sample mean direction, the maximum likelihood estimator and the Pitman estimator. A detailed simulation study is conducted to numerically compare the risk performance of these estimators. (Received September 24, 2018)

1145-VT-1869 **Melissa Innerst***, melissa_innerst1@baylor.edu, and **Jack Tubbs**, jack_tubbs@baylor.edu. *A Comparison of ROC Regression Techniques.*

In the medical field, ROC curves have long been a widely accepted measure of accuracy in diagnostic tests. In recent years, researchers have been interested in the effect that having a covariate or repeated measures data can have on the accuracy of these tests. The ROC regression methods that we considered are the binormal method, the beta regression method, and the Lehmann method. The binormal method and beta regression method are both based on the generalized linear model framework. The Lehmann method is based on the Cox proportional hazards regression model framework, and is still relatively new. One of our goals was to introduce this method, highlight situations in which it performs well, and warn of situations in which it performs poorly. We applied these methods to Texas childhood obesity data and compared the observed data to the CDC's body mass index charts. (Received September 24, 2018)

1145-VT-2070 **Benjamin S Lieberman*** (benjamin.lieberman2015@gmail.com), 7711 Mary Cassatt Drive, Potomac, MD 20854. *Analyzing Voter Behavior in the Lehigh Valley Through Semi-Parametric Regression and Geostatistical Techniques.*

Predicting voter behavior, and voter trends has been a missing piece that has flummoxed mathematicians, and politicians alike. In order to predict voter tendencies, semi-parametric basis splines and logistic regression with spatial information was used. A variogram modeling technique was considered for modeling spatial dependence of voters within the Lehigh Valley, however no significant spatial dependence was apparent. This method relied on spatial data to analyze voter behavior, and explain voter tendencies and trends. Some significant predictors for voting turnout were: Political party, age, gender and location. (Received September 24, 2018)

1145-VT-2108 **Kseniya Klyachko*** (kklyachko@albany.edu), kklyachko@albany.edu. *Random Processes of the Form $X_{n+1} = AX_n + B_n$ (mod p).* Preliminary report.

While examining the random process of the form $X_{n+1} = AX_n + B_n \pmod p$ where $A = \begin{bmatrix} 2 & 1 \\ 1 & 1 \end{bmatrix}$ is a fixed matrix, $B_0, B_1, B_2, ...$ are independent and identically distributed on $\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \begin{bmatrix} 1 \\ 0 \end{bmatrix}$, and $X_0 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$, we come upon the Fibonacci sequence. Keeping in mind the goal of bounding the rate of convergence of this process to the uniform distribution, we discuss the Fourier Transform and its role in this setting. We also introduce an expansion we call the Fibonary expansion useful in analyzing the Fourier Transform. (Received September 25, 2018)

1145-VT-2187 **Kalimuthu Krishnamoorthy** and **Md Sazib Hasan*** (sazib25@louisiana.edu), 200 E Lewis Street, Apt 147G, Lafayette, LA 70503. *Prediction Limits for the Mean of a Sample from a Lognormal Distribution: Uncensored and Censored Cases.*

For some regulatory purposes, it is desired to compare average on-site pollution concentrations in a narrowly defined geographic area with a large collection of background measurements. An approach to this problem is to treat this as a statistical prediction for the mean of a future sample based on a background sample. In this article, assuming lognormality, a fiducial approach is described for constructing prediction limits for the mean of a sample when the background sample is uncensored or censored. The fiducial prediction limits are evaluated with respect to coverage probabilities, and are compared with those based on another approximate method. Monte Carlo simulation studies for the uncensored case indicate that the fiducial methods are accurate and practically exact even for small samples, and they are very satisfactory for the censored case. Algorithms for computation of confidence limits are provided. The methods are illustrated using two real data sets. (Received September 25, 2018)

1145-VT-2217 **Achintya Roy*** (acroy21@gmail.com), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, 721302, India, and **Nitin Gupta** (nitin.gupta@maths.iitkgp.ac.in), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, 721302, India. *Importance of renewal of a coherent system using two cold standbys.*

It is of great importance in reliability engineering and system security to achieve a required availability level of a system by adding cold standby components. We investigate reliability importance of renewal of a coherent system using two cold standby components. In particular, we focus on a coherent system which has a probability of failure before the number of its failed components becomes three. There are 2 coherent systems of that type of order 2, 4 of order 3, 16 of order 4 and 131 of order. We compute signature based expressions for the reliability function which will help us to investigate the risk of system failure. In order to obtain a cost-effective cold standby parts package, we define mean cost rates for a coherent system without and with (one or two) cold standby components. Examples and graphical representations are provided to support theoretical results in this study. We showed that if usual stochastic ordering of two cold standby components is available, then for maximum improvement of the reliability by renewal a coherent system, we use the cold standby component which is better in usual stochastic order in place of the first failed component. (Received September 25, 2018)

1145-VT-2229 **Shilpa Bansal*** (shilpa.maths@iitkgp.ac.in), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, 721302, India, and **Nitin Gupta** (nitin.gupta@maths.iitkgp.ac.in), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, 721302, India. *Stochastic comparisons in multivariate reversed frailty model.*

