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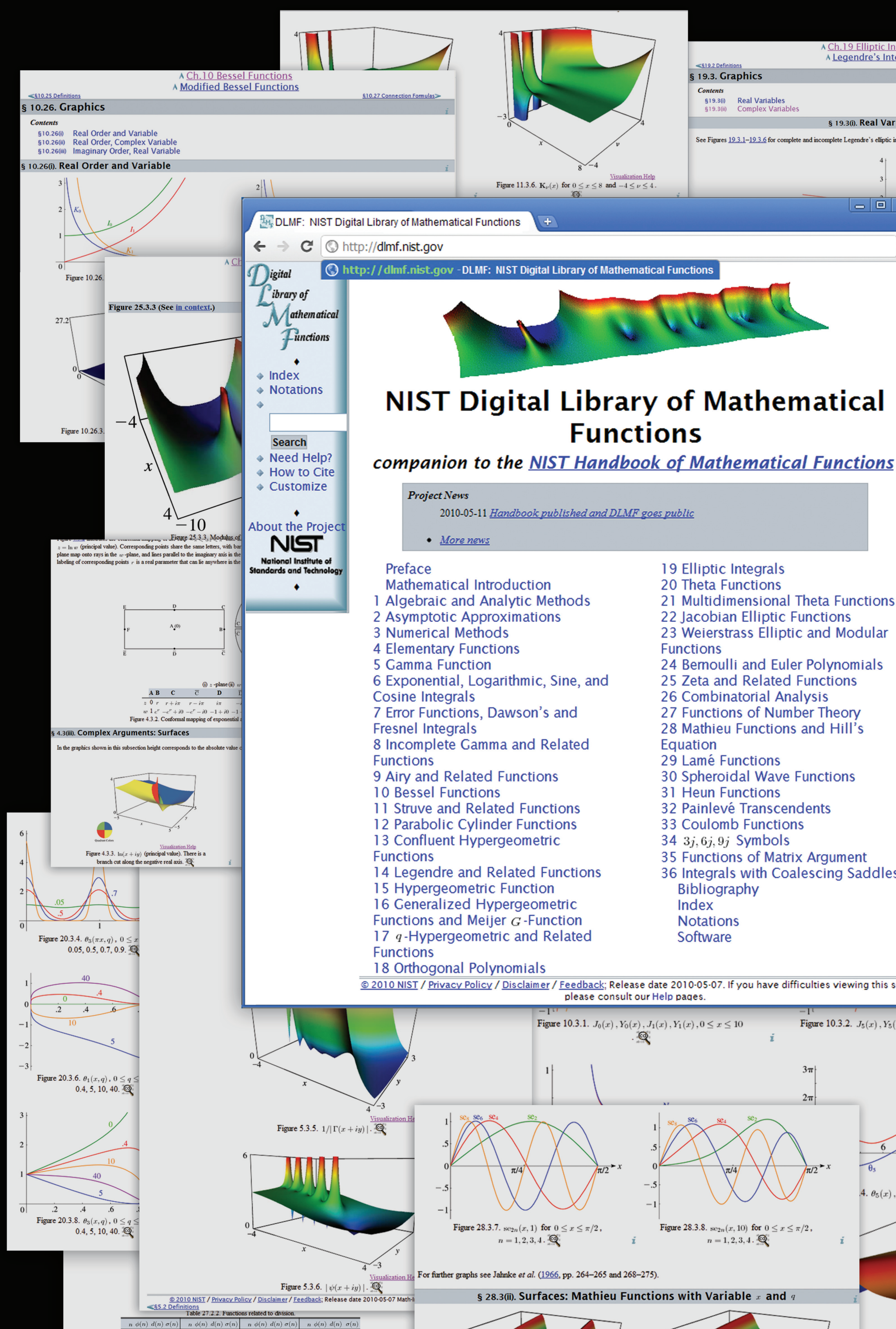
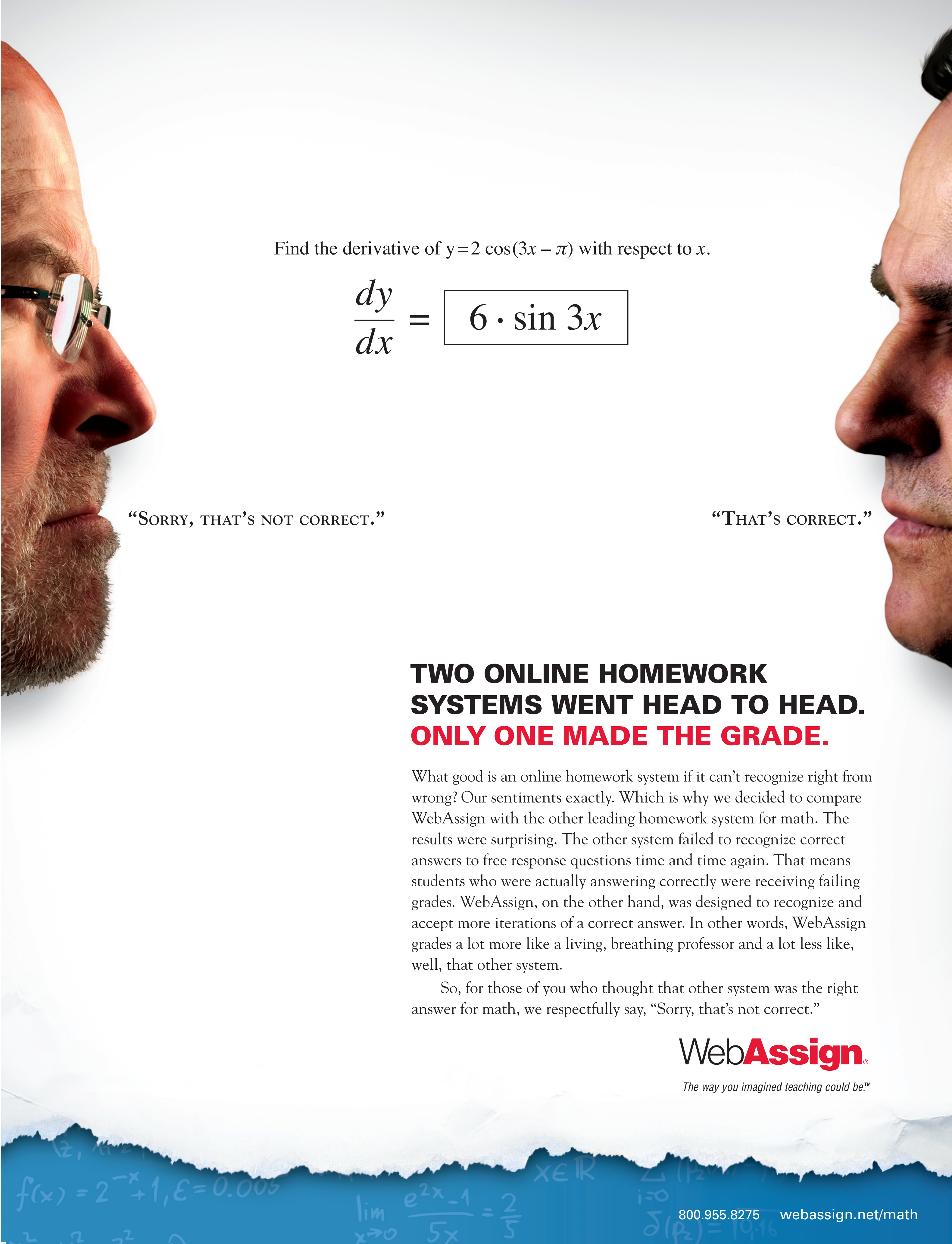


About the Cover:
Special functions
(see page 928)



Find the derivative of $y = 2\cos(3x - \pi)$ with respect to x.
$$\frac{dy}{dx} = \boxed{6 \cdot \sin 3x}$$
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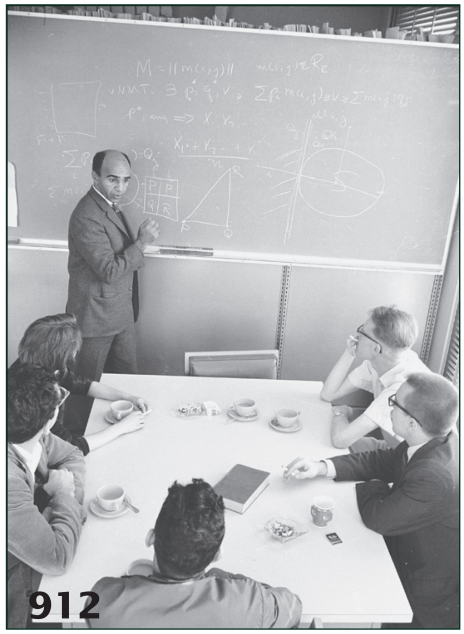
Notices

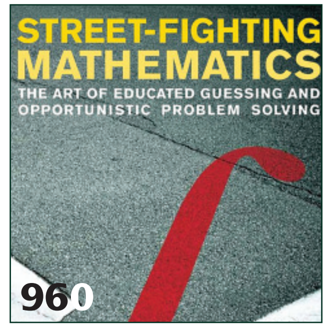
of the American Mathematical Society

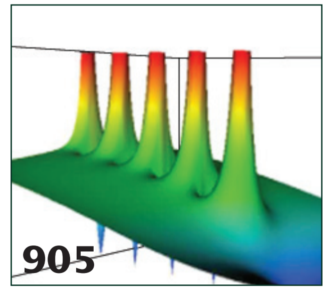
August 2011

Communications

Commentary







Features

In August we explore some new mathematical directions. One of these is mathematics and music by a seasoned musician, now a mathematician. Another is directional regularity for real and complex functions. Yet a third is an announcement of the completion of a twelve-year-long project to produce an update of the classic book of special functions by Abramowitz and Stegun. Finally we provide a detailed and intimate memory of the remarkable statistician David Blackwell.

—Steven G. Krantz, Editor

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Departments

From the AMS Secretary

I thank Randi D. Ruden for her splendid editorial work, and for helping to assemble this issue. She is essential to everything that I do.

—*Steven G. Krantz, Editor*

The Changing Nature of Mathematical Publication

We in the mathematics profession are witnessing significant changes and developments in the publication process. Electronic publishing, which is rapidly supplanting traditional hard-copy publishing, makes new research widely accessible, speeding up the publication process tremendously. Scientific breakthroughs can become part of our *lingua franca* in a matter of hours rather than months.

The purpose of this article is to announce a new publication column, *Scripta Manet*, for the *Notices of the American Mathematical Society*. We wish to address publication issues head-on. What, for example, is now the role of traditional paper journals and books? What does it mean today to "archive" scholarly work?

There is no doubt that the new media for publication have broken down social barriers. In the old days, mathematicians could send their preprints to a select few mathematicians and not to others. Today what is more typical is that a new mathematics paper will go up on the preprint server `arXiv` and then *everyone* can see it instantly. It can only enrich our culture to have more people made an integral part of it.

But there are both positive and negative features to posting a paper on `arXiv`. Because papers on `arXiv` are not refereed, we find here an undifferentiated melange of work; how do we know what is worthwhile and what is not? Is it not possible that readers of `arXiv` will gravitate to the work of established mathematicians and perhaps slight the work of new, younger people? That is an unfortunate side effect that could have a strong impact on our profession.

Furthermore, what are the copyright issues associated with putting our work on `arXiv`? If we ultimately publish our paper in a traditional journal, then how will that journal view our paper being first put on `arXiv`? If someone plagiarizes your work from `arXiv`, then what protections do you have?

Mathematicians and other scholars have long depended on publishing in order to (i) establish the priority of their results, (ii) make their scholarly reputations, (iii) attain tenure, and (iv) qualify for grants and other encomia. Deans and their committees tend to be rather stodgy; they are uncomfortable evaluating tenure cases that are based on electronic publishing. It is a brave new world that nobody completely understands.

Another vector in the modern publishing scene is open access journals. Initiated by people at the National Institutes of Health, these journals reject the traditional business model for an academic journal. Such journals do not have subscribers; they are freely accessible to all who are on the Internet. They are subsidized by each author paying a (nontrivial) fee. Some have argued that this makes journal publishing like a vanity press—those who have the bucks can publish and those who do not cannot. Others have suggested that funding will shift: universities, instead of funneling their money to overpriced traditional journals through subscription fees, will instead provide funds for authors to pay their tithes to the open access journals. We might wonder whether elite, wealthy universities will have the means to make this happen while other universities will not. Is this system in fact re-erecting the social barriers that `arXiv` and other features of the electronic environment have torn down?

Electronic media are clearly shaping our subject in myriad other ways. Mathematical blogging is now a way of life for many researchers. It is now possible to put tentative statements, guesses, and even incorrect arguments on a blog and receive constructive feedback in return. Whatever its merits, a blog will contain largely undifferentiated, perhaps casually formulated, thoughts of dubious value. Is this methodology advantageous for the development of our subject?

Another interesting direction, initiated by Fields Medalist Timothy Gowers and others, is the "polymath project". This initiative gets very large groups of mathematicians—sometimes many hundreds—to work together on a project or a problem. This project has been under way for more than two years now and has already met with some notable successes. It raises interesting questions, such as how the results will get written up, where they will be published, and who will get the credit. It is difficult enough to manage a collaboration of three authors. One shudders to consider controlling three hundred unbridled egos. Nonetheless, this is an exciting new direction in our field.

With issues like these that affect us all, we look forward to this new publication column being a dynamic and informative part of *Notices* discourse. We hope to showcase differing opinions and a broad panorama of information and experience. Our goal is to keep the readership informed and also to provide a forum for many views.

The first contributor to *Scripta Manet* will be Peter Olver, who is the new chair of the Committee on Electronic Information and Communication (CEIC) for the International Mathematical Union. He brings a broad, intriguing perspective to the subject. His topic is the changing nature of the mathematics journal.

Steven G. Krantz
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The inaugural installment of the *Scripta Manent* column, "Journals in Flux", by Peter Olver, will appear in the September 2011 issue of the *Notices*.

Letters to the Editor

Cryptography for Poets

Reading the translated article by Berold and Ye of Tianxin's "Mathematicians and poets", *Notices,* April 2011, 590–596, reminds one of the course often jokingly referred to as Math for Poets.

My premise is this: for a student to succeed in a university he or she should have some reasonable ability either in mathematics or language, coaches notwithstanding.

The first nine weeks of my course covered the traditional topics: logic, algebra, geometry, number theory, graph theory, statistics, and probability. Also student evaluations occurred here. The last week was devoted to cryptography. The final consisted of closed-book multiple choice over the entire course as well as an open-book hour exam about cryptography. Usually five out of a class of thirty wrote a perfect cryptographic exam, and knew it!

The majority of students did not do the last problem using translation rather than substitution cipher. They were told to merely comment about reaching it without solving it, for four out of ten points. (I prefer such admissions to lengthy work which both the student and I know is utter nonsense.)

The first half of this exam involved deciphering an encrypted message with word breaks; simple substitution; statistics of letters of the encrypted message; and in the clear, at least three appearances of "the", two of "and", and more "a" than "I". Then the keyword which constructed the cipher alphabet is found. Here, after duplicates are removed from the keyword, it is the first line of a matrix, then the balance of the alphabet in order fills this partial rectangle. Then column by column in order delivers the cipher alphabet. (Correct completion = sixty points.)

For fifteen points, encipher a short message using a given keyword for a polyalphabetic cipher. A couple of examples for solution involved mod 26 arithmetic while the rest used an included copy of the Vigenère Tableau.

For fifteen points decode a short message written in my private code: 0:D,O,Q; 1:I,J,T; 2:S,Z; 3:E,F; 4:X,Y; 5:U,V,W; 6:C,G; 7:L,M,N, 8:B,P,R; 9:A,H,K. In messages there is usually only one correct letter; however, 8983 yields several words.

In a semester course with more time one may study deciphering polyalphabet ciphers by a computer program, deciphering without word breaks, deciphering when clear in a foreign language. This I prefer to showing off how factoring creates trap-door ciphers. This last is very appropriate in a number theory course.

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(Received April 7, 2011)

Oswald Spengler's Philosophy

The discussion of mathematics and poetry in Cai Tianxin's essay (*Notices*, April 2011) is interesting and comports with the kinship between mathematicians and artists that Oswald Spengler notes in his magnum opus *Der Untergang des Abendlandes* (1918, 1922), a work which puts forth a philosophy of history that predates similar work by Arnold Toynbee—Toynbee is justly remembered as an eminent philosopher of history, while Spengler is unjustly forgotten. Spengler's theory, incidentally, provides an explanation for the difference in taste that he asserts exists between modern (Faustian) mathematics and classical (Apollonian) mathematics.

—Jim Tseng
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(Received April 25, 2011)

A Call for Collaboration

I read the entire March issue's series on mathematics education with great appreciation, but also with bafflement that I live in such a different world. I hope someone can help me make sense of my world, and perhaps offer advice as to how to change it.

From 1988 to 1995 I won fourteen grants for helping elementary school teachers mathematically, reported in my February 2005 *Notices* article, "Racial equity requires teaching elementary school teachers more mathematics", at `http://www.ams.org/notices/200502/fea-kenschaft.pdf`. A combination of political events in New Jersey conspired to stop this very satisfying program that was having a measurable and immeasurable impact on nine northern New Jersey school districts, including those of Newark, Paterson, and Passaic.

Since then an informant has told me of fifth graders in a different nearby nice suburban district being drilled in adding fractions by adding across the numerators and then across the denominators.

After I realized how bad elementary teaching of mathematics is affecting Americans' entire lives, I tried to get at least one course for elementary school teachers relevant to the mathematics they are expected to teach introduced at the university where I was a full professor of mathematics, so I could reach the teachers before they damage or possibly destroy children's mathematical ability. The math educators encouraged and helped me, and the mathematicians regarded the effort with indulgent bemusement.

Fifteen years of struggle yielded no success. The education leadership was adamant that no such course should be offered.

…My efforts to get a requirement in New Jersey for pre-service elementary school teachers to take at least one appropriate mathematics course also seem to lead nowhere. I have been told that there are a dozen New Jersey deans of education adamantly opposed to such a proposal. An email list of over one hundred concerned New Jersey residents seems to have little, if any, access to the powers who decide the requirements for teacher certification.

How do mathematicians and mathematics educators elsewhere obtain the privilege of teaching such courses?

How do they get the needed state requirements passed?

How do they gain access to the power brokers?

How do we focus the attention of national leaders on the importance of teacher knowledge preparation?

Almost all teachers I have known are educable and eager. But nobody can teach what we don't know. Testing, threats, and demeaning the profession will not undo that basic fact.

—*Pat Kenschaft*
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The Impact of Mathematics

Two articles caught my attention in the May issue of *Notices*—"Mathematical intimidation" and the review of the book "The Quants"—for their shared cautionary tale about the potential misuse of mathematics. As a Ph.D. in differential geometry and a member of Congress, I often see firsthand the impact that mathematics has in shaping our country's policies, both for better and for worse.

I deeply enjoyed my studies and professional applications of mathematics and understand how easy it is to be seduced by the beauty of our own craft. We must remember, however, that applications of mathematics have a powerful impact on the world around us. I urge all mathematicians to take note of how our tools—when misused—can have a devastating impact on real peoples' lives. With power and stature comes great responsibility.

—*Jerry McNerney*
Member of Congress
(California's 11th Congressional District)

(Received May 14, 2011)

Correction

Due to a program error while formatting the reference list for the article "How a medieval troubadour became a mathematical figure", by Michael P. Saclolo (May 2010 *Notices*, http://www.ams.org/notices/201105/rtx110500682p.pdf), four of the references were dropped from the list. The complete reference list is printed below.

—*Sandy Frost*

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Directional Regularity vs. Joint Regularity

Marek Jarnicki and Peter Pflug

We start by referring to an experience many of us have had, namely, being diagnosed in a hospital by a computer tomograph. What is the idea behind the computer tomograph investigation? The machine is measuring linewise (directionally) the density of the material, and out of this information a global (joint) picture of the material is created. This kind of principle, "from the simple case to the complicated one", is often used, also for studying various problems in mathematics, e.g., properties of functions in one and many variables. Recall various notions such as continuity, differentiability, harmonicity, real analyticity, holomorphy, etc., which may be defined for functions of one variable and also for functions of many variables. So the problem arises of whether the simpler one-dimensional property along "many" test directions implies the global property. Or, in our language, is joint regularity a consequence of the directional one? Exactly this kind of question will be studied in this article.