Multivariate frailty approach is commonly used to define distributions of random vectors representing lifetimes of individuals/systems and their stochastic comparisons. Here, we study the following multivariate proportional reversed hazard rate model and give sufficient conditions for stochastic order to hold between the two lifetimes and past lifetime vectors with different baseline. Let $\mathbf{X_k} = (X_{k1}, .., X_{kn}), k = 1, 2$ be n-dimensional vectors with joint cdf

$$F_{\mathbf{X_k}}(x_1, .., x_n) = E\left[\prod_{i=1}^{n} G_{ki}^{\Theta_k}(x_i)\right]$$

where $\Theta_k \in R^+$ is random frailty and G_{ki} is baseline cdf of $\tilde{X}_{k,i}(k = 1, 2; i = 1, .., n)$. In literature a generalised bivariate frailty model is defined and its two particular cases were studied. Analogous to this we study the bivariate reversed frailty model assuming dependence among components and give the conditions under which stochastic, likelihood ratio, weak reversed hazard rate orderings hold between two lifetime vectors with different frailties. We also consider a particular case of this model in which the baseline distribution function $F(x_1, x_2|\theta_1, \theta_2)$ is represented in terms of a copula and study stochastic and lower orthant order comparisons among the two lifetime vectors. (Received September 25, 2018)

1145-VT-2231 **Dawud Adebayo Agunbiade*** (bayoagunbiade@gmail.com), Department of Mathematical Sciences, Faculty of Science, Olabisi Onabanjo University, Ago-Iwoye, Ogun State 234, Nigeria. *Asymptotic analysis of the least squares as estimator of the linear regression model.*

Least squares are natural approach to estimation which makes explicit use of the structure of the model as laid out in the assumptions of the classical linear regression model. Its usage and recognition ascribed to it cannot be over emphasized. The main thrust of this work is therefore to examine the asymptotic behaviour of the least square estimator θ as the sample size goes to infinity. The task is complicated by the fact that θ depends on the design . Thus, emphasis is laid on the existence of a limiting distribution only when the design is governed by some regularity conditions. The study emphasized on both the regular deterministic design and regular random design. The asymptotic analysis was particularly done on a collinear regression variable of a linear regression model (LRM). The findings revealed that the parametric least-squares estimator is unbiased, and its typical rate of convergence under various norms and under regular designs is equal to $0\ 1 \to \infty$.

Keywords: Least squares estimator, regression variables, regular deterministic designs, regular random design, linear regression model. (Received September 25, 2018)

1145-VT-2253 **Hasthika S Rupasinghe Arachchige Don*** (hasthika@appstate.edu), 121 Bodenhiemer Dr., Department of Mathematical Sciences, Appalachian State University, Boone, NC 20608, and **Lasanthi C Pelawa Watagoda**. *A new regularization and variable selection technique - HRLR.* Preliminary report.

This work propose a new variable selection and parameter estimation method for the multiple linear regression model $Y = \beta_1 x_1 + \cdots + \beta_p x_p + e$. This new method is a hybrid of ridge regression and relaxed lasso regularization. Theoretical and simulated results demonstrate that the new method produces sparser models with equal or lower prediction loss than the regular Lasso and Relaxed Lasso estimators for high dimensional data. (Received September 25, 2018)

1145-VT-2257 **Davidson Barr*** (db3170@tc.columbia.edu) and **Salvatore P Giunta** (spg2133@tc.columbia.edu). *Are P-value Still Reliable? Discussing Statistical Significance.*

P-Values have long been the standard metric used to determine whether or not data from an experiment is statistically significant. In recent years, P-Values have faced increasing criticism and many consider them to no longer be sufficient to evaluate data and a contributor to the ongoing Replication Crisis in science. This culminated in the American Statistical Association's 2016 statement about proper use of p-values in statistical analysis. In this presentation, we examine the strengths and weaknesses of P-Values and introduce some alternative methods of determining statistical significance. In particular, we discuss confidence intervals, Bayesian Statistics, likelihood ratios, d-values, and w-values. We also examine other non-metric based adjustments to current practice including flexible thresholds, pre-registered studies and random auditing. Finally, we discuss some implications for teaching statistics at the secondary and university level. (Received September 25, 2018)

1145-VT-2260 **Lasanthi C Pelawa Watagoda*** (lasanthi@appstate.edu), 121 Bodenheimer Dr., Department of Mathematical Sciences, Appalachian State University, Boone, NC 28608, and **David J Olive**. *Bootstrapping Multiple Linear Regression After Variable Selection.*

This paper suggests a method for bootstrapping the multiple linear regression model $Y = \beta_1 x_1 + \cdots + \beta_p x_p + e$ after variable selection. We develop asymptotic theory for some common least squares variable selection estimators such as forward selection with C_p. Then hypothesis testing is done using three confidence regions, one of which is new. Theory suggests that the three confidence regions tend to have coverage at least as high as the nominal coverage if the sample size is large enough. (Received September 25, 2018)

1145-VT-2275 **Raid M Al-Aqtash*** (alaqtash@marshall.edu), One John Marshall Drive, COS - Department of Math, Smith Hall 721, Huntington, WV 25755, and **A Mallick** and **G G Hamedani**. *Gumbel-Burr XII Distribution; Inference and Application.*

The Gumbel-Burr XII (GBXII) distribution appeared in 2017. Some statistical properties have been studied. In this project we present additional properties on the distribution of order statistics, parameter estimation, simulation and inference. Real life data are used to illustrate the application of the GBXII and to test the significance of distribution parameters. (Received September 25, 2018)