To be more precise, let $f : D \times G \longrightarrow \mathbb{C}$ be a function. We say that f is *directionally (separately) regular* (e.g., directionally (separately) continuous) if for all pairs $(a,b) \in D \times G$ the functions $G \ni w \longmapsto f(a,w)$ and $D \ni z \longmapsto f(z,b)$ are regular (e.g., continuous) with respect to the other variable. Notice that directionally continuous functions are sometimes called *linearly continuous*. In the same spirit one says that a function $f : D_1 \times \cdots \times D_n \longrightarrow \mathbb{C}$ is *n-directionally regular* if for all points $(a_1,\dots,a_n) \in D_1 \times \cdots \times D_n$ and every j, $1 \le j \le n$, the function $D_j \ni z_j \longmapsto f(a_1,\dots,a_{j-1},z_j,a_{j+1},\dots,a_n)$ is regular. Instead of speaking of directional regularity we sometimes will also use the term *separate regularity*. We point out that, when we speak of directional regularity, even in $\mathbb{R}^n$, then we always discuss regularity only in directions parallel to the coordinate axes.

In the case in which directional regularity implies joint regularity, one may even sharpen the question in the following way: what are subsets $A \subset D$, $B \subset G$ such that whenever $f(a,\cdot)$, $a \in A$, and $f(\cdot,b)$, $b \in B$, are regular, then f is jointly regular; i.e., we ask how thick the test sets A, B have to be so that joint regularity follows.

On the other hand, if the answer to the problem above is negative, then one should either study the shape of singularities with respect to the joint regularity, exhibit additional conditions under which the joint regularity follows, or find a weaker joint regularity that all such functions share.

So far we have discussed the general idea of the problems we are going to describe. Of course, we expect that the answer will heavily depend on the class of functions discussed, i.e., on the notion of "regular". Therefore, phenomena appearing in different classes of regularity will be discussed in "almost independent" subsections. The reader is free to jump to those of particular interest.

Directional Continuity

In 1821, in his book *Cours d'analyse*, Augustin-Louis Cauchy claimed that if a function f of two real variables is directionally continuous, then it is jointly continuous. As every student nowadays knows, this statement is not correct. Nevertheless,

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it took time until people realized this mistake. Only in 1870, in the book *Abriss einer Theorie der complexen Functionen und der Thetafunctionen einer Veränderlichen* by J. Thomae, could one find a counterexample, which, according to Thomae, is due to E. Heine. The example is the following function defined on $\mathbb{R}^2$:

$$f(x,y) := \begin{cases} \sin(4\arctan\frac{x}{y}), & \text{if } y \neq 0 \\ 0, & \text{if } y = 0 \end{cases}.$$

If we approach the origin along the line $y = tx$ ($t \neq 0$), then we get for $x \neq 0$:

$$f(x,tx) = \sin(4\arctan(1/t)).$$

From here it is obvious that f is not continuous at $(0,0)$ as a function of two variables, although it is directionally continuous.

The example that is nowadays usually taught in classes is the following one due to G. Peano:

$$(*) \qquad f(x,y) := \begin{cases} \frac{xy}{x^2+y^2}, & \text{if } (x,y) \neq (0,0) \\ 0, & \text{if } x = y = 0 \end{cases}.$$

Observe that f is even directionally real analytic but not continuous at the origin. In other words, the directional regularity of f is as good as possible, but nevertheless its weakest joint regularity fails to hold.

Using this example, it is an easy exercise to construct a directionally continuous function $f : \mathbb{R} \times \mathbb{R} \longrightarrow \mathbb{R}$ that is discontinuous exactly at all points with rational coordinates; in particular, the set $S_C(f)$ of all points at which f is not continuous is dense. Moreover, there exists a directionally continuous function $f : [0,1] \times [0,1] \longrightarrow \mathbb{R}$ such that $S_C(f)$ is a full measure set (see G. Tolstov (1949)), i.e., the set of singularities, although small in the sense of topology, is large in the sense of measure theory.

The first general formulation of a weaker joint regularity (to be of Baire class 1) that all directionally continuous functions share was found by R. Baire (1899) in his thesis *Sur les fonctions de variables réelles*. Using modern notation we say that a function $f : A \longrightarrow \mathbb{R}$ ($A \subset \mathbb{R}^n$) is said to be of *first Baire class* (or *Baire class* 1) if there is a sequence of continuous functions $f_j : A \longrightarrow \mathbb{R}$ with $f_j \longrightarrow f$ pointwise. Then the result by Baire reads as follows:

Theorem (Baire 1899)**.** *Any directionally continuous function $f : \mathbb{R} \times \mathbb{R} \longrightarrow \mathbb{R}$ is of first Baire class and $S_C(f)$ is of first Baire category. In particular, each such function is Borel measurable.*

Functions for which S_C is of first Baire category are also known as *pointwise discontinuous* functions.

To comment on the last implication in the former result we quote from W. Rudin's paper "Lebesgue's first theorem" (1981): "Several years ago I used to pose this question (i.e., is a separately continuous function on $\mathbb{R} \times \mathbb{R}$ Borel measurable?) to randomly selected analysts. The typical answer was something like this: 'Hmm—well—probably not—why should it be?' The only group that did a little better were the probabilists. And there was just one person who said: 'Let's see, yes, it is—and it is of Baire class 1—and…'. He knew."

So we propose this question for any math exam.

Moreover, Baire proved the following stronger result.

Theorem (Baire 1899)**.** *If $f : \mathbb{R} \times \mathbb{R} \longrightarrow \mathbb{R}$ is directionally continuous, then there exist sets of first Baire category $A, B \subset \mathbb{R}$ such that $S_C(f) \subset A \times B$.*

This result may give a first idea of how small $S(f)$ should be.

These results have been generalized by Baire in a weak sense to the case of three-directional continuity; in fact, he showed that *any three-directionally continuous function $f : \mathbb{R}\times\mathbb{R}\times\mathbb{R} \longrightarrow \mathbb{R}$ is jointly continuous on dense subsets of all two-dimensional planes parallel to the coordinate axes.*

In arbitrary dimensions it was proved by H. Lebesgue (1905) in "Sur les fonctions représentable analytiquement" that any n-directionally continuous function $f : \mathbb{R}\times\cdots\times\mathbb{R} \longrightarrow \mathbb{R}$ is a *Baire function of class* $n-1$ (i.e., f is a pointwise limit of functions of Baire class $n-2$; continuous functions are functions of Baire class 0). An example in his paper shows that this result is even sharp. Then, in 1919, H. Hahn generalized the three-dimensional result of Baire to n-directionally continuous functions. He proved that, for any n-directionally continuous function and any $(n-1)$-dimensional plane H parallel to the coordinate axes, there exists a dense set H' of points of H such that $H' \cap S_C(f) = \emptyset$. Much later, namely only in 1943, R. Kershner succeeded in giving a general version of the Baire theorem for n-directionally continuous functions. In fact, his result is the following one:

Theorem (Kershner 1943)**.** *Let f be n-directionally continuous on the unit cube $I \times \cdots \times I$.*

(a) *Then $S_C(f)$ is an $\mathcal{F}_\sigma$-set, i.e., a set which is a countable union of closed sets, and all projections of $S_C(f)$ on all coordinate hyperplanes, i.e., $x_j = 0$, are sets of first Baire category.*

(b) *For any subset S of the unit cube in $\mathbb{R}^n$ which satisfies the above assumptions, there is an n-directionally continuous function f on the cube with $S_C(f) = S$.*

Let us add a somewhat strange result by K. Bögel (1926) for the two-dimensional case. Let f depend on the variables x and y. Assume that f is continuous in the direction of x and differentiable in the direction of y, in particular, continuous. Then f is jointly continuous except on a nowhere dense set. Observe that a set of the first category may be strictly larger than a nowhere dense set, so this set of points of discontinuity is really very small. Similar results are also found in the paper by Kershner. The last remark is due to R. L. Kruse and J. J. Deely (1969): if f is n-directionally continuous on $\mathbb{R}^n$ and monotone with respect to the variable x_j for all fixed $(x_1, \dots, x_{j-1}, x_{j+1}, \dots, x_n)$, $j = 1, \dots, n-1$, then f is jointly continuous everywhere.

But this is not the end of the story. Later, questions from above were discussed in more general settings. The component spaces (initially $\mathbb{R}$) were substituted by more general topological spaces. This kind of discussion is nowadays connected with the so-called *Namioka spaces*. We will not go into details here.

In any case, we are wondering why we have never learned about these results in a standard analysis course. We therefore suggest adding this part of interesting mathematics to such courses or, at least, discussing it in seminars following the introductory course.

We would like to point out that we learned most of the above results from the paper "The genesis of separate versus joint continuity" by Z. Piotrowski (1996).

Partial Differentiability

Recall that a partially differentiable function f in $\mathbb{R}^2$ need not even be continuous (see $(*)$). There are also partially differentiable functions that are continuous but that are not totally differentiable. For example take $f : \mathbb{R}^2 \longrightarrow \mathbb{R}$ given as follows

$$(**) \qquad f(x,y) := \begin{cases} \frac{x^2 y}{x^2+x^2}, & \text{if } (x,y) \neq (0,0) \\ 0, & \text{if } x = y = 0 \end{cases}.$$

The reason for this phenomenon lies in the fact that the graph of a jointly differentiable function has to be almost equal (at least locally) with its tangent hyperplane. Of course, this fact is much stronger than to approximate the directional graph by simple lines. In the case in which the partial derivatives are assumed to be continuous at some point, joint differentiability at that point follows (as we are taught in standard analysis courses).

It was already known to Baire that a partially differentiable function in $\mathbb{R}^2$ is differentiable at all points of a dense subset. This result has been sharpened by E. B. van Vleck (1907) in the sense that he only assumed the existence of the partial derivative with respect to the first variable together with the continuity with respect to the second variable.

Moreover, a result due to K. Bögel (1926) shows that any partially differentiable function f in two variables such that $\frac{\partial f}{\partial x}$ is continuous with respect to y and $\frac{\partial f}{\partial y}$ is continuous with respect to x is jointly differentiable except on a set of first category.

This may explain why all examples we present during our analysis course look similar. In each of them, the set of points at which f is not totally differentiable is in some sense very small.

Nevertheless, for any $\varepsilon \in (0,1)$ there exists a function $f_\varepsilon : [0,1] \times [0,1] \longrightarrow \mathbb{R}$ (due to G. Tolstov (1949)) that has all partial derivatives at all points of the square $[0,1] \times [0,1]$ but for which the measure of $S_C(f_\varepsilon)$ is larger than ε. In particular, the set in which f_ε is not jointly differentiable is a set of positive measure.

Now let $f : \mathbb{R} \times \mathbb{R} \longrightarrow \mathbb{R}$ be a partially differentiable function which, in addition, has locally bounded partial derivatives $\frac{\partial f}{\partial x}$, $\frac{\partial f}{\partial y}$. Then f is locally Lipschitz and therefore, using a result of H. Rademacher (1919), almost everywhere jointly differentiable. Nevertheless, (**) shows that there may exist points at which such a function is not differentiable.

Finally, let us also mention a result of J. Boman (1967), who discusses the situation in which the regularity information is known for a lot of test curves, not only along lines parallel to the axes.

Theorem (Boman 1967)**.** (a) *Let $f : \mathbb{R}^n \longrightarrow \mathbb{R}$ and assume that $f \circ u \in C^p(\mathbb{R}^n)$ for all $u \in C^\infty(\mathbb{R}, \mathbb{R}^n)$, where $p \geq 1$. Then $f \in C^{p-1,1}(\mathbb{R}^n)$, i.e., $f \in C^{p-1}(\mathbb{R}^n)$ and all partial derivatives of f of order $p-1$ are locally Lipschitz.*

(b) *There is an f as in* (a) *such that $f \notin C^p(\mathbb{R}^n)$.*

We note that we have mentioned only a special case of Boman's result.

This discussion shows that, in comparison with directional continuity, the situation does not change dramatically. To obtain better results one has to discuss big varieties of test curves. Nevertheless, one gets only a weaker joint regularity.

Directionally Lipschitz

It is a simple observation that every uniformly partially Lipschitz function is jointly Lipschitz. We will discuss certain analogues (involving also derivatives). For $0 < \alpha \leq 1$ let $\Lambda_\alpha(\mathbb{R}^k)$ denote the space of all functions $f : \mathbb{R}^k \longrightarrow \mathbb{R}$ that satisfy the Hölder condition with exponent α. If $\alpha > 1$, then

$$\Lambda_\alpha(\mathbb{R}^k) := \left\{ f \in C^1(\mathbb{R}^k) : \frac{\partial f}{\partial x_1}, \dots, \frac{\partial f}{\partial x_k} \in \Lambda_{\alpha-1}(\mathbb{R}^k) \right\}$$

is the *α-order Lipschitz space.* S. Bernstein (1912) proved a first version of the following general result.

Theorem. *Let $\alpha > 0$ and let $f : \mathbb{R}^n \longrightarrow \mathbb{R}$ be partially of class $\Lambda_\alpha(\mathbb{R})$ with*

(†)
$$\sup\{\|f(x_1, \dots, x_{j-1}, \cdot, x_{j+1}, \dots, x_n)\|_{\Lambda_\alpha(\mathbb{R})} : x \in \mathbb{R}^n, \\ j = 1, \dots, n\} < +\infty.$$

Then $f \in \Lambda_\alpha(\mathbb{R}^n)$.

Of course, the main point of the theorem is the case $\alpha > 1$. Note that (*) shows that the conclusion may be false without (†).

Two different proofs are presented by S. G. Krantz (1983).

As an immediate consequence we get: if a function $f : \mathbb{R} \times \mathbb{R} \longrightarrow \mathbb{R}$ admits $\frac{\partial^2 f}{\partial x^2}$ and $\frac{\partial^2 f}{\partial y^2}$ and both "pure" derivatives satisfy the uniform Lipschitz condition, then the function is of class C^2. The question arose of what might happen if the pure second derivatives are only assumed to be continuous. An example (based on discussion of special logarithmic potentials) was given by B. S. Mitjagin (1959). Below we present a simpler explicit one due to V. I. Judovič (which may be found in the book of O. V. Besov, V. P. Il'in, S. M. Nikol'skiĭ (1978)).

Let $\mathbb{B}_2 := \{(x, y) \in \mathbb{R}^2 : x^2 + y^2 < 1\}$,

$$f(x, y) := \begin{cases} xy \log(-\log(x^2+y^2)), & \text{if } (x, y) \in \mathbb{B}_2 \setminus \{(0, 0)\} \\ 0, & \text{if } x = y = 0 \end{cases}.$$

Then $f \in C^1(\mathbb{B}_2) \cap C^\infty(\mathbb{B}_2 \setminus \{(0, 0)\})$, f is partially C^2, and the partial derivatives $\frac{\partial^2 f}{\partial x^2}$, $\frac{\partial^2 f}{\partial y^2}$ are continuous on $\mathbb{B}_2$, but $\frac{\partial^2 f}{\partial x \partial y}(0, 0)$ does not exist, and $\lim\limits_{(x,y)\to(0,0)} \frac{\partial^2 f}{\partial x \partial y}(x, y) = +\infty$.

The above theorem may be extended to the case of Sobolev spaces. A first attempt was made also by S. Bernstein (see *Collected Works*, vol. I, 1952, pp. 96–98 (in Russian)). Let $W^s(\mathbb{R}^k)$ be the space of all functions $f : \mathbb{R}^k \longrightarrow \mathbb{R}$ whose derivatives of order $\leq s$ are in $L^2(\mathbb{R}^k)$.

Theorem. *Let $s > 0$ and let $f : \mathbb{R}^n \longrightarrow \mathbb{R}$ be partially of class $W^s(\mathbb{R})$ with*

$$\sup\{\|f(x_1, \ldots, x_{j-1}, \cdot, x_{j+1}, \ldots, x_n)\|_{W^s(\mathbb{R})} : x \in \mathbb{R}^n, \; j = 1, \ldots, n\} < +\infty.$$

Then $f \in W^s(\mathbb{R}^n)$.

Applying this result, it turns out that the mixed second-order derivatives of Judovič's example, although they have a singularity at the origin, are locally square integrable.

Notice that the assumption of uniform boundedness forces the function under discussion to behave in a similar way along nearby test directions. This explains the joint regularity in the above results.

Looking at the above three subsections, one might get the impression that, working from the point of view of real analysis, directional regularity (without additional assumptions) never implies joint regularity. But this is not the whole truth, as we will see now.

Directional Holomorphy

For an open set $\Omega \subset \mathbb{C}^k$, let $\mathcal{O}(\Omega)$ be the space of all functions holomorphic on Ω.

Let $D \subset \mathbb{C}^p$, $G \subset \mathbb{C}^q$ be domains. We say that a function $f : D \times G \longrightarrow \mathbb{C}$ is *directionally (separately) holomorphic* (and we write $f \in \mathcal{O}_s(D \times G)$), if $f(a, \cdot) \in \mathcal{O}(G)$ for each $a \in D$ and $f(\cdot, b) \in \mathcal{O}(D)$ for each $b \in G$.

Obviously, $\mathcal{O}(D \times G) \subset \mathcal{O}_s(D \times G)$. The problem is whether equality holds, i.e., whether every directionally holomorphic function is jointly holomorphic. For $f \in \mathcal{O}_s(D \times G)$, let $S_{\mathcal{O}}(f)$ denote the set of all points $(a, b) \in D \times G$ such that f is not jointly holomorphic in any neighborhood of (a, b).

At the end of the nineteenth century, using Cauchy integral representation, it was well known that every continuous directionally holomorphic function is jointly holomorphic, i.e., $\mathcal{O}_s(D \times G) \cap C(D \times G) = \mathcal{O}(D \times G)$. Next, using classical methods from that time, W. F. Osgood (1899, 1900) proved that if $f \in \mathcal{O}_s(D \times G)$ is locally bounded, then f is continuous and, consequently, $\mathcal{O}_s(D \times G) \cap L^\infty_{\text{loc}}(D \times G) = \mathcal{O}(D \times G)$. He also proved that for every $f \in \mathcal{O}_s(D \times G)$, the set $S_{\mathcal{O}}(f)$ is nowhere dense. Moreover, he made an observation that in order to prove that $\mathcal{O}_s(D \times G) = \mathcal{O}(D \times G)$ (for arbitrary p, q, D, G) we only need to check (for $p = 1$) the following lemma.

Lemma (Hartogs lemma (1906))**.** *Let $\mathbb{C}^p \times \mathbb{C}^q \supset \mathbb{B}(r) \times \mathbb{B}(s) \xrightarrow{f} \mathbb{C}$ ($\mathbb{B}(a, r)$ stands for the Euclidean ball centered at a with radius r, $\mathbb{B}(r) := \mathbb{B}(0, r)$) be such that $f(a, \cdot) \in \mathcal{O}(\mathbb{B}(s))$ for every $a \in \mathbb{B}(r)$ and $f \in \mathcal{O}(\mathbb{B}(r) \times \mathbb{B}(\delta))$ for some $0 < \delta < s$. Then $f \in \mathcal{O}(\mathbb{B}(r) \times \mathbb{B}(s))$.*

In his proof Hartogs used for the first time methods from potential theory in complex analysis. But finally it turned out (see K. Koseki (1966)) that this lemma can also be verified with a pure complex analysis argument. Hartogs also observed that the lemma is not true without the assumption that $f \in \mathcal{O}(\mathbb{B}(r) \times \mathbb{B}(\delta))$ for some $0 < \delta < s$. Thus we have the following fundamental result.

Theorem (Hartogs theorem (1906))**.** *$\mathcal{O}_s(D \times G) = \mathcal{O}(D \times G)$ (for arbitrary p, q, D, G).*

A more general question is to allow nonlinear fibers—a first step in this direction was done by G. M. Chirka (2006 = 1906 + 100).

The Hartogs lemma suggests the following problem, called the *Hukuhara problem*. We are given two domains $D \subset \mathbb{C}^p$, $G \subset \mathbb{C}^q$, a nonempty set $B \subset G$, and a function $f : D \times G \longrightarrow \mathbb{C}$ that is *directionally holomorphic* in the following sense: $f(a, \cdot) \in \mathcal{O}(G)$ for every $a \in D$, $f(\cdot, b) \in \mathcal{O}(D)$ for every $b \in B$. We ask whether $f \in \mathcal{O}(D \times G)$.

In the situation above we write $f \in \mathcal{O}_s(\boldsymbol{X})$ with $\boldsymbol{X} := (D \times G) \cup (D \times B)$. Notice that from the point of view of set theory, the set $\boldsymbol{X}$ is nothing other than the Cartesian product $D \times G$, which is, of course, independent of B. Writing $\boldsymbol{X} = (D \times G) \cup (D \times B)$ we point out the role played by the test set B.

Observe that the answer must be negative if B is too "thin". For example, if $B := g^{-1}(0)$, where $g \in \mathcal{O}(G)$, $g \not\equiv 0$, then for *arbitrary* function $\varphi : D \longrightarrow \mathbb{C}$, the function $f(z,w) := \varphi(z)g(w)$, $(z,w) \in D \times G$, belongs to $\mathcal{O}_s(\boldsymbol{X})$.