1145-VT-2353 **Alperen Ozdemir*** (aozdemir@usc.edu), 3620 S. Vermont Ave., KAP 104, Los Angeles, CA 90089-2532. *A fast mixing Markov chain on the symmetric group.*

Consider a Markov chain on the symmetric group where at each step a permutation is chosen with respect to probabilities that are exponentially proportional to the number of cycles and multiplied by the permutation

at the current state. In this talk, I will discuss the algebraic combinatorics techniques used to identify the eigenvalues of the transition matrix. Then I will focus on the mixing time analysis and show a total variation cutoff result. The results will be compared to the case of random walks generated by single conjugacy classes, e.g. random transposition walk on the symmetric group. (Received September 25, 2018)

1145-VT-2457 **Madhurima Datta*** (madhurima92.datta@iitkgp.ac.in), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, 721302, India, and **Nitin Gupta** (nitin.gupta@maths.iitkgp.ernet.in), Department of Mathematics, Indian Institute of Technology Kharagpur, Kharagpur, 721302, India. *A stochastic comparison study of series and parallel systems having Kumaraswamy's and Fréchet distributed components.*

Kumaraswamy's distribution is a double-bounded distribution similar to Beta distribution, with an advantage that the cumulative distribution function (cdf) of Kumaraswamy's distribution has a closed form, unlike Beta distribution. This helps in computational purposes by reducing complexity. The cdf of Kumaraswamy's distribution is

$$F(x;\alpha,\beta) = 1-(1-x^{\beta})^{\alpha},\ x>0;\ \alpha,\beta>0,$$

α,β are two shape parameters. Fréchet distribution is an extreme value distribution which is used to estimate stock index, extreme events like earthquake, rainfall etc. The cdf of Fréchet distribution is given by

$$F(x;\mu,\theta,\alpha) = e^{-\left(\frac{x-\mu}{\theta}\right)^{-\alpha}}, x>\mu, \alpha>0, \theta>0,$$

where μ,θ and α are the location, scale and shape parameters respectively. We study the hazard rate and reversed hazard rate ordering of minimum and maximum order statistic from heterogeneous Kumaraswamy's distributed samples with varying shape parameters. We also obtain likelihood ratio ordering, hazard rate and reversed hazard rate ordering of maximum and minimum order statistic from Fréchet distributed samples with varying scale and location parameters. (Received September 25, 2018)

1145-VT-2497 **Robert L Bassett*** (robert.bassett@nps.edu). *Data Smoothing via Minimum Fisher Information.* Preliminary report.

Smoothing empirical models is a common aspect of analyzing data. Especially in the high-dimensional setting, smoothing provides a common-sense check when working with extremely flexible models. In this talk we introduce a method for smoothing multivariate density estimates using Fisher information. We provide evidence for its utility through applications to nonparametric density estimation. (Received September 25, 2018)

1145-VT-2583 **Azar Khosravani*** (akhosravani@colum.edu). *Benford distributions in Music.* Preliminary report.

We analyzed a selection of classical and modern music, ranging from Beethoven to the Rolling Stones and Metallica and found a surprising connection with mathematics. For each composer/band, we extracted the time intervals each note was played in each piece of music/song and found that the corresponding data sets are Benford distributed in all digits. We will present the selection of instrumental music that we used and our strategies for extracting the note durations as well as how we used Mathematica to analyze the data. (Received September 25, 2018)

1145-VT-2700 **Ahmad Alzaghal*** (ahmad.alzaghal@farmingdale.edu), State University of New York, Whitman Hall, Room 180 G, 2350 Broadhollow Road, Farmingdale, NY 11735. *A new Lindley family of continuous distribution.* Preliminary report.

A family of Lindley Distribution, called a T-Lindley family of distributions, has been proposed using the T-RY framework. Several general properties of the new family are studied in detail including moments, mode, shannon entropy, mean deviations. Some members of T-Lindley family are developed and studied. One data set is fitted by using members of the T-Lindley family of distributions. (Received September 25, 2018)

1145-VT-2815 **Erin Beckman*** (ebeckman@math.duke.edu), Duke University, Department of Mathematics, Campus Box 90320, Durham, NC 27708-0320, and **Natalie Frank**, **Yufeng Jiang**, **Matthew Junge** and **Si Tang**. *The Frog Model on Trees with Drift.*

In this talk, I will introduce a version of the frog model interacting particle system. The system initially consists of a single active particle at the root of a d-ary tree and an inactive particle at every other node on the tree. Active particles move according to a biased random walk and when an active particle encounters an inactive particle, the inactive particle becomes active and begins its own biased random walk. We find an upper bound on the drift such that the model is recurrent. I will describe a subprocess of the frog model and how it can be coupled across trees of different degrees to give this result. (Received September 25, 2018)

1145-VT-2997 **Sharang Chaudhry*** (sharang.chaudhry@unlv.edu), **Daniel Lautzenheiser** and **Kaushik Ghosh**. *Sampling Prudently using Inversion Spheres on the Simplex.*

Building efficient sampling strategies is at the heart of computational Bayesian methods. The problem can get considerably hard when the parameters of interest are constrained. To mitigate the severity of this challenge, it is possible to transform the constrained parameter space to be more conducive to sampling. In this work, a particular transformation called inversion in a sphere has been embedded within the popular Metropolis-Hastings paradigm to effectively sample on a standard simplex (sum-to-one constraint). The method's performance has been assessed using simulation studies and comparative analyses. (Received September 26, 2018)