M. Hukuhara (1942) proved an analogue of Osgood's result (with less "horizontal" test directions) showing that if B is an identity set at a point $b_0 \in G$ (i.e., for any open connected neighborhood U of b_0 and $f \in \mathcal{O}(U)$, if $f = 0$ on $B \cap U$, then $f \equiv 0$), then every locally bounded function $f \in \mathcal{O}_s(\boldsymbol{X})$ is holomorphic on $D \times G$, i.e., $\mathcal{O}_s(\boldsymbol{X}) \cap L^\infty_{\mathrm{loc}}(D \times G) = \mathcal{O}(D \times G)$.

It was T. Terada who finally answered the question raised by Hukuhara, applying results of *pluripotential theory*—a new tool at that time.

Theorem (Terada 1967, 1972). *If B is not pluripolar (i.e., B is not "thin" from the point of view of the pluripotential theory), then $\mathcal{O}_s(\boldsymbol{X}) = \mathcal{O}(D \times G)$. Moreover, if D is bounded and B is a pluripolar set of type $\mathcal{F}_\sigma$, then $\mathcal{O}_s(\boldsymbol{X}) \subsetneq \mathcal{O}(D \times G)$.*

Just a few words to get an intuitive meaning of the notion "pluripolar". Recall that a convex function on $\mathbb{R}$ may be thought of as a sublinear function, i.e., whenever this function is majorized on the boundary of any subinterval by a linear function, then the same remains true inside of the interval. Note that linear functions are nothing other than the solutions of the simple differential equation $u'' = 0$. Subharmonic functions in the complex plane may be understood in the analogous sense substituting $u'' = 0$ by $\Delta u = 0$, Δ is the Laplace operator. And finally, plurisubharmonic functions are essentially functions that are subharmonic in all complex directions. By $\mathcal{PSH}(\Omega)$ we denote all plurisubharmonic functions on an open set $\Omega \subset \mathbb{C}^n$. A set $B \subset \mathbb{C}^n$ is called *pluripolar* if there is a $u \in \mathcal{PSH}(\mathbb{C}^n)$, $u \not\equiv -\infty$, such that $B \subset u^{-1}(-\infty)$.

Summarizing: The reader should be aware of the essential difference between real and complex differentiation—holomorphic functions are much less flexible than differentiable ones. This is so because of the identity principle, even along small (nonpluripolar) sets.

Directionally Polynomial Functions

To understand better the general problem of directional regularity, we first consider the case of polynomials. For $\mathbb{K} = \mathbb{R}$ (resp. $\mathbb{K} = \mathbb{C}$), let $\mathcal{P}(\mathbb{K}^k)$ be the space of all complex polynomials of k real (resp. complex) variables.

Let $\emptyset \neq A \subset \mathbb{C}^p$, $\emptyset \neq B \subset \mathbb{C}^q$, $\boldsymbol{X} := (A \times \mathbb{C}^q) \cup (\mathbb{C}^p \times B)$. We say that a function $f : \boldsymbol{X} \longrightarrow \mathbb{C}$ is *directionally polynomial on $\boldsymbol{X}$*, if $f(a,\cdot) \in \mathcal{P}(\mathbb{C}^q)$ for each $a \in A$ and $f(\cdot,b) \in \mathcal{P}(\mathbb{C}^p)$ for each $b \in B$. Let $\mathcal{P}_s(\boldsymbol{X})$ be the space of all functions directionally polynomial on $\boldsymbol{X}$. Clearly, $\mathcal{P}(\mathbb{C}^p \times \mathbb{C}^q)|_{\boldsymbol{X}} \subset \mathcal{P}_s(\boldsymbol{X})$. The problem is to characterize those pairs of test sets (A,B) for which $\mathcal{P}_s(\boldsymbol{X}) = \mathcal{P}(\mathbb{C}^p \times \mathbb{C}^q)|_{\boldsymbol{X}}$, i.e., every function that is directionally polynomial on $\boldsymbol{X}$ extends to a polynomial of $n := p + q$ complex variables.

A set $C \subset \mathbb{C}^k$ is a *determining set (for polynomials)* if for every $f \in \mathcal{P}(\mathbb{C}^k)$ with $f = 0$ on C vanishes identically. We say that a set $C \subset \mathbb{C}^k$ is a *strongly determining set (for polynomials)* if for every representation $C = \bigcup_{s=1}^\infty C_s$ with $C_s \subset C_{s+1}$, there exists an s_0 such that C_{s_0} is a determining set. Observe that if $C \subset \mathbb{C}^k$ is nonpluripolar, then C is strongly determining. A set $C \subset \mathbb{C}$ is strongly determining iff C is uncountable. The set $C := \{1/k : k \in \mathbb{N}\} \subset \mathbb{C}$ is determining, but not strongly determining.

With this notion at hand we have the following description of directionally polynomially functions.

Theorem (Siciak 1995). *The following conditions are equivalent:*

(i) *A and B are determining, and at least one of them is strongly determining;*

(ii) *for every $f \in \mathcal{P}_s(\boldsymbol{X})$ there exists exactly one $\hat{f} \in \mathcal{P}(\mathbb{C}^p \times \mathbb{C}^q)$ such that $\hat{f} = f$ on $\boldsymbol{X}$.*

We mention that there is a similar result for real-valued functions of two real variables due to Z. Sasvári (1992). As a consequence of the Siciak result (or the one of Sasvári in the case of $\mathbb{R}^2$) we get the following result.

Corollary. *Let $f : \mathbb{K}^p \times \mathbb{K}^q \longrightarrow \mathbb{C}$ be directionally polynomial, i.e., $f(a,\cdot) \in \mathcal{P}(\mathbb{K}^q)$ for each $a \in \mathbb{K}^p$ and $f(\cdot,b) \in \mathcal{P}(\mathbb{K}^p)$ for each $b \in \mathbb{K}^q$. Then $f \in \mathcal{P}(\mathbb{K}^p \times \mathbb{K}^q)$.*

Finally, we quote a result due to R. S. Palais discussing a similar question over an arbitrary field K.

Theorem (Palais 1978). *If K is a field, then a necessary and sufficient condition for every directionally polynomial function $f : K \times K \longrightarrow K$ to be a polynomial function is that K is either finite or uncountable.*

To summarize: to decide whether a function in many variables is a polynomial (in these variables), it suffices to prove its directionally polynomial behavior. Hence in this simple class of functions the directional regularity and the joint regularity coincide. Even more is true. If a function f defined on some cross-subset $\boldsymbol{X} \subset \mathbb{C}^n$ is directionally polynomial in many directions, then f is the restriction of a uniquely defined joint polynomial.

Directional Holomorphy—Crosses

Now we discuss the situation in which we only have few "horizontal" and "vertical" test directions. We are given two domains $D \subset \mathbb{C}^p$, $G \subset \mathbb{C}^q$ and two nonempty sets $A \subset D$, $B \subset G$. Define the *cross* $\boldsymbol{X} := (A \times G) \cup (D \times B)$. A function $f : \boldsymbol{X} \longrightarrow \mathbb{C}$ is said to be *directionally (separately) holomorphic on* $\boldsymbol{X}$ ($f \in \mathcal{O}_s(\boldsymbol{X})$), if $f(a, \cdot) \in \mathcal{O}(G)$ for every $a \in A$ and $f(\cdot, b) \in \mathcal{O}(D)$ for every $b \in B$. We ask whether there exists an open neighborhood $\widehat{\boldsymbol{X}} \subset D \times G$ of $\boldsymbol{X}$ such that every function $f \in \mathcal{O}_s(\boldsymbol{X})$ extends holomorphically to $\widehat{\boldsymbol{X}}$.

Observe that the Hukuhara problem was just the case in which $A = D$ and $\widehat{\boldsymbol{X}} = D \times G$. Notice once again that different crosses may have the same geometric image. In view of the Hartogs theorem, if A and B are open, then $\mathcal{O}_s(\boldsymbol{X}) = \mathcal{O}((A \times G) \cup (D \times B))$.

To get an intuition of the situation we are discussing, have a look at Figure 1.

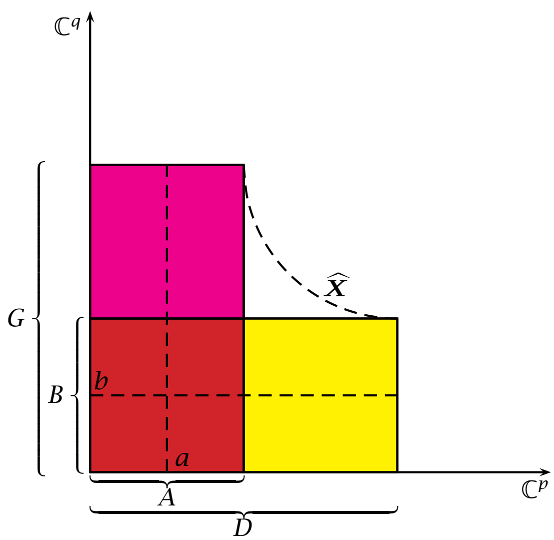

Figure 1.

Investigations of this kind of question began with S. Bernstein (1912) and have been continued in papers by J. Siciak (1969), N. I. Akhiezer and L. I. Ronkin (1973), V. P. Zahariuta (1976), J. Siciak (1981), B. Shiffman (1989), Nguyen Thanh Van and A. Zeriahi (1991, 1995), Nguyen Thanh Van (1997), and O. Alehyane and A. Zeriahi (2001). The problem has been completely solved. The breakthrough method, the so-called double basis method, was due to V. P. Zahariuta (1976). Recently, a new method of proof was found by Viêt-Ahn Nguyên that enables one to formulate the theorem even for arbitrary complex manifolds.

Theorem (Cross theorem (1912–2001))**.** *Assume that A and B are locally pluriregular, i.e., A (respectively, B) is "thick" from the point of view of the pluripotential theory at every point $a \in A$ (respectively, $b \in B$). Then for every $f \in \mathcal{O}_s(\boldsymbol{X})$, there exists an $\hat{f} \in \mathcal{O}(\widehat{\boldsymbol{X}})$ such that $\hat{f} = f$ on $\boldsymbol{X}$ and $\sup_{\widehat{\boldsymbol{X}}} |\hat{f}| = \sup_{\boldsymbol{X}} |f|$, where*

$$\widehat{\boldsymbol{X}} := \{(z, w) \in D \times G : h^*_{A,D}(z) + h^*_{B,G}(w) < 1\}$$

and $h^*_{C,\Omega}$ is the upper regularization of the relative extremal function

$$h_{C,\Omega} := \sup\{u \in \mathcal{PSH}(\Omega) : u \le 1,\ u|_C \le 0\}.$$

The result may reflect how holomorphic structures are rigid—a holomorphic function is in fact completely determined by its values along very small sets of test directions. Notice that in many cases the envelope $\widehat{\boldsymbol{X}}$ may be effectively calculated. To get a feeling of the power of this result, we add a simple example:

Let $A = B = \partial\mathbb{D}$ (here $\mathbb{D}$ stands for the open unit disc in the complex plane) and $D = G = \mathbb{C}$. If $f \in \mathcal{O}_s((\partial\mathbb{D}\times\mathbb{C}) \cup (\mathbb{C}\times\partial\mathbb{D}))$, then f is automatically the restriction of an entire function $\tilde{f} \in \mathcal{O}(\mathbb{C}^2)$.

We point out that, in contrast to real analysis, holomorphic functions are already globally determined by their values along small sets such as $\boldsymbol{X}$.

Directional Real Analyticity

For an open set $\Omega \subset \mathbb{R}^k$, let $C^\omega(\Omega)$ be the space of all complex-valued real analytic functions on Ω.

Let $D \subset \mathbb{R}^p$, $G \subset \mathbb{R}^q$ be domains. A function $f : D \times G \longrightarrow \mathbb{C}$ is said to be *directionally real analytic* ($f \in C^\omega_s(D \times G)$) if $f(a, \cdot) \in C^\omega(G)$ for each $a \in D$ and $f(\cdot, b) \in C^\omega(D)$ for each $b \in G$.

Obviously $C^\omega(D \times G) \subset C^\omega_s(D \times G)$. Observe that the function $f : \mathbb{R} \times \mathbb{R} \longrightarrow \mathbb{R}$,

$$f(x, y) := \begin{cases} xye^{-\frac{1}{x^2+y^2}}, & (x, y) \neq (0, 0) \\ 0, & x = y = 0 \end{cases}$$

is of the class $C^\omega_s(\mathbb{R} \times \mathbb{R}) \cap C^\infty(\mathbb{R} \times \mathbb{R})$ but is not analytic near $(0, 0)$.

For $f \in C^\omega_s(D \times G)$, let $S_{C^\omega}(f)$ be the set of all $(a, b) \in D \times G$ such that f is not jointly real analytic in any neighborhood of (a, b).

The central question is to characterize $C^\omega(D \times G) \setminus C^\omega_s(D \times G)$ and $S_{C^\omega}(f)$ for $f \in C^\omega_s(D \times G)$. The cross theorem may be applied to prove the following sufficient criterion for a directionally real analytic function to be jointly real analytic.

Theorem (Browder 1961, Lelong 1961)**.** *The space $C^\omega(D \times G)$ consists of all $f \in C^\omega_s(D \times G)$ such that for every $(a, b) \in D \times G$ there exists an open neighborhood $U \subset \mathbb{C}^p$ (resp. $V \subset \mathbb{C}^q$) of a (resp. b) with $U \cap \mathbb{R}^p \subset D$ (resp. $V \cap \mathbb{R}^q \subset G$) such that for every $x \in U \cap \mathbb{R}^p$ (resp. $y \in V \cap \mathbb{R}^q$) the function $f(x, \cdot)$ (resp. $f(\cdot, y)$) extends holomorphically to V (resp. U).*

Moreover, results due to J.-S. Raymond, J. Siciak, and Z. Błocki describe precisely the singular sets of directionally real analytic functions.

Theorem (S. Raymond 1989, 1990, Siciak 1990, Błocki 1992)**.** *If $f \in C_s^\omega(D \times G)$, then the projections $\mathrm{pr}_{\mathbb{R}^p}(S_{C^\omega}(f))$, $\mathrm{pr}_{\mathbb{R}^q}(S_{C^\omega}(f))$ are pluripolar as subsets of $\mathbb{C}^p$ and $\mathbb{C}^q$, respectively.*

Conversely, for every relatively closed set $S \subset D \times G$ for which the projections $\mathrm{pr}_{\mathbb{R}^p}(S)$ and $\mathrm{pr}_{\mathbb{R}^q}(S)$ are pluripolar, there exists an $f \in C_s^\omega(D \times G)$ such that $S = S_{C^\omega}(f)$.

Thus singular sets of directional real analytic functions are completely characterized.

Although real analytic functions seem to be very similar to holomorphic ones, they are restrictions of holomorphic functions; the above discussion shows that their basic properties are different.

Directional Harmonicity

For an open set $\Omega \subset \mathbb{R}^k$, let $\mathcal{H}(\Omega)$ be the space of all harmonic functions on Ω.

Let $D \subset \mathbb{R}^p$, $G \subset \mathbb{R}^q$ be domains. A function $h : D \times G \longrightarrow \mathbb{R}$ is said to be *directionally harmonic* ($h \in \mathcal{H}_s(D \times G)$), if $h(a, \cdot) \in \mathcal{H}(G)$ for each $a \in D$ and $h(\cdot, b) \in \mathcal{H}(D)$ for each $b \in G$.

It is clear that $\mathcal{H}_s(D \times G) \cap C^2(D \times G) \subset \mathcal{H}(D \times G)$. In the context of the previous theorem, it is surprising that we have the following result (which also may be obtained as a consequence of the cross theorem).

Theorem (Browder 1961, Lelong 1961)**.** *$\mathcal{H}_s(D \times G) \subsetneq \mathcal{H}(D \times G)$.*

The Extension Theorem with Singularities

So far our directionally holomorphic functions $f : \boldsymbol{X} \longrightarrow \mathbb{C}$ had no singularities on $\boldsymbol{X}$. The fundamental paper by E. M. Chirka and A. Sadullaev (1988) and applications to mathematical tomography (see O. Öktem (1998, 1999)) show that the following is important.

Let $A \subset D \subset \mathbb{C}^p$, $B \subset G \subset \mathbb{C}^q$ be as before, let $M \subset \boldsymbol{X} := (A \times G) \cup (D \times B)$ be fiberwise closed, and let

$$M_{(a,\cdot)} := \{w \in G : (a, w) \notin M\},\ a \in A,$$
$$M_{(\cdot,b)} := \{z \in D : (z, b) \notin M\},\ b \in B.$$

A function $f : \boldsymbol{X} \setminus M \longrightarrow \mathbb{C}$ is said to be *directionally (separately) holomorphic* ($f \in \mathcal{O}_s(\boldsymbol{X} \setminus M)$) if $f(a, \cdot)$ is holomorphic in $G \setminus M_{(a,\cdot)}$ for every $a \in A$, $f(\cdot, b)$ is holomorphic in $D \setminus M_{(\cdot,b)}$ for every $b \in B$. We ask whether there exists a relatively closed set $\widehat{M} \subset \widehat{\boldsymbol{X}}$ such that every function $f \in \mathcal{O}_s(\boldsymbol{X} \setminus M)$ extends holomorphically to $\widehat{\boldsymbol{X}} \setminus \widehat{M}$ (see Figure 2).

Observe that the case in which $M = \emptyset$ reduces to the one we discussed before. A positive solution has been found in a series of papers by O. Öktem (1998, 1999), J. Siciak (2001), and M. Jarnicki and P. Pflug (2001–2008). It turns out that if M

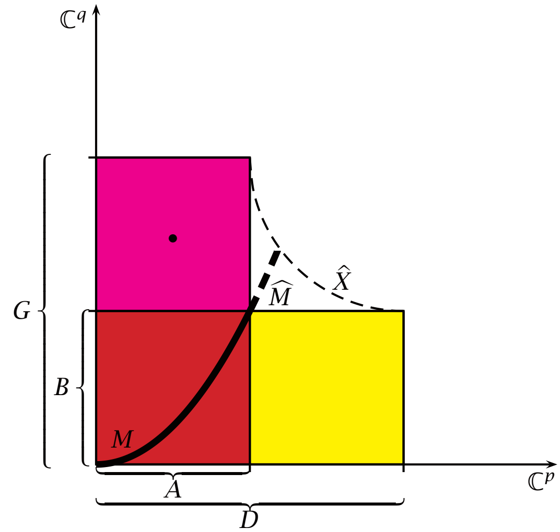

Figure 2.

is fiberwise pluripolar (resp. analytic), then $\widehat{M}$ is pluripolar (resp. analytic). So we meet again the well-known phenomenon in complex analysis that the type of the singularity does not change under holomorphic extensions. For example, take $D = G = \mathbb{C}$, $A = B = \mathbb{R}$, $M := \{(x, x) : x \in \mathbb{R}\}$. Then $\widehat{\boldsymbol{X}} = \mathbb{C}^2$ and $\widehat{M} = \{(z, z) : z \in \mathbb{C}\}$, which is the set of singularities of the function $f(z_1, z_2) := 1/(z_1 - z_2)$. In particular, $\hat{X} \setminus \widehat{M}$ is the maximal extension domain for $\mathcal{O}_s(\boldsymbol{X} \setminus M)$.

We conclude with a simple example due to T. Barth (1975). Let $f : \mathbb{C} \times \mathbb{C} \longrightarrow \overline{\mathbb{C}}$ be given by

$$f(z_1, z_2) := \begin{cases} \frac{(z_1+z_2)^2}{z_1-z_2}, & \text{if } z_1 \neq z_2 \\ \infty, & \text{if } z_1 = z_2 \neq 0 \\ 0, & \text{if } z_1 = z_2 = 0. \end{cases}$$

Observe that now f is a directionally holomorphic map, but, nevertheless, it is not continuous at the origin. This example shows that our story is definitely not finished for holomorphic mappings.

Final Remarks

The results presented here were obtained during the last 100 years. They clearly show that real analysis is very flexible and, therefore, that the possibility to derive something from directional information is very rare. Simultaneously, this leads to a lot of interesting questions to be solved and understood. On the other hand, complex analysis is, in fact, governed by the identity theorem, i.e., it is strongly rigid. That is the reason why Hartogs's result is true. Here the main point is to extend objects as far as possible. Of course, both disciplines have their beauty and challenging problems. Although the rigidity of holomorphic functions is fascinating for us as mathematicians working in several complex variables, there are, of course, other points of view.

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A Special Functions Handbook for the Digital Age

Ronald Boisvert, Charles W. Clark, Daniel Lozier, and Frank Olver

Trivia question: What is the most cited work in the mathematical literature? With an estimated 40,000 citations,[1] the *Handbook of Mathematical Functions* [1] may well be it. Edited by Milton Abramowitz and Irene Stegun (see Figure 1) and released by the National Bureau of Standards in 1964, the *Handbook* was the result of a ten-year project to compile essential information on the special functions of applied mathematics (e.g., Bessel functions, hypergeometric functions, and orthogonal polynomials) for use in applications [2]. The *Handbook* remains highly relevant today in spite of its age. In 2009, for example, the *Web of Science* records more than 2,000 citations to the *Handbook*. That is more than one published paper every five hours—quite remarkable! And the number of citations yearly has been steadily increasing since 1964 (see Figure 2).

Why so many citations? Many refer to the *Handbook* when introducing a special function in their papers; the citation relates the notation used to a precise definition. In this way, the *Handbook* has become a de facto standard for the definition and notation for the special functions. In addition, the *Handbook* succinctly displays the most important properties of the functions for those who need to use them in applications, things like series expansions, integral representations, recurrence relations, limiting forms, asymptotic expansions, and relations to other functions. The fact that the *Handbook* authors had such good taste when selecting material—one can write down an infinite number of mathematical truths for each function, of course—is demonstrated by the journals in which the *Handbook* is cited. The vast majority of citations come not from mathematics journals but from journals in physics and engineering. The *Handbook* has been undeniably *useful*!

But, by several measures, the NBS *Handbook* is also *old*. More than half of its 1,046 pages are tables of function values whose use has largely been superseded by modern numerical software. The field of special functions itself has not stood still in the intervening forty-six years. There have been enormous advances, including new methods of analysis and new classes of well-characterized functions. Finally, the revolution in modern communications has led to unique opportunities for the effective conveyance of technical information to a vast audience.

Recognizing both these problems and opportunities, the National Institute of Standards and Technology (NIST)[2] in 1997 undertook a project to update and modernize the Abramowitz and Stegun *Handbook*. The main goals of the project were to identify those mathematical functions and their properties that are most important in application, to present this information in a concise form accessible to practitioners, and to disseminate it to the widest possible audience.

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[1] *This estimate was produced with the help of the Thomson Reuters* Web of Science. *It is an estimate because the* Handbook *was cited in hundreds of different ways, making a complete harvest of citations quite laborious.*

[2] *NBS became NIST in 1988.*

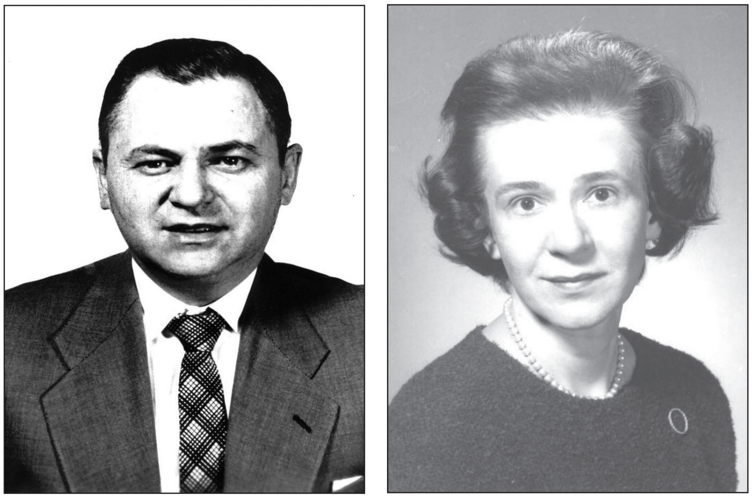

Figure 1. Milton Abramowitz (left) passed away in 1958, just nineteen months after the *Handbook* project was initiated. Irene Stegun (right) then undertook stewardship of the project. Stegun passed away in 2008.

The culmination of that project was the release in May 2010 of the online and freely available NIST Digital Library of Mathematical Functions (DLMF) (`http://dlmf.nist.gov/`) and its print companion, the *NIST Handbook of Mathematical Functions* [3]; see Figure 3.

Mathematical Content

The mathematical content of the DLMF[3] is organized into thirty-six chapters; see Table 1. The first three chapters are methodological in nature; they provide some essential definitions and background needed for the analysis and computation of special functions. Particular care is taken with topics that are not dealt with sufficiently thoroughly in the literature for our purposes. These include, for example, multivalued functions of complex variables, for which new definitions of branch points and principal values are supplied; the Dirac delta function, which is introduced in a more readily comprehensible way for mathematicians; numerically satisfactory solutions of differential and difference equations; and numerical analysis for complex variables. In addition, there is a comprehensive account of the great variety of analytical methods that are used for deriving and applying the extremely important asymptotic properties of the special functions, including exponentially powerful re-expansions of remainder terms, and also double asymptotic properties.

[3]*We use DLMF to refer to both the online handbook and its print companion.*

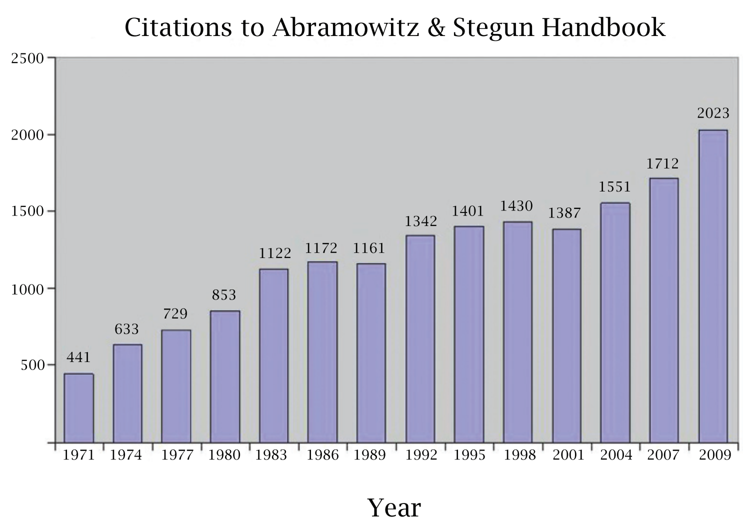

Figure 2. Citations to the NBS *Handbook of Mathematical Functions*, M. Abramowitz and I. Stegun, eds., 1964. Source: *Web of Science*.

The remaining thirty-three chapters each address a particular class of functions. These chapters each have a similar organization. The first section provides a brief description of the notation that is used and its relation to alternate notations. In most cases we have adopted notations in standard use. But we have deviated from this in a few cases where we feel existing notations have serious drawbacks. For example, for the hypergeometric function we often use the notation $\mathbf{F}(a,b;c;z)$ in place of the more conventional ${}_2F_1(a,b;c;z)$ or $F(a,b;c;z)$. This is because $\mathbf{F}$ is akin to the notation used for Bessel functions, inasmuch as $\mathbf{F}$ is an entire function of each of its parameters a, b, and c. This results in fewer restrictions and simpler equations. Other examples are: (a) the notation for the Ferrers functions—also known as associated Legendre functions on the cut—for which existing notations can easily be confused with those for other associated Legendre functions; (b) the spherical Bessel functions for which existing notations are unsymmetric and inelegant; and (c) elliptic integrals for which both Legendre's forms and the more recent symmetric forms are treated fully. Of these, the latter is remarkably powerful: the newer symmetric integrals achieve extensive reductions in numbers of transformations when compared with the classical Legendre forms of the elliptic integrals, from eighty-one to three, for example.

Following the notation section comes the meat of the chapter: an enumeration of mathematical properties, such as the defining differential equation, special values, periods, poles, zeros, elementary identities, series representations, integral representations, transformations, relations to other functions, asymptotic expansions, derivatives, integrals, sums, and products. All of these are presented in the telegraphic style characteristic of the Abramowitz and Stegun handbook. One noteworthy new feature of the DLMF is that references are provided that connect every formula to a proof. Not only is this a means of verification, but it also allows researchers to learn proof techniques that may help them derive variations on the formulae.

In each function chapter a section entitled Graphics provides a set of 2D and 3D views of the functions designed to convey visually their essential features. Complex-valued functions are displayed by showing a 3D surface representing the modulus of the function; the surface is color coded to convey information about the phase (a 4D effect); see Figure 3.

Each function chapter also has sections on mathematical and physical applications. The point here is not to provide a complete or exhaustive treatment of applications but instead to provide references to representative applications to give the reader an appreciation of their wealth and diversity.

Finally, each chapter ends with a section on computation. Here, rather than provide formal algorithms that can be transformed into code, the DLMF provides a set of hints on fruitful numerical approaches with references. Included are indications of key approximations that are particularly relevant to computation.

Some of the progress in the mathematics of special functions over the past fifty years can be seen by comparing the DLMF with the Abramowitz and Stegun handbook (A&S). Fully half the content of A&S was tables of numerical function values. None of these are present in the DLMF, though the volume of technical content (measured in printed pages) is similar. The technical information for classic special functions has been greatly expanded in the DLMF. For example, the topic of Airy functions, which occupies barely five pages as a subsection of the chapter on Bessel Functions of Fractional Order in A&S, has become a first-class chapter of twenty-one pages in the printed DLMF. As another example, the treatment of orthogonal polynomials has expanded from twenty to fifty pages.

In addition, a variety of functions absent in A&S receive full treatment in the DLMF. These include generalized hypergeometric functions, the Meier G-function, q-hypergeometric functions, multidimensional theta functions, Lamé functions, Heun functions, Painlevé transcendents, functions of matrix argument, and integrals with coalescing saddles. The last, for example, includes so-called diffraction catastrophes, which arise in the connection between ray optics and wave optics. Applications include the study of rainbows, twinkling starlight, and the focusing of sunlight by rippling water.

Online-only Content

The online version of the DLMF provides additional technical content in comparison with its print counterpart. For example, in some cases additional instances in a series of formulae, such as weights and nodes of higher-order Gauss quadrature formulae, are available online.

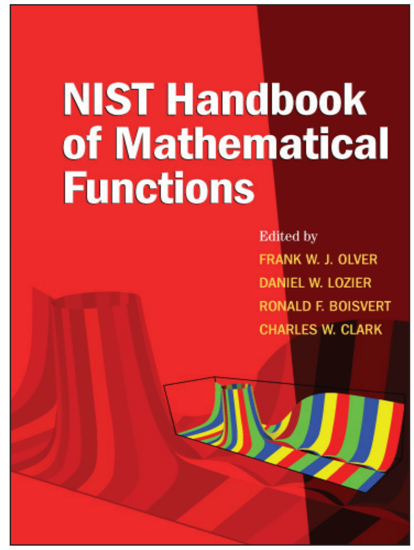

Figure 3. The print companion to the NIST Digital Library of Mathematical Functions.

The online DLMF also has a much larger collection of visualizations, and all 3D visualizations there are interactive [4]. Surface plots are used to display the essential properties of complex-valued functions in the DLMF. See Figure 4, for example, where we display the modulus of the psi function, $|\psi(x + iy)|$ for $-4 < x < 4$ and $-3 < y < 3$. Here the colors merely encode the value of the modulus itself, i.e., they are redundant. However, by clicking on this plot, DLMF users can summon up an interactive 3D visualization in which this can be changed. Users can have the colors correspond to the complex phase, either by a continuous mapping or by a four-color mapping based on quadrant (as in Figure 3). One can also rotate, zoom, and pan the view, change the axes' scaling, etc. So, for example, by viewing from the top, rescaling the z axis to zero, and selecting the continuous phase-color map, one obtains a color density plot of the phase. Finally, a tool is provided to generate a plane parallel to each of the three axes and viewing its intersection with the surface, either with a static plane or as a movie with the plane sweeping through the figure.

The DLMF provides its interactive 3D content in two separate formats: Virtual Reality Modeling Language (VRML) [5] and Extensible 3D (X3D) [6], a newer standard. Eventually both may be replaced by WebGL [7], an emerging standard that is gaining much support. Viewing such 3D interactive content requires a browser plugin, and, given the evolving and somewhat chaotic landscape for this technology, support for various browsers and operating systems is quite uneven. The DLMF Help page provides suggestions for how to obtain free plugins for common systems and browsers.

Another substantial collection of online-only content is information about software for the special functions. In each chapter, a Software section lists research articles describing software development efforts associated with functions covered in the chapter. In addition, a table of links is provided to help users identify available software for each function (`http://dlmf.nist.gov/software/`). Open-source software, software associated with published books, and commercial software are all included. We hope to make this list exhaustive and up-to-date; we invite suggestions for additions.

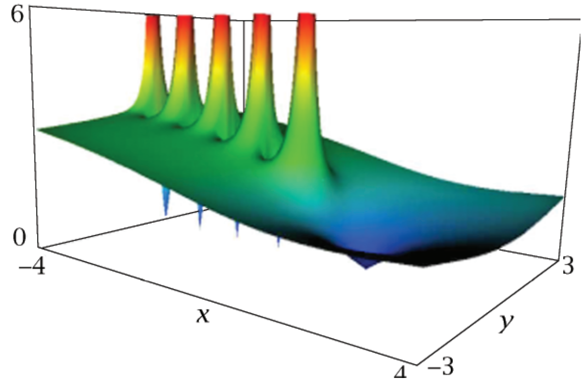

Figure 4. $|\psi(x+iy)|$**, the modulus of the complex psi function.**

The online DLMF also provides a rich set of tools that enhance its use as an interactive reference work. For example, each equation has a link providing the following additional information (metadata):

- The name of each symbol in the equation linked to its definition. This is particularly useful when the equation is encountered as the result of an online search.
- Reverse links to places in the DLMF where the equation is cited.
- A URL that can be used to refer to the equation.
- Alternate encodings of the equation: TeX, MathML, png (image).

The online references have a similarly rich set of links associated with them:

- Links to reviews in the AMS's MathSciNet and Zentralblatt's MATH database.
- Links to full text of articles online.
- Links to software associated with the reference.
- Reverse links to places in the DLMF where the reference is cited.

To ensure that reference links remain stable, the DLMF uses digital object identifiers (DOIs) [8] rather than URLs to refer to online versions of published articles. Developed and maintained by a consortium of publishers, DOIs have emerged as the de facto standard article identifier for the Web. DOIs are resolved to current URLs by presenting them to the resolver service at `http://dx.doi.org/`.

Math Search

While the DLMF does have an extensive index, the main way in which one finds reference information online is through search engines. Existing search technology is largely based upon analysis of words in documents. As a reference work written in a "telegraphic" style, there is just not a wealth of words in the DLMF for a search engine to index. As a result, it was necessary to develop our own math-oriented search engine. The DLMF search engine is based on Lucene [8], a full-featured open-source text-based search engine maintained by the Apache project. To enable math search this tool was augmented with additional data and processing layers [10, 11].

The query interface is a single text box. Query terms can be English text or mathematical expressions. The latter can be expressed in a LaTeX-like form, or using notation used in common computer algebra systems. So, for example, the Bessel function $K_n(z)$ can be referred to as $\mathsf{K_n(z)}$, $\mathsf{BesselK_n(z)}$, BesselK(n,z), or BesselK[n,z]. To enable alternative terminologies and notations in queries each equation is augmented behind the scenes with a number of additional metadata terms which can be used in matches. Examples of DLMF queries are given in Table 2.

To match mathematical expressions, the underlying search engine should understand elementary arithmetic rules like commutative and associative laws. It should also realize that a search for $\sin(x)$ should probably also return expressions with $\sin(y)$, etc. Providing a search engine with such mathematical smarts remains a challenge. Instead, we approximate this using query relaxation. If a user's search does not result in any matches, the system will allow matches with successively larger numbers of intervening symbols or matches with symbols in any order.

Finally, search results must be delivered in order of perceived relevance. Unfortunately, standard relevance metrics used in ranking, where the frequency of occurrence of terms and the size of matching documents are the primary factors, are inadequate for finding objects in a math reference. Instead, the nature of the matching object and the query terms carry considerably more weight. For example, equations which serve as definitions should rank higher, followed by theorems, and so on. Also, query terms that are special function names are given more weight than variable names such as x or t.

The page of search results delivered by the DLMF is a list of matched objects, which can include displayed equations, figures, tables, section titles or text, and references. Matched portions of equations and text are highlighted to help the user understand why the item was matched. Clicking on any item provides a link to see the object in context.

Figure 5. DLMF editors and developers at NIST included the following (l. to r.): Abdou Youssef, Brian Antonishek, Daniel Lozier, Marjorie McClain, Bruce Miller, Bonita Saunders, Charles Clark, Frank Olver, and Ronald Boisvert.

The DLMF search engine is but a tentative first step in the emerging area of math search. Many opportunities for fruitful progress in this field remain.

Math on the Web

Displaying mathematical content on the Web presents its own set of challenges. For the DLMF we have decided to embrace MathML [12], the open community standard for representing mathematics developed by the World Wide Web Consortium (W3C). MathML provides a number of advantages. It allows equations to be scaled automatically when one scales the text size in the browser. It enables accessibility features to be deployed; for example, a MathML browser plugin is available that recites equations. MathML also has the potential to support semantics-preserving exchange of mathematical content.[4] One example is cut-and-paste of equations between Web pages, text editors, and computation systems or other types of interoperability between computer algebra systems.

MathML presents some practical problems, however. First, it is not yet supported by all browsers. It is supported natively in Firefox, but in Internet Explorer only with a specialized (free) third-party plug-in. Opera has some MathML support, but has problems rendering pages with particularly complex notation like the DLMF. Other browsers, such as Safari and Chrome, do not currently provide MathML support. Because of this, the DLMF is delivered in two forms: with MathML and

1.	Algebraic and Analytic Methods
2.	Asymptotic Approximations
3.	Numerical Methods
4.	Elementary Functions
5.	Gamma Function
6.	Exponential, Logarithmic, Sine, and Cosine Integrals
7.	Error Functions, Dawson's and Fresnel Integrals
8.	Incomplete Gamma and Related Functions
9.	Airy and Related Functions
10.	Bessel Functions
11.	Struve and Related Functions
12.	Parabolic Cylinder Functions
13.	Confluent Hypergeometric Functions
14.	Legendre and Related Functions
15.	Hypergeometric Function
16.	Generalized Hypergeometric Functions and Meijer G-Function
17.	q-Hypergeometric and Related Functions
18.	Orthogonal Polynomials
19.	Elliptic Integrals
20.	Theta Functions
21.	Multidimensional Theta Functions
22.	Jacobian Elliptic Functions
23.	Weierstrass Elliptic and Modular Functions
24.	Bernoulli and Euler Polynomials
25.	Zeta and Related Functions
26.	Combinatorial Analysis
27.	Functions of Number Theory
28.	Mathieu Functions and Hill's Equation
29.	Lamé Functions
30.	Spheroidal Wave Functions
31.	Heun Functions
32.	Painlevé Transcendents
33.	Coulomb Functions
34.	$3j$, $6j$, $9j$ Symbols
35.	Functions of Matrix Argument
36.	Integrals with Coalescing Saddles

Table 1. Chapters of the DLMF.

with equations as images. The DLMF server identifies the requesting browser and sends the most appropriate form (though this can be overridden by the user).

The second issue is that MathML is a language for computers, not humans, and hence authoring in MathML is a challenge. See Table 3 for an illustration. Authors are more comfortable writing in LaTeX, and hence this is used as the input language for the DLMF. From this we wished to generate each of XHTML + MathML, HTML + images, and a traditional printed handbook. Generating MathML from LaTeX source is far from trivial, especially if one wants to represent mathematical semantics in the MathML. Such information is simply not available in the LaTeX.

A LaTeX to MathML translator was developed at NIST to confront this problem [13]. LaTeXML is a Perl program that completely mimics the processing of TeX but generates XML rather than dvi.

A postprocessor converts the XML into other formats such as HTML or XHTML, with options

[4] *MathML comes in two flavors: Presentation Markup and Content Markup. The former is focused only on proper display, while the latter includes some semantic-preserving markup. Most current implementations only support Presentation Markup.*

Query	Interpretation
`Gamma(?) = int`	$\Gamma(x) = \int$, for any x. ? is a single-character wildcard.
`int_$^$ BesselJ`	Any definite integral containing a J Bessel function. $ is a multicharacter wildcard, which will match "infinity" and "pi/2", for example
`sum_infinity^infinity BesselJ`	Any sum with limits -∞ to ∞ containing the J Bessel function
`zeta contour integral`	Text search for contour integrals of the zeta function

Table 2. Examples of DLMF queries.

to convert the math into MathML (currently only presentation) or images. The system relies on additional declarations and a variety of heuristics to perform the generation. For example, a style file was developed for the DLMF project that contains special LaTeX markup for common objects such as the special functions and common operators such as derivatives. The discipline imposed by such declarations greatly improves the reliability of the generated MathML without seriously inconveniencing authors. While it was developed specifically for the DLMF project, LaTeXML is a general-purpose tool and has been applied to much broader collections of scientific publications [14].

Putting It All Together

No one institution has the resources and technical expertise to carry out a project like this one alone. NIST is fortunate to have had the cooperation of a large number of experts worldwide in the assembly of the technical information contained in the DLMF. The DLMF chapters were assembled by twenty-nine external authors working under contract to NIST. NIST was responsible for editing the material so as to achieve the necessary depth and breadth of coverage and to ensure a uniform style of presentation. In addition, a set of twenty-five independent validators were enlisted to check the accuracy of the technical content. The extensive validation process is another feature that distinguishes the DLMF from A&S. Development of the DLMF website and its interactive content was performed by NIST staff. Overall responsibility for the project was vested in four NIST principal editors (F. Olver, D. Lozier, R. Boisvert, and C. Clark). They were advised by a group of external associate editors.