Topology

1145-VU-562 **Frank J Swenton*** (fswenton@middlebury.edu), Department of Mathematics, Warner Hall, Middlebury College, Middlebury, VT 05753. *Kirby Calculator / KLO software demonstration and feedback.*

This presentation in intended to serve as a meeting point for users of the free Knot-Like Objects (KLO) software—originally named the Kirby Calculator and hosted at http://www.kirbycalculator.net—and its developer. New and planned future functionality will be demonstrated and/or discussed, and feedback and suggestions from the user base are encouraged; the release of Version 1.0 is targeted for middle to late 2019. (Received September 10, 2018)

1145-VU-569 **Boris Goldfarb** and **Jonathan L Grossman***, JonathanLGrossman@gmail.com. *Coarse coherence of metric spaces and groups and its permanence properties.*

This paper introduces two properties of metric spaces: "coarse coherence" and "coarse regular coherence", and specifically applies these properties to finitely generated groups equipped with word metrics. Coarse coherence and coarse regular coherence are geometric counterparts of the classical notion of coherence in homological algebra and of the regular coherence property of groups defined and studied by Waldhausen, respectively. These coarse coherence notions are intelligible in the general context of coarse metric geometry and are coarse invariants. In particular, they are quasi-isometry invariants of spaces and groups. Coarse regular coherence is in fact a weakening of Waldhausen's regular coherence, but can be used as effectively in K-theory computations. This paper demonstrates that coarse regular coherence implies weak regular coherence as defined by Carlsson and Goldfarb, yet all groups known to be weakly regular coherent are also coarsely regular coherent. The class of coarsely regular coherent groups is therefore a large class of groups containing all groups with straight finite decomposition complexity as defined by Dranishnikov and Zarichnyi. This new framework allows us to prove structural results by developing coarse permanence properties for coarse coherence. (Received September 10, 2018)

1145-VU-825 **Jocelyn R Bell*** (bell@hws.edu). *A variation on an infinite game.*

The proximal infinite game is a two-player game played in a uniform space. We will introduce a variant of this game. A winning strategy for the first player in this variation implies the space satisfies a weak form of normality. (Received September 15, 2018)

1145-VU-925 **Pawel Grzegrzolka*** (pgrzegrz@vols.utk.edu), 1403 Circle Drive, Ayres Hall, Knoxville, TN 37916, and **Jeremy Siegert**. *Coarse proximity and proximity at infinity.*

In this talk, we introduce coarse proximity structures, which are an analog of small-scale proximity structures in the large-scale context. We show that metric spaces naturally induce coarse proximity structures, and we construct a natural small-scale proximity structure, called the proximity at infinity, on the set of equivalence classes of unbounded subsets of an unbounded metric space given by the relation of having finite Hausdorff distance. We show that this construction is functorial. Consequently, we obtain a new nontrivial coarse invariant of unbounded metric spaces. (Received September 17, 2018)

1145-VU-1242 **Joseph W Grenier*** (jgreni3@lsu.edu), Baton Rouge, LA 70806. *Iterated Doubles and Quantum Field Theory.*

The iterative double of a compact manifold with boundary is a sequence of null-cobordant manifolds described by a particular process. This talk will motivate the notion of Iterated doubles via Reflection Positivity in Topological Quantum Field Theory, give some basic results, and highlight current work being done to bridge the gap between Topological and Constructive QFTs. (Received September 20, 2018)

1145-VU-1385 **Jerzy Dydak** and **Thomas Weighill*** (tweighil@vols.utk.edu). *Three extension theorems: topological, uniform and large scale.*

We will present a unified proof of three different theorems of the form: a (certain type of) function from a subset of a (certain type of) space to the interval extends to that same kind of function over the whole space. The first such theorem is the classical Tietze Extension Theorem concerning bounded continuous functions which every topology student learns early on in their career. The second is the less well-known result of Katetov about uniformly continuous functions. The third is a new result of ours which generalizes a result of Dydak and Mitra about so-called slowly oscillating functions. Slowly oscillating functions are a subject of interest in the fairly new field of large scale geometry - the study of spaces as viewed from far away - and were introduced by Higson and Roe, motivated by their work in index theory. The unification of the proofs of these three results will be achieved via a more general extension theorem for a set equipped with a neighbourhood operator. (Received September 21, 2018)

1145-VU-1464 **Claire C. Zajaczkowski***, cczajacz@ncsu.edu. *Surgery Obstructions for Seifert Fibered Integral Homology Spheres.*

We examine surgery on a knot in S^3 to determine surgery obstructions to Seifert fibered integral homology spheres. Dehn surgery is one of our key ways of understanding 3-manifolds, and Seifert fibered integral homology spheres are a class of manifolds we understand well. Thus it is a well explored topic to find such surgery obstructions. In this talk we will find such surgery obstructions using Heegaard Floer and Knot Floer homology, which has been a commonly used approach in the past. Here however, we take a different approach and use the number of singular fibers of a Seifert fibered integral homology sphere to find obstructions, which is the toroidal structure. This approach led us to some significant and new results by looking at the genus of the knot and the number of singular fibers. (Received September 22, 2018)

1145-VU-1967 **Keely J Grossnickle*** (kgrossni@ksu.edu). *Overlapping Discs Filtration in the Commutative Operad.*

The space of configurations of non-k-overlapping discs has been studied as a bimodule over the little discs operad. In fact, the spaces form a filtered operad. We define and study the induced structure on the homology. (Received September 24, 2018)

1145-VU-1985 **Gangadhar R Hiremath*** (gangadhar.hiremath@uncp.edu), 3345 Altaloma Dr, Vestavia Hills, AL 35216. *Weaker Separation Axioms and Diagonal Properties and Their Implications in the Class of Second Countable Spaces.* Preliminary report.