A project as complex as this one (both technically and organizationally) takes time. The initial plans for the project were laid out at a workshop held at NIST in 1997. So the DLMF has been some twelve years in the making. The development of A&S itself took about ten years. It is to their credit that NBS/NIST management had the patience to see these efforts through such a long and exacting process.

The Future

NIST is committed to the continued maintenance and development of the DLMF. We already have had lots of suggestions for improvements and extensions. New chapters on probability functions and computer algebra are under consideration. We are also considering bringing back tables, but, rather than static tables, tables generated on demand with certified correct values (quite a challenge!).

We do hope that the DLMF provides a firm foundation for extending the legacy of Abramowitz and Stegun far into the twenty-first century.

Math	TeX	MathML Presentation Markup
$\operatorname{Ln} z = \int_1^z \frac{dt}{t}$	\[\mathop{\mathrm{Ln}\/} \nolimits z=\int _{1}^{z} \frac{dt}{t}\]	<m:math display="block"> <m:mrow> <m:mrow> <m:mi>Ln</m:mi> <m:mo>⁡</m:mo> <m:mi>z</m:mi> </m:mrow> <m:mo>=</m:mo> <m:mrow> <m:msubsup> <m:mo>∫</m:mo> <m:mn>1</m:mn> <m:mi>z</m:mi> </m:msubsup> <m:mfrac> <m:mrow> <m:mi mathvariant="normal">ⅆ</m:mi> <m:mo>⁡</m:mo> <m:mi>t</m:mi> </m:mrow> <m:mi>t</m:mi> </m:mfrac> </m:mrow> </m:mrow> </m:math>

Table 3. Representing equations in TeX and MathML.

Acknowledgements

The DLMF is the result of efforts by more than fifty editors, authors, validators, and developers. A complete list can be found on the DLMF website at `http://dlmf.nist.gov/about/staff`.

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A Tribute to David Blackwell

George G. Roussas, Coordinating Editor

On July 8, 2010, Professor David Blackwell of the University of California, Berkeley, passed away at the age of ninety-one.

In appreciation of this great mathematical scientist, the editor of *Notices of the American Mathematical Society*, Steven Krantz, decided to compile a rather extensive article consisting primarily of short contributions by a number of selected invitees. Krantz, being a mathematician, felt the need for a bridge toward the community of statisticians and probabilists. I had the good fortune to be invited to fill this role and to be given the opportunity to offer a token of my affection and immense respect for Professor Blackwell.

A limited number of invitations were sent to a selected segment of statisticians/probabilists. The response was prompt and enthusiastic. At the final stage, twenty contributions were collected of average length of about one and a half pages. The contributors were selected to represent four groups of people: former students of Professor Blackwell; former students at the University of California, Berkeley, but not Professor Blackwell's students; faculty of the University of California, Berkeley; faculty from other institutions.

The heart of the present article is the set of contributions referred to above.

Deep gratitude is due to the twenty contributors to this article for their response to the extended invitations; for their sharing with the mathematical sciences community at large their experiences with Professor Blackwell; their reminiscences about him; and their expressed appreciation of Professor Blackwell's work.

—*George Roussas*

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Manish Bhattacharjee

In David Blackwell, we have that extraordinary combination of exceptional scholarship and superb teaching that all academicians aspire to but rarely achieve. The teaching aspect was manifest at all levels, ranging from a basic introductory course to cutting-edge research. Anyone who has been at Berkeley for any length of time is familiar with the fact that his section of "Stat-2" class routinely had more students than the combined enrollment of all other sections of the same course, which were typically taught by others. My own introduction to his teaching style was also through an undergraduate course in dynamic programming that I took in my second or third semester as a graduate student. His engaging style of explaining a problem and bringing it to life in this class I believe, on reflection, was a decisive influence on my choosing stochastic dynamic programming and its applications to probability as the primary area for my dissertation research. One of my fond memories of how he brought a problem to life in class concerns a story of how, over a period of time, he and Samuel Karlin wrestled with the problem of proving the optimality of the so-called "bold play" strategy in a subfair "red-and-black" game that is an idealized version of roulette.

The *New York Times* obituary of July 17, 2010, describes him as "a free-ranging problem solver", which of course he truly was. His was a mind constantly in search of new challenges, breaking new ground in different areas every few years with astounding regularity. As Thomas Ferguson told *UC Berkeley News* in an interview recently, Blackwell "went from one area to another, and he'd write a fundamental paper in each." His seminal

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contributions to the areas of statistical inference, games and decisions, information theory, and stochastic dynamic programming are well known and widely acknowledged. He laid the abstract foundations of a theory of stochastic dynamic programming that, among other things, led Ralph Strauch, in his 1965 doctoral dissertation under Blackwell's guidance, to provide the first proof of Richard Bellman's *principle of optimality*, which had remained until then a paradigm and just a principle without a proof!

Each of us who have been fortunate enough to count ourselves to be among his students will no doubt have our personal recollections of him that we will fondly cherish. A recurring theme among such recollections and the lasting impressions they have left on us individually, I believe, would be his mentoring philosophy and style. He encouraged his students to be independent and did not at all mind even if you did not see him for extended periods as a doctoral student under his charge. He trusted that you were trying your level best to work things out yourself and waited until you were ready to ask for his counsel and opinion. A consequence of this, exceptions notwithstanding, was perhaps that his students took a little longer than average to complete their dissertations (although I have no hard data on this), but it made them more likely to learn how to think for themselves.

Richard Lockhart

I was David Blackwell's Ph.D. student from mid-1977 to early 1979, having asked him to supervise after hearing the clearest lectures I had, and have, ever heard. I was Ph.D. student number sixty-two of sixty-five, according to the Mathematics Genealogy Project, where it will be seen that David had four students finish in 1978, two in 1979, and two more in 1981. I remember the chair outside his office where I would wait for my weekly half hour. I remember that he suggested a problem to me by giving me a paper and saying he didn't think he had done everything there that he could have. A few months later I gave up and asked to work on something he was doing currently—programmable sets.

David gave a talk at Stanford in the Berkeley-Stanford colloquium series in which he described these objects. I emerged from the talk amazed by how clear and easy it all was. Trying to tell others about it, I saw quickly that the lecture was a very clear presentation of something not so easy at all and that David had the capacity to organize arguments far, far better than I. The idea is simple as he described it. Imagine a computer represented as a countably infinite sequence of lights. A computer program is a function f that turns off some lights. Which lights are extinguished is a function of the current pattern of on and off lights. You start with some initial pattern of lights, x_0 say, and let the program run by computing $x_1 = f(x_0)$, $x_2 = f(x_1)$, and so on inductively, generating the sequence $x_n; n = 0, 1, 2, \ldots$. The sequence x_n decreases so it has a limit, which we call x_ω. But for a general function f the program might not be finished—x_ω need not be a fixed point of f. So continue applying f inductively, once for each countable ordinal α arriving at x_{ω_1}, the limit at ω_1, the first uncountable ordinal. The limit must actually be reached at some countable ordinal, which may depend on x_0.

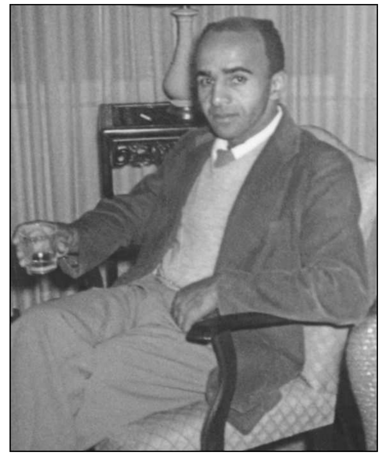

Photo from Paul R. Halmos Photograph Collection, di_07305, Dolph Briscoe Center for American History, U. of Texas at Austin.

David Blackwell early in his career.

The iterates x_α are, of course, iterates of the function f applied to x_0, so that we may think of the functions f_α converging (pointwise) to the limit function f_{ω_1}, and we may wonder what sorts of functions g have the form of such limits if the basic function f is Borel? David looked at the output program f_{ω_1} as a step in defining general functions g between two polish spaces U and V, which were defined by mapping U into the computer's state space by a Borel function, running the program, and then mapping the result into V in a Borel way. Any function admitting such a factorization is Borel programmable (BP), and sets are BP if their indicator functions are. David's 1978 paper, establishing the basic properties of the sets and functions and showing that they had potential as useful objects in probability theory, is typical of his work—very clear, very concise, questions not answered set forth, and not quite four pages long.

In my thesis I solved one or two minor problems connected with these ideas. I was trying to clarify the relation between BP-sets, R-sets studied by Kolmogorov and others, and C-sets. I wanted to know, for instance, if letting the program, encoding, and decoding functions be BP, rather than just Borel, gave you a larger class of sets than the BP class. (John Burgess did the problem properly in *Fundamenta Mathematica* in 1981 using results from logic concerning monotone operators, the lightface and boldface set hierarchies and game quantifiers.) I cannot remember how I came to realize that I needed to think not about sigma fields but about collections of sets like the analytic sets which had fewer closure properties. I now think,

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though, that David planted the seed of this idea in my head one day—just by emphasizing the importance of closure properties to me; I rather suspect that my thesis would not have taken him more than a few weeks to put together and that the result would have been much shorter and far clearer.

I wish I could say I knew him well, but my weekly meetings were all I knew—and they were all mathematics. I was young and shy and David was friendly but formal, I think. I wish we could all learn mathematics from people who see it as clearly as David did.

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John Rolph

I was a statistics graduate student at Berkeley in the mid-1960s. It was my good fortune that David Blackwell taught the inference course to the first-year students in my cohort. I was so taken with him and his teaching that I subsequently enrolled in virtually every course he taught. They embraced a dizzying array of topics, ranging from information theory to game theory to seminars on dynamic programming, bandit problems, search, and related topics. In his teaching as in his research, his interests and knowledge were broad.

David Blackwell was a teacher without parallel. I was particularly impressed by how he could make truly deep concepts transparent—even to the beginner. Indeed, the depth was such that understanding sometimes blossomed mysteriously and gradually. I recall going over class notes after class and only then beginning to understand how deep and subtle some of the concepts he had presented were. To make sure we understood the ideas, a group that included Steve Stigler, Bruce Hoadley, and me made a practice of assigning two to take notes and one to listen intently to his lectures. We would meet afterward, reconstructing the lectures to make sure we all actually understood the concepts and results he covered.

Unlike most faculty members who specialized in one or perhaps two areas, Blackwell was a man of remarkably diverse interests; thus his students worked on a wide variety of topics. While I was there, he supervised dissertations in information theory, dynamic programming, game theory, Bayesian inference, search theory, probability theory, stochastic processes, and stopping rules. He moved from student to student and hence topic to topic with astonishing flexibility and focus.

To say he was a quick study is a remarkable understatement. When you met with him, he would look over what you had done, ask a few probing questions, suggest an approach or two to your current problem, and send you on your way. These sessions typically ran ten to twenty minutes. Indeed, when I finally brought him a draft of what I hoped was my completed dissertation, he read it, asked a few penetrating questions, listened to my responses, then told me I was finished—all in a half hour! This modus operandi obviously worked splendidly—he supervised sixty-five doctoral students during his career.

Although David Blackwell had strong beliefs and points of view, he was not an avid proselytizer. Indeed, it was only gradually that I came to understand and appreciate that David Blackwell was the lone Bayesian in the Berkeley Statistics Department. Interestingly, the content of the first-year inference course he taught us was very similar to the course Erich Lehmann customarily gave—Bayes estimates only came up as a convenient mathematical concept, not as a philosophy of inference. That Blackwell was not a vociferous proponent of his belief in the superiority of the Bayesian approach was typical of his nonconfrontational way of interacting with his colleagues.

David Blackwell was a man we shall all remember with great respect and affection. He was a man of modest demeanor who would solve seemingly intractable problems with mathematical rigor, elegance, and transparency. The impact of his research was both substantial and broad. And he treated his students as equals, both helping them and challenging them to be successful in their research. He was a person of extraordinary character and ability; it was a privilege to know him and to learn from him.

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George Roussas

I joined the Department of Statistics at the University of California, Berkeley (UCB) in the spring semester 1960, after having graduated with a degree in mathematics from the University of Athens, Greece, and having served my two-year military service in the Greek army.

David Blackwell was the chair of the department at that time, and Lucien Le Cam was the graduate advisor. Blackwell would have a brief interview with every incoming graduate student, and it was in this capacity that I first met him. Right after my interview with him, a couple of other, also new, graduate students pointed out to me that we had a black man as chair of the department. In a way,

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I was taken by surprise, and I responded "come to think of it, we certainly do!" Professor Blackwell's personality was overwhelmingly strong and yet gentle and enchanting, radiating kindness around him. These attributes transcended any trivialities such as noticing the color of his skin. Besides, my cultural background was alien to it.

The UCB campus was an earthly paradise, and the faculty of the department were like Olympian figures to me in the statistics pantheon. I had the utmost respect and admiration for all and each one of them.

Nevertheless, some did stand out, as it were. Thus it was the grand old man Jerzy Neyman from whom, foolishly, I never took a course. He was nice to me, and more than once he recounted his experiences in Greece as a member of a certain commission soon after World War II. It was Michel Loève from whom I took my first course in probability and who inspired me with rigor and deep interest in the subject matter. Later, I also took his year-long course in probability and stochastic analysis. It was the mathematician-philosopher Edward Barankin from whom I learned measure-theoretic probability, and I was also introduced to time series analysis and sufficiency. It was Lucien Le Cam from whom I managed to chip away bits of his vast knowledge of asymptotics in statistics. They were destined to play a formative role in my academic career.

And it was David Blackwell who was destined to be my thesis advisor under some peculiar circumstances.

If I remember well, it was in the early 1960s that Lester Dubins was offering a seminar based on his book (coauthored with Jim Savage) *How to Gamble if You Must: Inequalities in Stochastic Processes*. Blackwell was attending that seminar, as well as a fair number of students, including myself. At the end of each lecture, Blackwell would suggest a number of open questions for possible thesis topics. It was such a question that he brought to my attention and insisted that I look into. Indeed, I did, and in a couple of months I asked for an appointment with him to report accordingly. At that time, he was advising a large number of students, and his appointments were limited by necessity to a half-hour block of time. Apparently, he was pleased by what he read, was very encouraging, and also made a number of concrete suggestions. After another couple of sessions like this, he decided that the solution that I arrived at was what he expected. Encouraged by this, I asked whether I could combine this piece of work with another paper on asymptotics, which was already accepted for publication in the *Annals of Mathematical Statistics*, to make up my thesis. Blackwell's response was as always brief and clear-cut. "To me, this by itself is more than enough."

And that is how I had the privilege and honor to be David Blackwell's student.

From the courses I took from him (one in game theory and the other in coding/information theory) I saw firsthand how a great scientist can also be an inspiring and superb teacher. From my interaction with him, as his advisee, I could not help but admire the clarity of his thoughts, articulated in an amazingly brief and simple way. At the same time, his polite disposition and abundant kindness had absolutely no match.

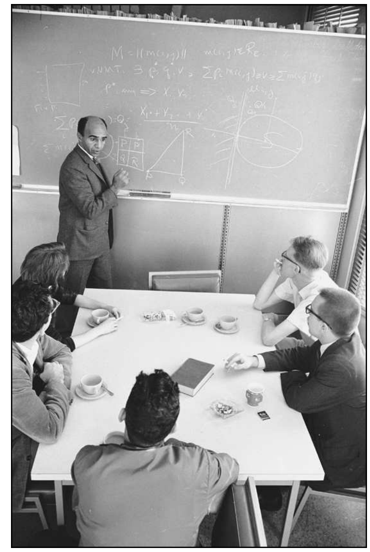

Photo courtesy of Getty Images.

Blackwell teaching a class in game theory at UC-Berkeley.

Soon after I was conferred my Ph.D. degree in 1964, I had the opportunity to host a dinner party for Professor and Mrs. Blackwell in a rather original and upscale restaurant in the Bay area (I believe it was called the Nero's Nook), located in the Los Gatos area. It was apparent that all three of us had a truly enjoyable time.

After I moved to the University of Wisconsin-Madison (UWM), the first time that I met him was in 1972 during the Sixth (and last) Berkeley Symposium in Statistics and Probability. The next ten years or so I spent overseas, at the University of Patras, Greece, and I more or less lost contact with him except for a Christmas card. In 1984 I dropped by UCB after I returned to the West Coast (at the University of California, Davis). In Berkeley, I had the opportunity to have lunch with Edward Barankin (in the restaurant of the Durant Hotel), who, unfortunately, succumbed to cancer soon thereafter. David Blackwell received me very warmly and invited me for lunch at the canonical fish restaurant in Berkeley (Spenger's Fresh Fish Grotto). Also, he expressed his satisfaction that one of his old students did fairly well as a senior faculty member now (full professor at UWM and chair of applied mathematics at the University of Patras) and also as an academic administrator (dean of the School of Physical and Mathematical Sciences at Patras and also chancellor of the same university). However, for me, David Blackwell remained "Professor Blackwell" as an expression of my utmost respect for him and also because of my European early upbringing. But this would not do anymore for Blackwell. On the spot he put me in a difficult dilemma; "Either you call me David or I will never talk to you again!" So, Professor Blackwell became David for me henceforth.

Once at UCD, I was given the opportunity to drop by UCB, but not as often as I would have liked. From what remained of the old guard, Blackwell and Le Cam were the people that I would always visit.

It was in early June 2010 when we received an email message at UCD from Bin Yu, the current chair of the Department of Statistics at UCB, that David was not doing well. I was about to depart for the annual pilgrimage to Greece (on June 13), but I did make a concerted effort to obtain a brief visit with David before my departure. That effort was not successful. I resolved to try again soon after my return (July 7). Unfortunately, that effort never came to be; David Blackwell departed on July 8.

His memory will remain alive among all those who were fortunate enough to know him and to profit from his wisdom and his gentle and kind disposition. For me, David Blackwell was and will remain the role model of a great mathematician, an inspiring teacher, and a superb human being.

Howard Tucker

David Blackwell was a considerable influence in my life. This influence is best summarized in my dedication of a joint paper I was invited to submit for the *I.M.S. Lecture Notes Monograph* series in his honor, which stated, "To David Blackwell, who with his characteristically concise sentences taught me, among other things, how to write a mathematics paper, how to look at mathematics, how to welcome responsibility and how to face one's more mature years, this paper is affectionately dedicated."

When David arrived at Berkeley in 1954 I was beginning my last year as a graduate student. My hazy recollection of my first interaction with him was that I was appointed as his teaching assistant for the graduate course in probability at the measure-theoretic level. When I asked him what he wanted me to do during the two one-hour sessions per week for the semester, his instructions were for me to do what I felt I should do for the six or seven students in the class. Since he wanted to cover other topics, I had a very enjoyable time for the semester or the year (I forget which) going through the recently published Gnedenko and Kolmogorov book on limit distributions.

I received my Ph.D. in mathematics in June 1955 and am listed as David's first doctoral student. This occurred as follows. The problem that I was working on starting in 1953 was one suggested by Professor J. Neyman. However, some time after David arrived at Berkeley, Neyman asked him if he would be available to advise me in the throes of putting the dissertation into its final shape. Among other things during that period, he showed me how to write a mathematics paper, which is recalled in the dedication quoted above. So somehow David was appointed chairman of my committee, and I am listed as his first doctoral student. This was and is a great honor for me.

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Roger J.-B. Wets

I first thought I would devote this short contribution to a couple of remarkable technical achievements of David Blackwell and how they influenced subsequent research. This would have included the deep insight provided by his elegant proof of Lyapunov's theorem about the range of a vector measure, about his seminal articles laying the foundations of dynamic programming, and so on. But it is in his role as a lifelong advisor and model that his influence turned out to be most significant.

It is impossible to find any information about David that does not refer to him as an outstanding teacher, and indeed he was. He liked his classes to be scheduled as early as reasonable. The first course I took with him was an undergraduate course on dynamic programming, in which he mostly covered his own development of the field. It was listed as an undergraduate course, I suppose, on the basis that he didn't require much more than a decent background in real analysis and linear algebra. But one could never have guessed that it was an undergraduate class on the basis of the student body. There might have been one or two smart undergraduates lost in the audience, but the rest consisted mostly of graduate students in operations research and statistics and a not insignificant number of faculty members. In addition to remembering that homework assignments were extensive, instructive, and relatively hard, I was fascinated by the constructive approach; not just whether it exists or might be done but the fact that the results were derived in such a way that suggested the potential of solution procedures. I didn't realize at the time how strongly it would eventually influence my own research strategy.

After I took a couple more courses with him and chose to work in stochastic optimization, David became a natural coadvisor of my thesis. The subject stochastic programming (decision making under uncertainty) had been proposed by G. B. Dantzig.