Some weaker separation axioms and diagonal properties for the topological spaces are introduced in this paper and their implications are investigated in the class of second countable topological spaces. Some interesting metrization or pseudo-metrization results for the second countable spaces are derived. In the class of Hausdorff spaces, second countability is equivalent to metrizability if any of the following property is satisfied. (i) Countable discrete closed subsets can be expanded to countable locally finite open collections. (ii) Delta-regularity (iii) Countable paracompactness In the class of pseudo Hausdorff spaces, second countability is equivalent to pseudo-metrizability if any of the following property is satisfied. (i) The sequences that do not cluster can be expanded to countable locally finite open collections. (ii) Delta*-regularity (iii) Countable paracompactness In addition some interesting counter examples and open questions are incorporated. (Received September 24, 2018)

1145-VU-2077 **Zeinab Bandpey*** (zeinab.bandpey@morgan.edu), 1700 East Cold Spring Lane, Baltimore, MD 21251, and **Bhamini P. Nayar** (bhamini.nayar@morgan.edu), 1700 East Cold Spring Lane, Baltimore, MD 21251. *A Study of Generalized Continuous Functions.*

In the paper, Weak Continuity Forms, Graph Conditions and Applications, the concept of u-continuous functions are introduced and presented several applications of such functions. In the present study, by generalizing the concept of u-continuity using the notion of an α-set, introduced by O. Njastad , three classes of functions are introduced and studied.The concepts introduced here are strongly u-continuous functions, αu-continuous functions and semi-αu-continuous functions. A function $g : X \to Y$ is αu-continuous (strongly u-continuous, semi-αu-continuous) at $x \in X$, if for each α-set (α-set, open set) W which contains a closed neighborhood of $g(x)$, there exists an α-set (open set, α-set) Vwhich contains a closed neighborhood of x and satisfies condition $g(clV) \subseteq clW$. If g is αu-continuous (strongly u-continuous, semi-αu-continuous) at each $x \in X$, we say $g : X \to Y$ is αu-continuous (strongly u-continuous, semi-αu-continuous) on X. (Received September 24, 2018)

1145-VU-2186 **Samantha C Sandberg*** (samantha.c.sandberg@gmail.com), **Cory Glover**, **Leslie Colton** and **Mark Hughes**. *A Complete Set of Moves for Petal Words.*

When working with knot projections, the standard method to determine whether two projections represent the same knot type is to create a sequence of Reidemeister moves connecting the first knot diagram to the second. We discuss a similar approach using petal projections and petal words of a knot. Petal projections, as defined by Adams' et. al., allow us to describe a knot using a finite sequence of integers, called a petal word. While each knot type has infinitely many petal words associated with it, we describe a sequence of moves which allows us to relate any two petal words representing the same knot type. (Received September 25, 2018)

1145-VU-2343 **Matthew J Sequin*** (msequin@saintpeters.edu). *A Functorial Formulation of the Hennings Invariant.*

We will define a functor from the category of blackboard framed tangles to the category of vector spaces, using a finite dimensional involutory, ribbon Hopf algebra H. The functor is such that it preserves the rank of tensors in each of these vector spaces. When this functor is applied to a link, the corresponding scalar is a multiple of the Hennings Invariant, thusgeneralizing the Hennings Invariant to tangles. (Received September 25, 2018)

1145-VU-2533 **Ik Jae Lee***, Department of Mathematics, Rowan University, 201 Mullica Hill Rd., Glassboro, NJ 08028, and **David N Yetter**. *Stratified spaces, Directed Algebraic Topology, and State-Sum TQFTs.* Preliminary report.

In this talk, we apply the theory of directed topology developed by Grandis to the study of stratified spaces by describing several ways in which a stratification or a stratification with orientations on the strata can be used to produce a related directed space structure. This description provides a setting for the constructions of state-sum TQFTs with defects, which we extend to a similar construction of a Dijkgraaf- Witten type TQFT in the case where the defects (lower dimensional strata) are not sources or targets, but sources on one side and targets on the other, according to an orientation convention. (Received September 25, 2018)

1145-VU-2699 **Jonah Amundsen*** (amundsjj3573@uwec.edu). *On the Indeterminacy of the Triple Linking Number.*

In the 1950s, Milnor defined a family of higher order linking invariants generalizing the linking number. Even the first of these new invariants, the triple linking number, has been of intense and fruitful study since its inception. In the case of a link with vanishing pairwise linking numbers, this triple linking number gives an integer valued invariant. When the linking numbers fail to vanish, this invariant is only well defined modulo their greatest common divisor. In recent work, Davis-Nagel-Orson-Powell produce a single invariant refining the triple linking number taking values in some abelian group which we call the total Milnor quotient. The goal of this talk is to compute this group and show that when the number of components $n \geq 6$, it is nontrivial. Thus, this refined triple linking number carries information for every ($n \geq 6$)-component link, even when the classical triple linking number carries no information. (Received September 25, 2018)

1145-VU-2732 **Mark Hughes** and **Spencer Reschke*** (spencerreschke@gmail.com). *Deep Reinforcement Learning and Constructive Proofs in Topology.*

Abstract: Low-dimensional topology has numerous examples of problems whose solutions require constructing sequences of operations taken from a fixed set of moves. In knot theory, constructing genus-minimizing slice surfaces of a knot is an example of such a problem. In this talk we'll discuss how recent advances in deep reinforcement learning can be leveraged to construct these surfaces. In particular we'll discuss deep Q-learning and its modern improvements such as double Q-learning, dueling architectures, prioritized experience replay, and asynchronous methods. (Received September 25, 2018)

1145-VU-2898 **Indu Rasika Churchill***, indurasika.churchill@oswego.edu. *f-Quandles.*

Quandles are non-associative algebraic structures whose axioms are motivated by Reidemeister moves in Knot Theory. The concept of a quandle can be used to help solve the fundamental knot theory problem of determining if two different knot diagrams represent the same knot. In this talk, we will give the precise definitions to make the talk self contained. We present some of the recent research that generalizes quandles by introducing the notion of f-quandles wherein we attach a map f to the usual equation identities. We will give some examples of f-quandles and also will discuss cohomology of f-quandles. (Received September 25, 2018)

Other Topics

1145-VV-307 **Clifford A Reiter*** (reiterc@lafayette.edu), Department of Mathematics, Lafayette College, easton, PA 18042. *Searching for Complex Cellular Automata.*

Cellular automata are often classified as exhibiting ordered, complex or chaotic behavior. We investigate using the average and standard deviation of input entropy to search for random examples of automata that exhibit complex behavior. We illustrate this with searches for complex one and two dimensional general automata and for one and two dimensional Larger than Life automata. Self-organizing structures occur and spontaneous symmetries appear from random initial conditions with surprising frequency. (Received August 29, 2018)

1145-VV-380 **Trevor K Karn*** (tuk377@psu.edu) and **Max D Wakefield** (wakefiel@usna.edu), 572C Holloway Rd, Annapolis, MD 21412. *Stirling Numbers in Braid Matroid Kazhdan-Lusztig Polynomials.*

Restricted Whitney numbers of the first kind appear in the combinatorial recursion for the matroid Kazhdan-Lusztig polynomials. In the special case of braid matroids (the matroid associated to the partition lattice, the complete graph, the type A Coxeter arrangement and the symmetric group) these restricted Whitney numbers are Stirling numbers of the first kind. We use this observation to obtain a formula for the coefficients of the Kazhdan-Lusztig polynomials for braid matroids in terms of sums of products of Stirling numbers of the first kind. This results in new identities between Stirling numbers of the first kind and Stirling numbers of the second kind, as well as a non-recursive formula for the braid matroid Kazhdan-Lusztig polynomials. (Received September 04, 2018)

1145-VV-684 **Wing Hong Tony Wong*** (wong@kutztown.edu), 15200 Kutztown Rd, Kutztown, PA 19530, and **Jiao Xu**. *A probabilistic chip-collecting game.*

Alice and Bob are playing a very simple game. Each of them starts with no chips, and they take turns to gain 1 or 2 chips randomly and independently with equal probability, with Alice going first. The first player who collect at least n chips is the winner. In this talk, we discuss the winning probability for Bob and analyze a new integer sequence. We also show that this game is highly disadvantageous to Bob, even when n is large. Furthermore, we study several variations of this game and determine the winning probability for Bob in each case. (Received September 12, 2018)

1145-VV-891 **Hassan Almusawa*** (almusawah@vcu.edu), 301 Karl Linn Drive, Apt. 215, North Chesterfield, VA 23225. *Symmetry Algebras of the Canonical Lie Group Geodesic Equations in Dimension Five.* Preliminary report.

Geodesic equations of the canonical Lie group connection have recently appeared in the context of the inverse problem of Lagrangian mechanics. Our research main goal is to investigate the Lie symmetry properties of the canonical geodesic system and it is confined to the five-dimensional indecomposable Lie groups. In this talk, I will discuss the Lie symmetry properties for the algebra $A^{ab}_{5,19}$. For such algebra, an over-determined system of linear PDEs of its associated system of geodesics will be provided and described. In addition, a basis for the associated Lie algebra of symmetries as well as the corresponding non-zero Lie brackets are constructed and classified.
(Received September 17, 2018)

1145-VV-893 **Laura Mora-Mercado*** (laura.mora2@upr.edu), 25 Calle los Rotarios, Isabela, PR 00662. *Some Criteria for Permutation Binomials over Finite Fields.*

A Permutation Binomial $f = x^r + Bx^s$ over a finite field with p elements, p prime, is a function that permutes the elements of the field. Criteria to determine when a binomial is a Permutation Binomial are scarce. Due to its applications, including to cryptography, we want to focus to find criteria for a family of binomials of the form $f = x^{p-4} + Bx^{\frac{p-7}{2}}$, to be Permutation Binomials.We proved that no such binomials can be found if p is of the form $3k + 4$, moreover we found a relationship between the distribution of quadratic residues over the field and the capacity of f to permute its elements. That is, we found criteria for f to be a Permutation Binomials in terms of the position of B among such quadratic residues. Also we found a suitable formula for the inverse of f.We will present such results and future plans involving the inverse of f. (Received September 17, 2018)

1145-VV-1082 **Emily Cilli-Turner***, University of La Verne, 1950 Third Street, La Verne, CA 91750. *Mathematics Teacher as Learner: What I Learned from Participating in the NOAA Teacher at Sea Program.*