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I was pleased but not surprised by David's acceptance to act as coadvisor. But his advice/comments could be quite candid and to the point. The first time I went to discuss what I was planning to do, I gave a too-succinct version of the class of questions I was going to consider, and David bluntly told me "but that's just finding the minimum of an expected function", and he definitely was not impressed. When, a bit later, I explained that this "function" was not a simple one but involved not just an objective but also (complex) constraints, he revised his assessment to "Oh, that, make sure you first handle some manageable cases", and he immediately started with a couple of suggestions that eventually turned up as illustrations in my thesis.

He had played, more than once, the role of the "wise uncle" for students interested in optimization who were concerned about getting a degree in a field whose mathematical standing wasn't yet well established or recognized. They somehow felt that they could confide their concerns to him and would then receive the appropriate advice. He could be quite plainspoken in such situations and simply told the hesitating student, "You are telling me that you are interested in area A, but would consider getting a degree in statistics, how can this make sense?" For one of my friends, this advice turned out to be exactly what was needed, and it resulted in a brilliant, mathematically rich career.

I didn't return to statistics until it became difficult to ignore the ubiquitous lack of statistical data available to construct reliably the distribution of the random quantities of a stochastic optimization problem. My approach was based on the idea of incorporating in the estimation problem all the information available about the stochastic phenomena, not just the observed data but also all nondata information that might be available, and relying on variational analysis for the theoretical foundations and optimization techniques to derive nonparametric, as well as parametric, estimates. This didn't look like an easy sale to either frequentist or Bayesian statisticians. So, I went to see David, by then professor emeritus. After all, this could be fitted in the framework of the theory of games and statistical decisions. This time, it didn't take him more than a few minutes to understand and encourage me to pursue this approach. Of course, he also immediately suggested further possibilities and reserved a place for a lecture in the Neyman Seminar, as well as time for further discussions.

On repeated occasions, David provided this steady anchor that made you feel that what you were trying to do was or was not worthwhile, and, given the wide scope of his interests and knowledge, this always turned out to be an invaluable resource. Thanks, professor extraordinaire, David Blackwell.

Peter Bickel

I first met David Blackwell when I took his course on information theory during my first year as a doctoral student. David had chosen as a text Jack Wolfowitz's *Information Theory for Mathematicians*, which, as the title suggests, was somewhat dry. David made the subject come to life. His style was well established. Strip the problem of all excess baggage and present a solution in full elegance. The papers that I read of his, such as those on the Blackwell renewal theorem and on Bayesian sequential analysis/dynamic programming, all have that character. I didn't go on in information theory, but I didn't foreclose it. My next memorable encounter with David, or rather the strength of his drinks, was at a party he and Ann gave for the department. When I declined his favorite martini he offered Brandy Alexanders. I took two and have trouble remembering what happened next!

And then I had the great pleasure and good fortune of collaborating with David. I was teaching a decision theory course in 1966, relying heavily on David and Abe Girshick's book, *Theory of Games and Statistical Decisions*. I came across a simple, beautiful result of theirs that, in statistical language, can be expressed as: If a Bayes estimator is also unbiased, then it equals the parameter that it is estimating with probability one. In probabilistic language this says that if a pair of random variables form both a forward and a backward martingale, then they are a.s. equal.

Unbiasedness and Bayes were here specified in terms of squared error loss. I asked the question "What happens for L_p loss for which a suitable notion of unbiasedness had been introduced by Lehmann?" I made a preliminary calculation for p between 1 and 2 that suggested that the analogue of the Blackwell-Girshick result held. I naturally then turned to David for confirmation. We had essentially an hour's conversation in which he elucidated the whole story by giving an argument for what happened when p equals 1, and, in fact, the result failed. He then sent me off to write it up. The paper appeared in 1967 in the *Annals of Mathematical Statistics*.

It is still a paper I enjoy reading. It led to an interesting follow-up. In a 1988 *American Statistician* paper, Colin Mallows and I studied exhaustively what happens when the underlying prior is improper, which led to some surprises.

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David was a Bayesian belonging, I think, to the minority who believed that axioms of rational behavior inevitably lead to a (subjective) prior. He was essentially alone in that point of view in the department but never let his philosophical views interfere with his most cordial personal relations.

Sadly, our collaboration was the last of my major scientific contacts with David. We were always on very friendly terms, but he would leave the office at 10 AM, which was my usual time of arrival.

After we both retired, we would meet irregularly for lunch at an Indian restaurant, and I got a clearer idea of the difficulties as well as triumphs of his life. Despite having grown up in the segregated South, David always viewed the world with optimism. As long as he could do mathematics, "understand things", rather than "doing research", as he said in repeated interviews, he was happy.

It was my fortune to have known him as a mathematician and as a person. He shone on both fronts.

Thomas S. Ferguson

It was my good fortune to have been a graduate student in statistics at U. C. Berkeley when David Blackwell joined the faculty there in 1954. The distinguished statisticians who were there already—Neyman, Lehmann, Le Cam, Scheffé, Loève, and others—constituted the most approachable faculty I've seen anywhere. We students shared coffee and conversation with them in the afternoons. When Blackwell joined the group, he fit right in with his warm humor, his winning smile, his modesty and his congeniality with the students.

He had an outstanding mathematical reputation by that time, having been invited to give an address in probability at the ICM meetings in Amsterdam in 1954. In 1955 he was elected president of the Institute of Mathematical Statistics. Important for me personally was his book with M. A. Girshick, *Theory of Games and Statistical Decisions*, which came out in 1954. At that time, I was working on my thesis under the direction of Lucien Le Cam. I took a course from Blackwell and read his book, which views statistics as a subset of the art of making decisions under uncertainty. The beauty of this view influenced me to such an extent that my subsequent work did not go so much in the direction of the topics of my thesis but more in the direction of the areas that interested Blackwell—game theory, probability, and sequential decisions.

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Dave was one of the early Bayesian statisticians, that is, he considered statistics, and life as well, as a process of observation, experiment, information gathering, and, based on one's prior beliefs and the outcomes of the observations, modifying one's opinions and acting accordingly. Although his views certainly influenced me, I was never a complete Bayesian—no student of Le Cam could be—but of all the Bayesians I know, he was the most persuasive. It was characteristic of him to spread his interests over several areas rather than to specialize in one. It is amazing how he managed to produce deep and original results in several fields. The underlying theme of his work springs from his Bayesian perspective: probabilistic, sequential decision making and optimization.

Let me mention just a few of his achievements. In probability, there is a basic renewal theorem that goes by his name. There is his work in Markov decision processes in which he conceived the concepts of positive and negative dynamic programs and in which the notion of Blackwell optimality plays an important role.

In statistics, there is the famous Rao-Blackwell theorem and its association with a simple method of improving estimates now called Rao-Blackwellization. There is a fundamental paper of Arrow, Blackwell, and Girshick that helped lay the foundation for Bayesian sequential analysis. The subject of comparison of experiments was introduced by Blackwell and Stein in 1952. The notion of merging of opinions with increasing information was introduced by Blackwell and Dubins in 1962.

In game theory, he has initialized several areas: games of timing, starting with Rand reports on duels; games of attrition; the vector-valued minimax theorem, leading to the notions of approachability and excludability, etc. He has had a long interest in set theory and analytic sets. This led to his study of conditions under which certain infinitely long games of imperfect information have values. This has had a deep impact in the field of logic; logicians now call such games Blackwell games.

My own professional interaction with him came in 1967–1968. He suggested working on a problem in the area of stochastic games. In 1958 Gillette had given an example of a stochastic game that did not have a value under limiting average payoff if the players are restricted to using stationary strategies. Dave called this example game the "Big Match". He wondered if the game had a value if all strategies were allowed. After working on the problem together for a while, we simultaneously and independently came up with different proofs of the existence of a value. To me, it was just an interesting problem. But Dave somehow knew that the problem was important. It was the first step in showing that all stochastic games under limiting average payoff have a value. This

Photo courtesy of Statistics Dept., U. C. Berkeley.

David Blackwell (center) at his birthday party at the Dept. of Statistics at Berkeley in 2009. On his right is Erich Lehmann, on his left Peter Bickel.

took another fourteen years, with many scholars contributing partial results before the result was finally completely proved.

Dave Blackwell is one of my role models. He influenced me in my professional work and in my personal life. He was a great teacher, both in the classroom and in conversations on general subjects. He had a way of cutting through massive detail to get to the heart of a problem. He had over sixty Ph.D. students. But if you count people like me, he had many more students. His spirit and his works are still alive in all of us.

Albert Lo

David Blackwell wrote one of the first comprehensive treatments of Bayesian statistics, and his insistence on the Bayesian approach is legendary. I approached Blackwell for a Ph.D. thesis topic in the mid-1970s. He told me to look in the *Annals of Statistics*, find a topic I liked, and come back. After some searching, I reported that kernel density estimation interested me. Blackwell, staring at me with his piercing big eyes, said "The topic is fine, yet it *must* be done the Bayesian way." This was exactly what he said to me. Later, when I presented to him a result on the consistency of the posterior distribution of a location parameter with respect to a Lebesgue prior, he concluded matter-of-factly, "It is good since it is *almost* Bayesian." Again, these were his exact words. On another occasion he stated that all the non-Bayesian papers in the *Annals* have to be rewritten using a Bayesian approach, and I myself found this "Bayesianization" a good source of research topics.

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Blackwell always insisted on the exactness and clarity of solution. For all his undoubted mathematical ability, his preference was for simplicity over mathematical abstraction. On the density estimation problem, he suggested modeling a density by a location mixture of uniform kernels and putting a Dirichlet process prior on the mixing distribution. The problem was hard then, and after a year and a half of futile searching, I had to present an alternative, yet more standard, approach based on expanding the square root of the density in an orthogonal series with a prior on the infinite sequence of coefficients that lies on the shell of a Hilbert sphere. Upon hearing the proposed approach, Blackwell simply commented "Al, you are not ready." To this day, I can still hear his devastating voice! His opinion about the maturity/readiness of students was perceptive; two years later his Bayesian mixture density problem was resolved with an explicit solution that he had anticipated, presumably at a time when the student was ready.

Though there are suggestions of a good-natured rivalry between Blackwell and some of his famous colleagues, he was not one for direct confrontation. He was very quiet about the racial injustice that he endured and overcame, never mentioning the subject in my hearing. It brings to mind how he handled me as a student, who had been expertly trained by Berkeley frequentists. His only advice to me on how to learn Bayesian statistics was to read Part III of De Groot's text. Though he made some extremely valuable suggestions in his nice and gentlemanly way, he never really discussed or showed me *how* to approach a research problem, except by example. I had to find my own way by observing him and others (mostly others) in the department. The discrimination Blackwell experienced may have given him the philosophy that one should also be able to fight his own way up, or perhaps that if one is worthy, one will eventually be able to make it on one's own. Or perhaps he understood that this was the right approach to take with certain students individually.

David Blackwell was an intellectual giant. But he was modest and unassuming on a personal level. He always dressed properly in an aged jacket/suit, and he drove an old car that often invited jokes from students. While graduate students all over the world were learning about the Rao-Blackwell theorem, I never saw him teaching a graduate course. He enjoyed teaching undergraduate courses, and he placed great emphasis upon spending time on preparation to improve classroom teaching.

A great mind and a great spirit has departed. The world is a richer place because of his writings, but those of us who had the privilege of meeting him personally have benefited even more.

Madan L. Puri

If ever a definition of gravitas was sought, one need look no further than Professor David Harold Blackwell—the first black admitted to the National Academy of Sciences—who died Thursday, July 8, 2010, at age ninety-one. David had substance; he had weight (intellectual weight); he had depth; he was compassionate to the core; and he was genuine. In the course of a career marked by great accomplishments in a number of areas in statistics, probability, and mathematics, he had earned the reputation for intellectual rigor and integrity, and he commanded deep respect in the global academic community. He was an outstanding person, both intellectually and morally, and it is a pleasure to say a few words about this noble man.

I will not talk about his scientific accomplishments. First, they are too many, and second, they are well known. I will concentrate on David as a man.

On the basis of the personal association that I was fortunate to have had with Professor Blackwell, first as a student, and then as a colleague, I say with a sense of pride that David was a rare individual who possessed warmth, integrity, humility, intellectual passion, a commitment to students, faculty, colleagues, and friends alike. He had the courage to take a stand on important issues—the qualities that a creative, gifted scholar imbued with high moral sense is supposed to possess—and we were fortunate that we had such a person as our colleague. I am doubly fortunate to have had him as my teacher as well.

Good stories always invite us to slip into the shoes of other people—a crucial step in acquiring a moral perspective. Stories about friendships require taking the perspective of friends, taking them seriously for their own sake. In the best friendship, we see in perhaps its purest form a moral paradigm for all human relations. Professor Blackwell was a good friend. He had a unique talent, a rare gift of making everybody and anybody feel as though they were his best and most intimate friends. His steadfast friendship, his counsel, his magnanimity, and his example over many years placed me forever in his debt.

David was a living legend whose work not only influenced probability, statistics, and mathematics but has also had far-reaching implications for many fields, including economics. To quote him, "I've worked in so many areas—I'm sort of a dilettante. Basically, I'm not interested in doing research and I never have been. I'm interested in understanding, which is quite a different thing. And often to understand something you have to work it out yourself because no one else has done it." He received his Ph.D. in 1941 at the age of twenty-two from the University of Illinois under the direction of Professor J. L. Doob, and he directed sixty-five Ph.D.s. It is well known that in 1942 Jerzy Neyman of the University of California at Berkeley asked Doob if he was interested in going west. "No, I cannot come, but I have some good students, and Blackwell is the best," he replied. "But of course he's black," Doob continued, "and in spite of the fact that we are in a war that's advancing the cause of democracy, it may not have spread throughout our own land." Neyman then wanted to offer Blackwell a position, but the idea met with protest from the wife of the mathematics department chairman. She was a Texas native who liked to invite the math faculty to dinner occasionally, and she said she "was not going to have that darky in her house", according to Dr. Blackwell's recollection in an oral history interview. The job offer never came. Neyman had never forgotten Blackwell and finally hired him in 1954, and Blackwell would stay at Berkeley for the remainder of his career.

As a teacher he kept his expectations high. When the students walked into his class, they felt the spirit of excellence. He saw to it that no student was left behind. He made every effort to see that at the end of the day, the poor student became good and the good student became superior. Students were his audience. He never walked away from them as long as they did not walk away from him. As long as they were buying what he was selling, he kept on selling. He was the shining light.

Professor Blackwell received many honors in his lifetime, which include, among others, elected membership in the National Academy of Sciences (the first and the only black mathematician) and the American Academy of Arts and Sciences, president of the Institute of Mathematical Statistics, vice president of the American Statistical Association, vice president of the American Mathematical Society, and twelve honorary degrees of doctorate of science from Harvard, Yale, Carnegie Mellon, and other universities.

We live in a difficult world; we live in a complicated world; a demanding, unforgiving world, a world in which honesty and integrity are becoming rare commodities; where malice, jealousy, and self-centeredness motivate people to act in unprofessional, unethical, and undesirable manners. Ironically, and painfully, these things are happening even in the academic world, which is supposed to be the moral voice of humanity, but during these difficult and complicated times, in this demanding and unforgiving world, Professor Blackwell mastered the art of living the difficult life with integrity and style, and he made it look easy

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and certainly desirable. He showed his strength by siding with the weak and helping the downtrodden, and with his loyal heart and with his purest hands, he executed faithfully the university, public, and professional trusts. Anybody who knew him, or met with him, respected him, revered him for his bright sunny nature and the saintly unselfishness by which or with which he discharged his responsibilities and earned the respect and trust of his friends and colleagues. The mathematical community in general, and those who knew him outside the mathematical community, loved him while he was living; they love him even now when he is gone.

Stephen Stigler

David Blackwell's research work places him in the pantheon of twentieth-century probability, game theory, and statistical inference, but it is as a teacher that I best recall him. To hear Blackwell lecture was to witness a master of the art. He was not charismatic; he spoke slowly and deliberately, and, when not writing on the board, used slight hand gestures with his palms toward the audience, to conjure up a shape or an entire space in our minds. His mastery came from the way he was thinking through the material with us at our speed and making his thoughts our thoughts. With simple gestures he could create an infinite-dimensional space in our minds and let us see with startling clarity how a result could follow—or, more accurately, how it would be absurd that it could fail to follow. It was magical—but it was lasting magic, since the knowledge imparted remained with us.

Even in a classroom the work he presented acquired a new flavor in the process. When he presented a wonderful generalization of von Neumann's minimax theorem designed for statistical games in function spaces, he named it after the author of an article he cited, but when I consulted that article later I could see that Blackwell had without comment recast it in a new form; the sparkling clarity of that form was a hallmark of this extraordinary mathematician's mind and style.

For a few years in the 1960s Blackwell taught an extremely elementary Bayesian statistics course to a very large audience of undergraduates. The book he wrote for that class is almost unknown today, but in his hands it was a gem. The insights he brought to a tired old syllabus were a wonderful reward to the students and teaching assistants alike. At the end of the term he invited the large team of TAs to his home at 5 PM and served soft drinks and a large pitcher of martinis. Many of the foreign TAs were new to this libation, and some took to it too enthusiastically, but the gracious host reined them in, and all felt the warmth of his collegial fellowship.

Blackwell was a second-generation beneficiary of an early 1930s grant from the Carnegie Corporation to Harold Hotelling at Columbia University. In 1932 Hotelling had supported Joe Doob, fresh from a Ph.D. in mathematics at Harvard and with no good job prospects, and introduced Doob to probability and statistics. A decade later Doob did the same for Blackwell at the University of Illinois. No Carnegie money was ever better spent.

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W. Sudderth

My first encounter with David Blackwell was as a student in his course on dynamic programming at Berkeley in the fall of 1965. There were, as I recall, about forty or so students from various applied areas, together with a few math types like me. The class met once a week in the evening for about two hours. David always arrived right on time, nattily dressed and sporting a bow tie. He would take a small piece of paper from his shirt pocket, glance at it briefly, and then, with no additional notes, lecture for about an hour. There was then a short break, after which David would look at the other side of the piece of paper before lecturing for the second hour.

The lectures were so clear that the applied students could understand and we math types could easily see that the arguments were airtight. David would often give an intuitive explanation for why a result should be true and then follow it with a rigorous proof. I still have my notes from the course and consult them almost every year to remind myself of an argument or a key example.

David held office hours at 8 AM. Since few students showed up at this early hour, I was able to see him a number of times with questions about dynamic programming and later on about my thesis problem and other matters. These meetings were always fruitful for me. David could always see quickly to the heart of a problem. Sometimes he knew the solution and, if he did not, he always had a good idea about where to look.

My thesis adviser Lester Dubins was a good friend of David's. Lester liked to work with finitely additive probability measures, and, following his lead, I worked with them, too. David was quite dubious of this because of the nonconstructive nature of purely finitely additive measures. He once remarked that he was impressed by all the

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interesting results we were able to prove about these measures that do not exist.

On another occasion, when Roger Purves and I had been working a long time on an obscure measurability problem, we asked David whether he thought our endeavor was worthwhile. He said that when a problem arises naturally in a theory and is difficult to solve, its solution may well require new mathematical tools that will be useful for other purposes as well. Indeed, when, with the aid of Lester Dubins and Ashok Maitra, we finally found the answer to our problem, it did require new techniques that we were able to apply elsewhere.

David made seminal contributions to mathematical statistics, probability theory, measure theory, and game theory. He also found deep connections between game theory and descriptive set theory. As already suggested, he was a great teacher. His only failing, which I observed while serving on search committees at the University of Minnesota, was that he was too kind to ever write anything but a good letter of recommendation for a job candidate.

Yannis Yatracos

I came to meet David Blackwell in the 1978–1979 academic year, when I commenced my graduate work in statistics at UC Berkeley. I found him to be a very warm individual, exhibiting a positive attitude toward all students, and in particular newcomers. He made himself available to answer all kinds of questions regardless of time. During my stay at Berkeley, I had the opportunity to hold several discussions with him about the subject of statistics and the profession, the department there, academic careers, and life outside academia. He was always straightforward, informative, helpful, and generous in sharing his vast knowledge and experiences. In social and student-related issues and in departmental issues shared with students, he was in general more liberal than most of his colleagues, usually in agreement with Lucien Le Cam. Here is a token of remembrance of some instances of personal interaction with him. As a member of my Ph.D. thesis committee, he provided in my mailbox the solution to one of the questions I had asked him about related references. With regard to the potential employment of undergraduates as teaching assistants in statistics courses, the Statistics Graduate Students Association (SGSA), expressing serious concerns, created an ad hoc committee to handle the issue. I also participated, and a meeting of the ombudsman was arranged with the entire department. Professor Blackwell unequivocally stated to the ad hoc committee that the department had a financial obligation toward Ph.D. students until completion of the degree and that this obligation should be addressed. In 1983, before my graduation, I had an extensive discussion with him about the various models of academic careers and, not to my surprise, he supported the British model. At that time faculty ranks in the British universities were lecturer, senior lecturer, reader, and professor. Lecturers became permanent after a probationary period that normally required no more than three years. Promotion to senior lecturer was often based on prowess in teaching and administration. Promotion to reader was based on achievements in research and would usually precede promotion to professor. In a more recent email contact with him in June 2008, I sent a greeting note with some of my papers that he might be interested in. He replied immediately with kind and warm words, as he always did during the last thirty years. Berkeley students who came to know Professor David Blackwell will always remember him as the generous, kind, and warm person he was; he will be greatly missed.

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David Brillinger

I am one of the many whose careers and lives David Blackwell influenced in important ways.

My first contact with David was in 1958. I bought a copy of the Blackwell and Girshick (1954) book using part of my Putnam Prize money. From that work I learned the decision theory and Bayesian approaches to statistical problems. I also remember liking the group theory material.

My next contact with David came in spring 1961. He telephoned me at Princeton inviting me to Berkeley. The conversation ended with "If ever..." I didn't accept the invitation then as I had a postdoctoral fellowship to spend the following year in London, but I did not forget it. What happened eventually is that I became a lecturer and then a reader at the London School of Economics (LSE) for most of the 1960s. I did follow David's work, and I did think about Berkeley from time to time. One thing that I noticed was that David was typically spoken of with awe both in the United Kingdom and United States. I particularly remember that, in the mid-1960s, I went through David's 1951 paper "The range of certain vector integrals" when I was preparing a 1967 *Proceedings of the AMS* paper, "Bounded polymeasures and

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associated translation commutative polynomial operators".

During the academic period 1967–1968, I spent nine months in Berkeley's Statistics Department on sabbatical leave from LSE. I found David to be larger than life, and also I finally met a nonaggressive Bayesian! Just after that visit he further helped my career when he communicated my 1969 paper, "An asymptotic representation of the sample distribution function", to the *Bulletin of the AMS*.

I became David's colleague in January 1970 when I joined the Berkeley faculty. There his collegiality, teaching, research, power-packed talks, committee work, treatment of students, and social conscience were role models for academic behavior. To mention one personal research example, his work with Lester Dubins that appeared in the 1983 *Proceedings of the AMS*, "An extension of Skorokhod's almost sure representation theorem", surely influenced my 1980 work, "Analysis of variance problems under time series models", *Handbook of Statistics 1*. In that paper Skorokhod representation results allowed formal development of asymptotic noncentral chi-squared and *F* distributions for various time series statistics.

David Blackwell has been there my whole academic life, and his contributions and style remain. It was a privilege to share conversations and experiences with him, for he was a major reason why I came to Berkeley. He helped me out continually when I was department chair.

I wish to end by mentioning that, in an encounter, David seemed always to have a pungent quip to offer. One I remember from the early 1980s is "Ronald Reagan likes strong trade unions—in Poland."

Leo A. Goodman

This statement, due to space constraints, will describe only two experiences that I had with David Blackwell. The first experience took place a very long time ago, and the second took place more recently.

After David received his Ph.D., he was given a one-year appointment as a postdoctoral fellow at the Institute for Advanced Study at Princeton. When his tenure at the Institute was drawing to a close, he applied for teaching positions at 105 historically black colleges and universities. He didn't apply to institutions that were not black institutions because it was assumed at that time that such institutions would not accept him because of his race. His first teaching job was at Southern University in Baton Rouge, Louisiana, and his second was at Clark College in Atlanta, Georgia. In 1944 he joined the mathematics department at Howard University in Washington, D.C., and he was promoted to full professor and head of the department in 1947. He stayed there until 1954. I was a faculty member in the statistics department at the University of Chicago beginning in 1950, and in 1951 or 1952 we invited David to become a professor in our department. We made him a good offer. I believe we were the first university that was not a black university to offer him a job. This was, as I have just noted, in 1951 or 1952.

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Photo courtesy of Statistics Dept., U. C. Berkeley.

Also at the 2009 birthday party, with (left to right) Erich Lehmann, Ching-Shui Cheng, Bin Yu, Cari Kaufman, and Juliet Shaffer. Others in the background are staff members and students.

He turned us down. Here is why. This is what he told me: He was born and grew up in a small town, Centralia, in southern Illinois right on the borderline of segregation. If you went a bit south of Centralia to the southern tip of Illinois, the schools were completely segregated in those days. Centralia had one school only for blacks, one school only for whites, and a few "mixed" schools. He attended one of the "mixed" schools. His family would sometimes travel north in Illinois from Centralia to visit relatives living in Chicago; and he could see, when he visited his relatives living there, what life was really like for black people living in Chicago. He told me that he would definitely prefer to live with his wife and children in Washington, D.C., where Howard University is located, than to live with them in Chicago.

David didn't accept our University of Chicago offer; but in 1954, he accepted an appointment at the University of California at Berkeley as a visiting professor for the 1954–1955 academic year. And starting with the 1955–1956 academic year, he was a professor in the statistics department at the University of California at Berkeley.

The second experience that I had with David, which I will describe next, dates from the late 1990s and early 2000s. I moved from being a faculty member at the University of Chicago to being a faculty member at the University of California at Berkeley in 1987, so David and I were colleagues from then on. In 1998 a best-selling book called *A Beautiful Mind* was published, and it inspired the making of a movie with the same name in 2001 that won four Academy Awards. The book was a biography of John Nash, the winner of a Nobel Memorial Prize in Economic Sciences. The prize was for the research that Nash had done on game theory when he was a graduate student in the mathematics department at Princeton University. Because of the book, the movie, and the Nobel Memorial Prize, interest in Nash was high for quite a few years—even, it seems, for example, among San Francisco's social elite, members of the Bohemian Club and Bohemian Grove. Albert (Al) Bowker, a devoted member of the Bohemian Club and Bohemian Grove—and also a well-known statistician and former chancellor at the University of California at Berkeley and a friend of David's and a friend of mine—invited David and me to speak about Nash at the Bohemian Club. Al invited David because David was an expert in game theory, and he invited me because John Nash and I had been graduate students at the same time in the mathematics department at Princeton. John and I were friends then, and we continued to be friends after leaving Princeton. On the evening when David and I spoke at the Bohemian Club, David spoke beautifully—as he always did. It was striking to see how well he was able to speak on game theory to this audience—members of the Bohemian Club—who were largely unfamiliar with this rather arcane subject. I think that the audience did gain some understanding of what game theory was about and why Nash's research was important. David and I had a good time, and our talks were well received. David was, simply, a great lecturer and teacher, as well as a gracious and interesting colleague and a sterling human being. We all miss him very much.

Juliet Shaffer

With the death of David Blackwell, following the death last year of Erich Lehmann, both at ninety-one years old, the senior level of statisticians at U.C. Berkeley is gone.

Erich and I were reasonably close to David. For many years we drove him to the joint Berkeley-Stanford colloquia when they were held at Stanford, giving us time for much conversation.

Erich told me that, when David first came to Berkeley, his large family could not find any place that would accommodate them, and they lived for some months camping out in a park. In David's interview in *Statistical Science* in 1986, he stated that the early discrimination he faced (before Berkeley) "never bothered me". Since the early Berkeley experience wasn't mentioned, it's not clear that he was similarly unbothered by this early Berkeley discrimination. I know that he was keenly aware of such issues later.

I talked with him from time to time about discrimination, mentioning things that had happened to me both as a woman and a Jew. I had the impression that he thought a lot about discrimination in general (not necessarily against him personally) in later years. I understand his initial unconcern very well. When I was first looking for jobs there were many ads, at least half, that stated "men only". It didn't bother me then—it was the way things were. Only later with the rise of feminism did I begin to see things differently. David was usually very unruffled, but I saw a rare strong reaction when I told him how the Georgia flag, which resembles the Confederate flag, bothered me as I saw it flying over a hotel in which I had just stayed in Atlanta. He mentioned that a white beggar on Telegraph Avenue had approached him for money while wearing a Confederate flag costume and how angry he had felt about that.

It must have been somewhat difficult being a Bayesian in the strongly-non-Bayesian Berkeley Statistics Department. I once mentioned to David that I was not very sympathetic to the Bayes approach but did have some interest in empirical Bayes. He noted that he didn't believe in empirical Bayes and showed that it didn't make sense when applied to a single inference. I remarked that it made sense in the context of a large number of similar inferences, to which there was no reply. I interpreted his reaction as illustrative of an aspect of his approach to statistics. He liked elegance and simplicity. Issues had to be clear in the very simplest of situations. Empirical Bayes didn't meet this test. He felt a Bayesian prior was necessary. His ability to clarify issues in simple and elegant ways was presumably what made him such an outstanding lecturer and teacher.

David was a kind and wonderful person, but he was also a very private person, and there was always the feeling of an inner core that couldn't be penetrated. I urged him many times to write his memoirs, but he never did.

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Herman Chernoff

I first met David Blackwell in 1951 when we were both invited to visit the new Stanford University

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Department of Statistics. By then he was a recognized force in statistics, having contributed the Rao-Blackwell theorem on the use of sufficient statistics to derive efficient unbiased estimates and the Arrow-Blackwell-Girshick derivation of the optimality of the sequential probability ratio test.

The latter derivation was based on a plan proposed by Wald and Wolfowitz, the details of which suffered from a serious measurability difficulty. Arrow, Blackwell, and Girshick bypassed that problem by employing a backward induction argument, the success of which depended on the fact that a decision to be made in the distant future would have a negligible effect on the current expected value of the overall strategy. This backward induction argument was essentially the origin of dynamic programming. Blackwell used to claim that sequential analysis and dynamic programming were the same subject.

At the time we met, David and his wife Ann already had five of their eight children. Transporting his family by car across country was a major challenge requiring considerable discipline and planning at a time when professorial salaries were extremely limited. We were disappointed when David chose to go to Berkeley rather than to Stanford.

Ann and I had a vice in common. We both loved ice cream. My wife Judy noticed that at picnics, Ann had a definite tendency to overcount the consumers, as a result of which we always had an extra portion, which Ann would gracefully consume to avoid a battle among her children.

I have known many very smart people, including some Nobel laureates, but David had the greatest ability to take a complicated situation, scientific or personal, and explain the issues clearly and simply. This gift made him a great expositor and advisor. His book, *Basic Statistics*, was an extraordinary illustration of his ability to clearly and concisely explain the subject to beginners.

We had one major misunderstanding. He maintained that I had introduced him to the secretary problem, and I just as distinctly claim that he had introduced me to it. Judy and I both enjoyed visiting with David and Ann, and we were honored to be invited by David to the special dinner Harvard had for its recipients of the honorary doctorate.

Persi Diaconis

David Blackwell was a brilliant, gentle man. I don't think I ever met anyone with so many IQ points fused into such an agreeable exterior. We had many areas of contact: Bayesian statistics, descriptive set theory, and his damned triangle problem. Let me briefly comment on each.

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Photo courtesy of Statistics Dept., U. C. Berkeley.

Blackwell at the 2009 birthday party. On the left behind him is Juliet Shaffer, and David Aldous is at the right. The others are staff members and students.

David had been converted (his phrase) to the Bayesian view during a walk with Jimmy Savage. Bayes made sense to David, and he made sense of it to others. Since not everyone is a Bayesian, some of us learn to speak both classical and Bayesian languages. Once, David heard me give a colloquium using both languages. Afterward, he gave me a really hard time! "Persi, it sounded as if you were apologizing for being a Bayesian. You don't have to apologize, it's the only sensible statistical theory."

Berkeley was a hotbed of descriptive set theory—analytic, coanalytic, and universally measurable sets were friends of Blackwell, Dubins, and Freedman. I learned the subject from Freedman and wrote a small paper with Blackwell: the *American Mathematical Monthly* had published a longish paper constructing a nonmeasurable tail set in coin-tossing space. We noticed that the standard construction of a nonmeasurable set due to Vitali also had this property. We sent a one-page note to the *Monthly* and received a scathing referee's report in return: "Why would you send a paper about such junk to the *Monthly*?" Clearly, not everyone likes measure theory. We published our paper elsewhere. I recently gave a talk on it at Halloween (when the monsters come out).

I had dinner with David, Erich Lehmann, Julie Schaffer, and Susan Holmes about a year before he died. You don't ask someone in his high eighties if he's still thinking about math. However, David had taken up computing late in life, and I asked if he was still at it. He answered with a loud pound on the table and “Yes, and damnit I’m stuck.” He explained: “Take any triangle in the plane. Connect the three vertices to the midpoints of the opposite sides; the three lines meet in the middle to give the barycentric subdivision into six triangles. If you do it again with each of the six little triangles, you get thirty-six triangles, and so on.” He noticed that most of the triangles produced get flat (the proportion with largest angle greater than 180 degrees minus epsilon tends to one). He was trying to prove this and had gotten stuck at one point. His proof idea was brilliant: he turned this geometry problem into a probability problem. Construct a Markov chain on the space of triangles by picking one of the six inside, at random. He defined a function on triangles that was zero at perfectly flat triangles and that he believed was superharmonic. Nonstandard theory shows the iteration tends to zero; hence the average tends to zero, and so “most triangles are flat”. The proof of superharmonicity was a trigonometric nightmare, and he had not been able to push it through. I couldn’t believe that such a simple fact about triangles was hard (it was). I tricked several colleagues into working it through by various complex arguments. After a lot of work, we found the result in a lovely paper by Barany, Beardon, and Carne (1996). Blackwell’s approach remains a tantalizing possibility.

Murray Rosenblatt

I had only occasional contact with David Blackwell through the years. But I always found him to be a warm, gracious person with a friendly greeting. He entered the University of Illinois at Urbana–Champaign in 1935 at the age of sixteen and received a bachelor’s degree in mathematics in 1938 and a master’s degree in 1939. Blackwell wrote a doctoral thesis on Markov chains with Joseph L. Doob as advisor in 1941. Two earlier almost-contemporary doctoral students of J. L. Doob were Paul Halmos, with a doctoral degree in 1938, and Warren Ambrose, with the degree in 1939.

Blackwell was a postdoctoral fellow at the Institute for Advanced Study for a year from 1941 (having been awarded a Rosenwald fellowship). There was an attempted racist intervention by the then-president of Princeton, who objected to the honorific designation of Blackwell as a visiting fellow at Princeton (all members of the Institute had this designation). He was on the faculty of Howard University in the mathematics department from 1944 to 1954. Neyman supported the appointment of David Blackwell at the University of California, Berkeley, in 1942, but this fell through due to the prejudices at that time (see [4]). However, in 1955 David Blackwell was appointed professor of statistics at UC Berkeley and became chair of the department the following year.

Blackwell wrote over ninety papers and made major contributions in many areas—dynamic programming, game theory, measure theory, probability theory, information theory, and mathematical statistics. He was an engaging person with broad-ranging interests and deep insights. He was quite independent but often carried out research with others. Interaction with Girshick probably led him to research on statistical problems of note. Researches with K. Arrow, R. Bellman, and E. Barankin focused on game theory. Joint work with A. Thomasian (a student of his) and L. Breiman was on coding problems in information theory. He also carried out researches with colleagues at UC Berkeley, such as David Freedman, Lester Dubins, J. L. Hodges, and Peter Bickel. The Rao–Blackwell theorem dealing with the question of optimal unbiased estimation is due to him.

He was elected the first African American member of the National Academy of Sciences, USA, and received many other awards. He was a distinguished lecturer. We’re thankful that he survived the difficulties that African Americans had to endure in a time of great bias (in his youth). He was a person of singular talent in the areas of statistics and mathematics.

I shall describe limited aspects of the research of Blackwell and Dubins [2] on regular conditional distributions (see Doob [1] for a discussion of conditional probability). This was an area that Blackwell often found of interest. Given a measurable space $(\Omega, \mathcal{B})$ with $\mathcal{A}$ a sub σ-field of the σ-field $\mathcal{B}$, call P defined on $\Omega \times \mathcal{B}$ a *regular conditional distribution* (r.c.d.) *for $\mathcal{A}$ on $\mathcal{B}$* if for all $\omega \in \Omega$, $B \in \mathcal{B}$,

(1) $P(\omega, \cdot)$ is a probability measure on $\mathcal{B}$.
(2) For each $B \in \mathcal{B}$, $P(\cdot, B)$ is $\mathcal{A}$-measurable and related to the probability distribution via

$$\int_A P(\omega, B)\, \mathrm{d}P(\omega) = P(A \cap B)$$

for $A \in \mathcal{A}$, $B \in \mathcal{B}$.

Such regular conditional distributions do not always exist. But assuming existence, call it *proper* if

$$P(\omega, A) = 1$$

whenever $\omega \in A \in \mathcal{A}$.

The probability measure P on $\mathcal{A}$ is called extreme if $P(A) = 0$ or 1 for all $A \in \mathcal{A}$. An $\mathcal{A}$-atom is the intersection of all elements of $\mathcal{A}$ that contain a given point of Ω. If for $A \in \mathcal{A}$, $P(A) = 1$, P is said to be *supported* by A.

Then we have:

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Theorem. *Assume $\mathcal{B}$ is countably generated. Then each of the conditions implies the successor.*

(a) *There is an extreme countably additive probability measure on $\mathcal{A}$ that is supported by no $\mathcal{A}$-atom belonging to $\mathcal{A}$.*
(b) *$\mathcal{A}$ is not countably generated.*
(c) *No regular conditional distribution for $\mathcal{A}$ on $\mathcal{B}$ is proper.*

This result shows that, for Ω the infinite product of a separable metric space containing more than one point, neither the tail field, the field of symmetric events, nor the invariant field admit a proper r.c.d (regular conditional distribution). They weaken the countable additivity condition of an r.c.d. to finite additivity and add (1) to obtain the notion of a *normal conditional distribution* and arrive at sufficient conditions for existence. Later related research by Berti and Rigo [3] considers the r.c.d.s with appropriate weakenings of the concept of proper.

References

[1] J. L. Doob, *Stochastic Processes*, John Wiley, 1953.

[2] D. Blackwell and L. Dubins, On existence and non-existence of proper, regular conditional distributions, *Ann. Prob.* **3** (1975), 741–752.

[3] P. Berti and P. Rigo, 0–1 laws for regular conditional distributions, *Ann. Prob.* **35** (2007), 649–662.

[4] National Visionary Leadership Project, Oral History Archive, David Harold Blackwell.

Francisco J. Samaniego

Because of David Blackwell's widely recognized genius, as evidenced in his path-breaking research, the many creative ideas he generously shared with students and colleagues, his election to the National Academy of Sciences, and his receipt of the coveted Berkeley Citation upon his formal retirement from the faculty, it is perhaps understandable that another facet of his remarkable career would be less known and less universally celebrated. This facet was his extraordinary ability to teach mathematics and statistics in new, clear, and compelling ways. There is a good deal of evidence that may be advanced in support of the proposition that Blackwell was an exceptional teacher. We would be remiss if this aspect of his wonderfully successful career was overlooked in the present overview of his work. While our discussion of Blackwell's teaching is necessarily brief, we hope that we will leave no doubt among readers of this piece that Blackwell was a preeminent teacher and mentor.

The most telling evidence of Blackwell's teaching prowess is simply the testimonials from students and colleagues that exist in a number far too great to attempt a comprehensive summary. Suffice it to say that many of his students considered him to be the finest instructor that they ever had the privilege to study with.

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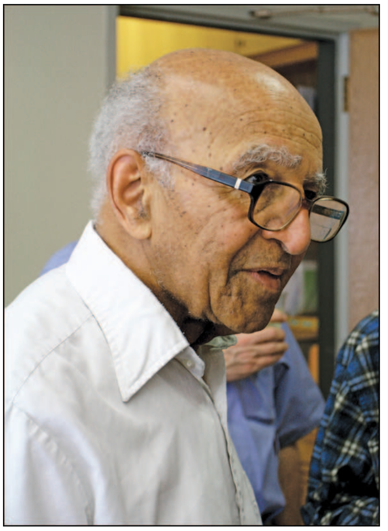

David Blackwell, 2009.

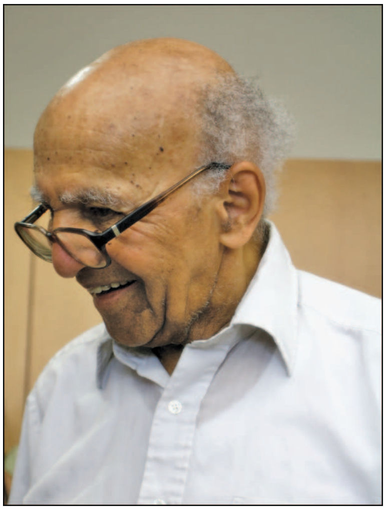

Photo courtesy of Statistics Dept., U. C. Berkeley.