The National Oceanic and Atmospheric Administration (NOAA) runs numerous research vessels each year in the fields of fisheries, oceanography and atmospheric research. NOAA also runs a program called Teacher at

Sea, where any teacher can apply to go out on one of these research cruises and be incorporated into the team of scientists. In this talk, I will discuss my experience participating in this program stationed on NOAA Ship Oscar Dyson in the Eastern Bering Sea and assisting in conducting a pollock survey to assess quantity and biomass of pollock for future fishing quotas. I will cover the application process, the experience on the ship and the mathematics that I learned. Additionally, I will give an overview of how I will incorporate what I learned on the ship into my mathematics courses. (Received September 18, 2018)

1145-VV-1362 **Madison Lydic*** (lydicmn@jay.washjeff.edu) and **Ryan Higginbottom**. *Equilibrium patterns in the candy-sharing circle.* Preliminary report.

A well-known game called the candy-sharing circle is played this way: Position n players in a circle, each with a positive, even number of pieces of candy. Each player passes half their pile to their left and takes a piece from a common pile only if they end the round with an odd number of pieces. It is easily shown that a candy equilibrium is reached. In this talk we present initial results, for small numbers of players, concerning the equilibrium and the number of rounds played until equilibrium is reached. (Received September 21, 2018)

1145-VV-1824 **Masayoshi Kaneda*** (mkaneda@uci.edu), American University of Kuwait, P.O. Box 3323, 13034 Safat, Kuwait. *Structure and a duality of binary operations on monoids and groups.*

We introduce novel views of monoids and groups. More specifically, for a given set S, let $S^{S\times S}$ be the set of binary operations on S. We equip $S^{S\times S}$ with canonical binary operations induced by the elements of S. Let $S_{mn}^{S\times S}$ (respectively, $S_{gr}^{S\times S}$) be the set of binary operations that make S monoids (respectively, groups). Then we have the following "duality": for each $z \in S_{mn}^{S\times S}$ a certain subset of $S^{S\times S}$, denoted by S_z^*, is a monoid with a canonical binary operation and is isomorphic to (S, z). If $z \in S_{gr}^{S\times S}$, then $S_{gr}^{S\times S}$ can be partitioned into copies of S_z^*. We also give a new characterization of group binary operations which distinguishes them from the other binary operations. These results give us new insights into monoids and groups, and will provide new tools and directions in studying these objects. (Received September 26, 2018)

1145-VV-1868 **Molly Lynch*** (melynch4@ncsu.edu). *Relations in doubly laced crystal graphs via discrete Morse theory.*

Many crystal graphs have a natural partial order associated to them. Much of the structure of these graphs has been revealed by local relations given by Stembridge and Sternberg. However, there exist relations among crystal operators not implied by these local relations. We use a tool from topological combinatorics known as lexicographic discrete Morse functions to relate the Möbius function of a given interval in a crystal poset to the type of relations that can occur among crystal operators within this interval. More specifically, for a crystal of a highest weight representation of finite classical Cartan type, we show that whenever there exists an interval whose Möbius function is not equal to -1, 0, or 1, there must be a relation among crystal operators within this interval not implied by Stembridge or Sternberg relations. (Received September 24, 2018)

1145-VV-1922 **John Baez**, **David Weisbart** and **Adam Yassine*** (ayass002@ucr.edu), University of California, Riverside, 900 University Ave., Riverside, CA 92521. *A Category Theoretic Framework for Classical Mechanics.*

The heuristic principles that physicists employ in constructing certain classical systems from subsystems are grounded in a category theoretic framework. We construct such a framework for both the Lagrangian and Hamiltonian settings. In each setting, the composition of morphisms corresponds to the construction of larger systems from smaller subsystems. A symmetric monoidal functor between the two categories translates between the Lagrangian and Hamiltonian perspectives. (Received September 24, 2018)

1145-VV-2261 **Chris Ahrendt*** (ahrendcr@uwec.edu), HHH 508 - Mathematics Dept., 124 Garfield Avenue, UW-Eau Claire, Eau Claire, WI 54701. *Periodic Solutions and Bifurcations of the Bernoulli Dynamic Equation on a Certain Class of Time Scales.* Preliminary report.

The time scale calculus generalizes and unifies differential and difference equations, but also is a source of many interesting results that do not have a direct analog to these classic cases. An introduction to the key results of the time scale calculus will be provided, and then used to develop the so-called Bernoulli dynamic equation on time scales.

Using the framework of the time scale calculus, we will focus on the discrete analog of the classic Bernoulli differential equation. In particular, we will explore the bifurcations that occur as a parameter determining the time scale is varied. For certain parameter values, periodic solutions occur. We will apply classic dynamical system results to understand the nature of these periodic solutions. (Received September 25, 2018)

1145-VV-2584 **Volker Sorge*** (v.sorge@mathjax.org) and **Davide P Cervone** (dpvc@union.edu). *Accessibility Features for Advanced Mathematics in the new MathJax Version 3.*

MathJax is a Javascript library for TeX-like typesetting of Mathematics on the web. Since its beginnings one of its goals is to provide accessibility support for blind and visual impaired people; either by supporting third party assistive technology or, more recently, via it's own integrated accessibility extension.

In MathJax's new version 3 the accessibility extension is not only again an important aspect but has been considerably improved in terms of the information it can provide on formulas. With support from the Simons Foundation we developed improved semantic recognition of source material as well as means to exploit context information in documents. One particular emphasis is to provide better accessibility to advanced mathematical material exploiting information gained from the original LaTeX code, to provide more appropriate speech for different areas of Mathematics but also for subjects like Physics, Chemistry and Logic. Our aim is to ease the study of mathematics for more people with visual impairments as well as to encourage subject specialists to contribute via better authored content, semantically meaningful LaTeX packages, and expert knowledge for speech generation. (Received September 25, 2018)

1145-VV-2665 **Lisa Schneider*** (lmschneider@salisbury.edu) and **Jathan Austin**. *Sequences and PTPMs.* Preliminary report.

In the study of primitive Pythagorean triples, two ternary trees of PPTs were created: Berggren in 1934 and Price in 2007. Using "Fibonacci boxes" for Price's tree and other observations relating PPTs and Fibonacci numbers, we will discuss the relationship between PTPMs and other Fibonacci-like sequences. In addition, we will use different sequences to generate PPTs. (Received September 25, 2018)

1145-VV-2684 **John Robert Botzum*** (botzum@kutztown.edu) and **Andrew Martin** (andrew.martin@kysu.edu). *Odd items from the complex history of the real numbers;* i^i.

Leibniz wrote in 1702," The imaginary number i is an elegant and wonderful resource of divine intellect and unnatural birth in the realm of thought, almost an amphibian between being and non-being." In this presentation we will look at the historical background of i and re-discover some peculiar properties of i^i. (Received September 25, 2018)

1145-VV-2762 **Abd Al Rahman R Al Momani** (almomaa@clarkson.edu), 8 Clarkson Ave., Potsdam, NY 13699, and **Ahmad R Almomani*** (almomani@geneseo.edu), 1 College Circle, Math. Dept., Geneseo, NY 14454. *Compressive Sensing with the Non-Convex Quantized Particle Swarm Optimization.*

The L_0 regularized problem in compressed sensing reconstruction is nonconvex with NP-hard computational complexity. A relaxation of the problem can be expressed as a constrained minimization problem with a non-convex regularizing objective function depending on a parameter and a least squares data fit constraint. In this paper, we propose an efficient method for the reconstruction of sparse signals from undersampled data by developing a Quantized Minimum Energy Particle Swarm Optimization algorithm (QPSO). We are applying our algorithm for the standard phantom image recovery example as well as for models of system identification of chaotic systems. (Received September 25, 2018)

1145-VV-2848 **Chaogui Zhang*** (chaoguizhang@clayton.edu). *Prince Rupert's Cube in Higher Dimensions.* Preliminary report.

Prince Rupert's Cube is the largest cube that can pass through the inside of a unit cube. Its side length is $\frac{3\sqrt{2}}{4}$, as found over two hundred years ago by Pieter Nieuwland. Finding Prince Rupert's Cube is equivalent to finding the largest square that lies completely inside a unit cube. Therefore, a generalization of Prince Rupert's Cube problem in higher dimensions is to find the largest m-dimensional hypercube that fits completely inside an n-dimensional unit hypercube, where $m < n$. We will present some preliminary results by converting the question into a constrained optimization problem. (Received September 25, 2018)

1145-VV-2970 **Alice Chudnovsky*** (achudn3@illinois.edu) and **Anna Chlopecki**. *How To: Create a Community for Undergraduate Mathematicians.*

This talk is based on the experience of the presidents and founders of the undergraduate mathematics club and the undergraduate AWM chapter at the University of Illinois at Urbana-Champaign. The UIUC campus has experienced a significant increase in undergraduate "social" activity participation over the past several years, due to the incorporation of multiple innovative initiatives. Such include an undergraduate-run seminar, a student-run freshman orientation, mental health/study habits workshops, incorporation of enthusiasm over extra curricular mathematical learning, etc. The overarching themes: creation of a virtual community/forum, regular inclusion of engaging and inspiring mathematical speakers, as well as regular social events that appeal to the academically-driven students. (Received September 25, 2018)

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
06 Order, lattices, ordered algebraic structures
08 General algebraic systems
11 Number theory
12 Field theory and polynomials
13 Commutative rings and algebras
14 Algebraic geometry
15 Linear and multilinear algebra; matrix theory
16 Associative rings and algebras
17 Nonassociative rings and algebras
18 Category theory; homological algebra
19 *K*-theory
20 Group theory and generalizations
22 Topological groups, Lie groups
26 Real functions
28 Measure and integration
30 Functions of a complex variable
31 Potential theory
32 Several complex variables and analytic spaces
33 Special functions
34 Ordinary differential equations
35 Partial differential equations
37 Dynamical systems and ergodic theory
39 Difference and functional equations
40 Sequences, series, summability
41 Approximations and expansions
42 Fourier analysis
43 Abstract harmonic analysis
44 Integral transforms, operational calculus
45 Integral equations
46 Functional analysis
47 Operator theory
49 Calculus of variations and optimal control; optimization
51 Geometry
52 Convex and discrete geometry
53 Differential geometry
54 General topology
55 Algebraic topology
57 Manifolds and cell complexes
58 Global analysis, analysis on manifolds
60 Probability theory and stochastic processes
62 Statistics
65 Numerical analysis
68 Computer science
70 Mechanics of particles and systems
74 Mechanics of deformable solids
76 Fluid mechanics
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
94 Information and communication, circuits
97 Mathematics education

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