His style was unfailingly engaging, as it was his custom to share his natural curiosity with his students, explaining not just the "how" associated with a statistical procedure but the "why" as well, along with the motivation for the ideas involved and the (often surprising) connections with other ideas usually of interest in their own right. It was a pleasure to hear him speak. One generally came away from a lecture by David Blackwell both impressed with his mastery of the subject and intrigued by questions he had left his audience to think about. His colleagues at Berkeley looked to him as a model and often sought his advice on the best way to present a given topic (as well as on a host of other matters, personal and professional). In spite of his wonderful gifts as a teacher, Blackwell was very modest about his skills and would give his advice as if it was a tentative, off-the-cuff suggestion. Once, in a reception prior to a seminar he presented at UC Davis, a former student of his asked him, "David, what do you do when you've presented an idea in a way that you consider to be 'just right', and a student raises his hand and says 'I didn't get that'?" Without missing a beat, David answered, "Well, I just repeat exactly what I just said, only louder."

David Blackwell's well-honed teaching instincts were as evident in his writings as they were in the classroom. Two of his many published "notes" come to mind in this regard. These notes appeared in the *Annals of Statistics* volume in which Thomas Ferguson presented his now celebrated paper on Bayesian nonparametrics (an idea, by the way,

About the Cover

Very special functions

The cover was suggested by this issue's article by Daniel Lozier and others on the National Institute of Standards and Technology's (NIST) mathematical functions project. It amounts to an assembly of screenshots taken from the associated online Digital Library of Mathematical Functions.

Graphics are a distinctive part of this project. When we asked Bonita Saunders of the NIST Mathematical Software Group to say something about its production, she replied:

> We first thought the development of graphics for the DLMF would be fairly straightforward: Create the graphs using a commercial or free package and export the data to a format that could be viewed on the Web. While this worked well for 2D graphs of function curves, it did not work for 3D graphs. A considerable amount of user input was needed to plot accurate graphs of function surfaces in most packages. This has improved considerably in recent years, but in many cases it is still difficult to export the data to suitable formats, especially if the goal is interactive viewing on the Web.
>
> To eliminate or lessen the severity of our plotting problems, we designed custom-made computational meshes to properly clip the surfaces and capture key function features such as zeros, poles, branch cuts, and other singularities. To ensure the accuracy of all function data, we computed the functions using at least two different methods. We designed our own translators to export the 3D data to file formats such as VRML (Virtual Reality Modeling Language) and X3D, which allow a user to manipulate 3D scenes and objects on the Web with a free downloadable viewer. We wrote code to supplement the standard rotate, zoom, and pan capabilities with user options—to change the color map, vary the scaling of the surface, create density plots, change the look of the axes, and interactively move a cutting plane through the surface in each coordinate direction.
>
> We expect to continually enhance the graphics on the website. In particular, sometime in the future we hope to offer an option that allows users to view the interactive graphics inside a webpage without the need of a special viewer.

Our thanks also to Brian Antonishek, also of NIST, for much help in assembling the cover.

—Bill Casselman
Graphics Editor
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that he acknowledged as grounded in his discussions with Blackwell). In a note entitled "Discreteness of Ferguson Selections", Blackwell gave an elementary proof of the discreteness of draws from a Dirichlet process, shedding much light on this particular characteristic of Dirichlet processes (which had been proven by Ferguson in an *Annals of Probability* paper using much more complex arguments). In the same AoP issue, Blackwell and MacQueen presented an alternative derivation of the Dirichlet process using a lovely and quite intuitive construction involving Pólya urn schemes. The latter paper has led to much fruitful research in Bayesian nonparametrics. Both papers contained useful techniques, but their greatest contribution was, without doubt, the clarification of the properties and potential of Ferguson's Dirichlet process.

Blackwell published the elementary textbook *Basic Statistics* in 1969. The book is unique in the field and is recommended reading both for students just being exposed to the subject and, we dare say, for the statistics community as a whole. It is no exaggeration to refer to the book as a "gem". In the book, Blackwell covered the "standard topics" found in an introductory course—elementary probability, the binomial and normal models, correlation, estimation, prediction, and the chi-square test for association. The treatment of these topics was, however, fresh and crisp, with most of the ideas motivated by thinking about drawing balls from urns. For example, he chose to introduce the idea of Bayesian point estimation through the problem of estimating the number of fish in a pond via a mark-recapture experiment. Although the mathematical level of the book was intentionally low, the conceptual reach was much broader than what one usually finds at the introductory level. In his preface, Blackwell describes his approach as "intuitive, informal, concrete, decision-theoretic and Bayesian". He took on the notions of probability densities, mean squared error, multiple correlation, prior distributions, point estimation, and the normal and chi-square approximations, all with the very modest expectation that the students reading the book "could do arithmetic, substitute in simple formulas, plot points and draw a smooth curve through plotted points". He was true to his promise of making statistics accessible to anyone who had only these skills. Perhaps the most remarkable thing about this book is that Blackwell managed to pack a treasure trove of ideas into 138 pages, divided into sixteen chapters and containing 118 problems and their solutions. He had a gift for getting to the core of the topics he wrote or taught about. This book is a lovely example of that gift in action.

Can One Hear the Sound of a Theorem?

Rob Schneiderman

Mathematics and music have been intertwined in a long-running drama that stretches back to ancient times and has featured contributions from many great minds, including Pythagoras, Euclid, Mersenne, Descartes, Galileo, Euler, Helmholtz, and many others (see, e.g., [1]). Applications of mathematics to music continue to develop in today's digital world, which also supports active communities of musicologists and experimental composers who examine music methodically, often using mathematical elements. In light of the recent wave of musico-mathematical books, blogs, journals, and even articles in the *Notices*, this multifaceted side of the mathematical world deserves reexamination. Although the scrutiny given here will reveal many problems posing as solutions, some promising prospects will also emerge, and positive turns in the plot may yet unfold, especially when viewed from a novel educational angle described below.

From the mathematician's perspective, besides providing a bounty of physical applications, the search for relationships between music and mathematics should serve both as a philosophical reflection pool and as a portal to an engagement of the general public with mathematics. But the view is often obstructed by the unwitting entanglement of several distinct lines of thought. It is not uncommon for commentary on music and mathematics to bounce between the physics of sound, theoretical analysis of music, and metaphorical prose. While each approach has its strengths and weaknesses, unjustified juxtapositions can serve to cloud the big picture by masquerading as implicit unifications of unresolved key issues or by appearing to support pseudoscientific arguments. For example, [4] and [5] exposit useful mathematical techniques in the setting of digital audio processing, which are then associated with flawed musical analysis and exaggerated conclusions. A historical article on the mathematics of fretting a guitar in [6] is presented side-by-side with musical numerology in a collection whose introduction enthusiastically includes as evidence of connections between mathematics and music the "ordering by number" of Bach's Goldberg variations!

As one who came to mathematics after a career as a professional musician, I offer here a personal viewpoint in hopes that it will provide a helpful framework for unwinding the current strands of a fascinatingly elusive subject. This essay will argue that while mathematics provides satisfying analyses of sound and useful parameterizations of musical choices, deeper scientific relationships between mathematics and music remain largely beyond reach. But the adoption of a more metaphorical point of view will uncover support for a return of music and mathematics to a quadrivium-like partnership in education that is based on a common strength of intrinsic structure.

The goal here is not to give a survey of the present state of musico-mathematical affairs but rather to highlight a representative sample of points that seem to be overlooked or underappreciated in the current general discourse. Of course personal taste enters into any discussion of music, and many issues raised below are subject to differing interpretations. The arguments are mostly critical because such objections seem to have had trouble finding their way into print, but I support many aspects of even the approaches criticized here and hope to clarify and stimulate the ongoing dialogue. It is in the interest of the mathematics community to engage in and be aware

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of the development of interdisciplinary work in all directions.

The body of this article is roughly divided into the subtopics of *science of sound*, *analysis of music*, and *metaphorical comparisons*.

The Science of Sound

There is much solid and fascinating mathematical work, classical and ongoing, which is related to musical sound, including instrument design, acoustics, and audio processing, among many interrelated topics. Applications of mathematics are readily apparent in the modern recording studio, where the signal of digitally recorded instruments (both electric and acoustic) is routinely manipulated in a wide variety of ways, including the independent adjustment of tempo and pitch of individual voices, as well as the elimination of ambient noise and creation of audio effects. Fourier theory plays a central role throughout these settings, essentially due to the periodic nature of musical sound waves and the graded elasticity of our ears' basilar membranes, which act as harmonic analyzers. (A broad introduction to the mathematics of musical sound can be found in the first eight chapters of David Benson's book [2].)

While elements such as rhythm, melody, and harmony are frequently described as fundamental "dimensions" of music, the case can be made that in fact *timbre* (or *tone color*) is the most important universal musical quality: The strike of Pablo Casals' bow to a cello string can send chills up the spine, and Nat Cole's voice can convert a single syllable into the sublime. In this case Fourier theory provides a very strong mathematical explanation for this musical phenomenon: namely, that the timbre of a sound—which closely corresponds to the frequency spectrum of its wave shape—lives in an infinite-dimensional space! Well, infinite dimensional in principle, but even taking into account the limited frequency range of our conscious hearing (20Hz–20,000Hz), just a single second of reasonably digitized musical sound will require tens of thousands of coordinates, as even the very short-term time evolution of wave shape is critical to the perception of tone quality. The depth and complexity of timbre is further illustrated by the extreme difficulty of synthesizing musically interesting sounds by directly prescribing wave spectra and by the fact that a pure sine wave corresponds to a completely boring musical sound.

Of course almost all musicians remain blissfully unaware of the elegance of Fourier theory as they coax out expressively complex sounds from traditional instruments, guided only by the analysis provided by their own ears. While it is true that, by electronically synthesizing "unnatural" spectra, it is possible to generate sounds that cannot be made by traditional instruments—perhaps following a musical analogue of studying nonstandard axiomatic systems in mathematics—such variations are not ends in themselves and have value only if they lead to "interesting" results.

Although timbre is fundamental to music, extending musico-mathematical relationships becomes problematic as sequences of sounds are extended in time and begin to acquire musical meaning. For instance, the well-studied relationships between whole number ratios and consonant pitch intervals, while interesting from a physical point of view and historically important, ultimately do not correspond to any cohesive *mathematical* notion, as musical esthetics rightfully leads to compromises and approximations in choices of scales and tunings, with the resulting widely accepted equal-tempered chromatic scale having frequency ratios of $\sqrt[12]{2}$ for all pairs of adjacent notes. Explanations of this are readily available, for instance in Chapter 5 of [2], as well as in Ian Stewart's delightful expository piece in Chapter 4 of [6], describing how a classical construction for placing the frets on a guitar ties together discussions of Pythagorean and equal-tempered scales, ruler and compass constructions, continued fractions, and fractional linear approximations of exponential functions. Although there does exist a small minority of musicians who are obsessed with subtleties of tuning choices and justifications of scale constructions, the vast majority of musicians have no trouble making beautiful music with the equal-tempered pitch system, easily incorporating together instruments having fixed tunings with those that are more flexible and happily exploiting the freedom to modulate between unrelated keys that is afforded by "theoretically compromised" scales. In any event, many instruments are tuned by hand, and notes are bent by ear, so it is not surprising that once musical flow commences, mathematical imperfections in pitch fade into the background.

Perhaps the irony that ancient hopes for combining rational numbers and music into a cohesive world view have been dashed by the general acceptance of a musical system based on $\sqrt[12]{2}$ is an omen representative of problems that will haunt future attempts to build bridges between mathematics and music.

Analysis of Music

Three overlapping goals of music theory are to *explain why* music sounds the way it does, find good *ways to listen* to music, and describe *how to create* music. What might mathematics have to do with these goals? It certainly is natural to use permutations and transformations in describing *available* musical choices and relations between them (for instance, by representing pitch/rhythm in frequency/time coordinates or numbering scale tones relative to a root). But attempts at exhibiting substantial connections between *meaningful* musical choices and mathematics struggle to emerge from behind cloaks of terminology, perhaps precariously propped up by constructions of auxiliary geometric objects. The problem is that mathematical content comes in the form of proven statements about well-defined structures, and attempts at "explaining" musical phenomena usually involve structures that are not well defined, with conclusions justified by carefully chosen examples and multitudes of counterexamples ignored. And any logical development of well-defined structure is inevitably based on dubious or pedantic musical principles, so that the resulting conclusions can say precious little about what is important in music.

The types of problems illustrated in the basic examples considered below are compounded in more complicated analytic treatments of music.

Mathematical Explanations of Music

For instance, the recent *Notices* articles [4, 5] use short-time Fourier transforms and continuous wavelet transforms to produce families of images from digital audio and claim to provide insight into musical structure that is both "quantitative" and "objective". The images do exhibit patterns that correspond to rhythmic accents, pitches, and volume, but the analysis of musical content is riddled with flaws and weaknesses that undermine most of the extremely enthusiastic conclusions.

The problems are well illustrated in Example 6 of [4], where four trivial musical observations are made about a short Duke Ellington excerpt: Sometimes symmetries appear in melodies, instruments can bend pitches, jazz can be syncopated, and melodies can contain varying groupings of notes. Areas of the associated images corresponding to these observations are located. It is claimed that "We can see from this analysis that this passage within just six seconds reveals a wealth of structure, including many features that are unique to jazz. Such mastery illustrates why Duke Ellington was one of the greatest composers of the twentieth century." The implication that the examination of the images illustrates anything about the music (let alone the greatness) of Duke Ellington is unfounded for several reasons.

First of all, the "analysis" admittedly includes listening to the recording; the note blobs in the image only contribute frequency readings from one coordinate and indicate rhythmic placement along the time coordinate. The observation of a slurring of pitch together with a brief descending-ascending motif leads the authors to conclude that Ellington is synthesizing "a melodic characteristic of jazz (micro-tones) with one of classical music (reflection about a pitch level)." This conclusion, besides being musically trivial, ignores the fact that symmetries of melodic fragments and bending of pitches (not to mention syncopation) occur in all kinds of music—certainly in both jazz and classical music. The fourth observation refers to a notion of "hierarchy" as giving "preferred" groupings of musical notes via grammar-like rules. But this notion of hierarchy is not well defined, as even recognized in [9] by the authors who coined the notion. And surely the "wealth of structure" visible in the images could also be created by a mediocre or even poor performance of the same or a similar piece. In fact, much richer visual structures could certainly be created by sounds that are more complicated, including sounds that are essentially devoid of musical content. No control examples are given, and the visual data requires listening for interpretation, yet it is claimed "most importantly" that the images "provide an objective description of recorded performances". What does "objective" mean here? Are the authors suggesting that looking at their images provides some true measure of music? Even putting aside the trivial nature of the musical observations, this paragraph makes clear that any meaningful conclusions are in fact being *entirely drawn from listening.*

Example 6 of [5] implies that the images provide an answer to the question: What do Beethoven, Benny Goodman, and Jimi Hendrix have in common? The evidence of "approximate mirror symmetry" is only the trivial observation of melodic lines that descend and then ascend, a property of music that is probably familiar to even the untrained casual listener. Again, all kinds of sounds, including nonmusical ones, could give rise to similar images, and the restricted set of examples contained in [4] and [5] surely reflects the fact that extracting any meaningful general correspondence between the visible patterns and musical content is highly unlikely.

Acclaimed as the first musico-mathematical article to appear in *Science* magazine, [13] claims to illustrate how composers "exploit" the geometry of an orbifold and to show "precisely how harmony and counterpoint are related". Although this article contains well-defined statements and arguments, the weakness of the underlying musical principles erodes any meaningful connection with mathematics. The entire construction is based on the notion of "efficient voice leading", which is justified by the statement that "Western pedagogues instruct composers to minimize voice leading while eschewing crossing changes." In fact, this extremely limited notion can be considered relevant only when it is desired to have an accompaniment that is musically *benign* so as not to interfere with other concurrent statements and is at best a rule of thumb for a student composer/arranger. The experienced creator of music certainly hears every voice and is guided by what sounds best rather than instructions from pedagogues. So, even ignoring some other questionable musical assumptions, it is difficult to derive any conclusions from a geometric construction that is based on a principle that "minimizes" musical content.

Other examples of "geometric" analyses are common, and musical scores written in the time and pitch coordinates of standard notation provide a plethora of patterns and data. The discovery of symmetries and other transformations of musical motifs (as notated) is often presented as evidence of an underlying mathematical component of music. But such discoveries do not correspond to musically coherent or mathematically interesting notions. While repetition and variation pervade music, precise symmetries among musical phrases are certainly not generic, so if such symmetry were musically meaningful, one would expect it to have a recognizable effect. But convincing counterevidence is provided by J. S. Bach's completely palindromic Crab Canon from his Musical Offering. What is remarkable about the Crab Canon is that even the most diligent listener is not going to have a clue that the piece is palindromic without access to the score, and in spite of the extreme notational symmetry the piece sounds characteristically Bach-like and by Bach's standards less memorable than average. (In this case Bach's compositional tour de force is in response to a challenge from Frederick the Great; more on composer-embedded musical patterns will be discussed later.)

A method commonly employed in mathematical analyses of music (including [13]) is to identify pitches that differ by a whole number of octaves, and the resulting equivalence classes are assumed to be a natural object of study. While it is true that pitches that are an octave apart have a clear notion of "sameness" (which is reflected in their shared overtones), the *musical* effect of changing the register of a note (choosing a representative of the pitch class) is not at all negligible. This suggests an interesting experiment: Listen to musical pieces whose pitch class representatives have been randomly permuted. Such shuffling of notes will certainly generate some bizarre-sounding music, and it is a safe bet that your favorite listening would lose its special place in your heart if always subjected to having its notes scattered in this way. But any musical theory that takes seriously the idea of working with pitch classes will apply equally to "explain" such sounds! This modding out by octave "translations" is often invoked by music theorists to construct tori as parameter spaces.

Mathematical Ways of Listening to Music

The second goal of musical analysis raises an interesting question: How does extramusical information affect the listener? The effects are certainly wide ranging, from the relatively benign influences of knowing a song title or anecdotal stories about the performer to the enrapturement of an associated religious ritual. Lyric content or dance generally tends to interact strongly with accompanying musical statements, and when music is presented with video, the music will likely play a subservient role (and in such a setting the power of sound to generate its own images has been compromised). In the case of mathematically oriented music theory, it is usually tacitly assumed that an awareness of any "explanatory" mathematical notions will improve the musical experience. While this may be true for some music theorists, it is important to recognize that it is not necessarily a mathematical insight into essential general musical properties, but more likely a personal enhancement for one who enjoys attaching intellectual constructions to music. In fact, it can often be beneficial to remain ignorant of extramusical information, even when provided by the composer. More than once I have been inspired by music accompanied by lyrics in a language I did not understand only to discover later that the words were not just unrelated to my appreciation but even unappealing to me. More generally, it is remarkable how in spite of the strong link between music and its ambient culture of origin, appreciation of music can bridge wide cultural gaps. For instance, secular appreciation of religious music abounds, the blues can go over well in Asia, hip-hop pieces are sometimes based on loops from classic jazz recordings, and World Music has its own category in the commercial music market. The point here is that, while music comes wrapped in webs of extramusical connections, it is a very subtle matter to extract *essential* threads from the midst of the many personal ones.

The effects of imposing conscious listening techniques often appear in the setting of music pedagogy: The journey from student to professional musician usually involves many years of music theory in the form of organizing sounds into recognizable bits and studying how they interact (there are many methods for doing this). This process of intellectualizing about music is often very difficult, as the student can become hypercritical and overly self-conscious, both as a performer and as a listener. Eventually the experienced musician is able to return to the appreciation of sound for its own sake, retaining the ability to analyze tension and resolution in theoretical terms at will but also free to enjoy the transcendental in-the-moment nature of music.

To clarify, I'm not proposing that analytic listening, mathematically motivated or otherwise, is wrong, just that it is not fundamental to the appreciation of music in general. All kinds of attentive, repeated, and earnest listening can access the full range and depth of musical meaning that is present in sound.

Creation of Music

The most effective use of theory in the creation of music is to provide frameworks for *experimentation* rather than rules to be followed. Again, the methodical organization of sound may motivate the use of mathematical terminology, but while the resulting explorations may help the practicing musician gain insights into subtleties of musical tension and resolution, they are not going to lead to meaningful theorems expressing general essential musical qualities. In fact, even completely arbitrarily formulated methodologies can spark fruitful musical studies (and sometimes give birth to "styles" and "schools") merely by reducing the profusion of available musical choices.

For instance, the various serial composition techniques developed by Western atonal composers such as Schoenberg a century ago involve applications of various formal rules that were designed to avoid traditional combinations of sounds and can be described using elementary mathematical notions like transformations and permutations of pitches and rhythms. But this formalism expressed a self-conscious rebellion against tonality rather than any natural musical structure, and the value of the resulting music always depended, not surprisingly, on the creativity of the composer rather than (or in spite of) the formal structure. By mistaking rigidity (in the colloquial sense) for rigor (in the mathematical sense) such musical formalism is often presented as a "mathematical" aspect of music (e.g., Chapter 8 of [6]). The importance of twentieth-century formalist schools in music has been greatly exaggerated by academics, while the incorporation of dissonance and breaching of harmonic boundaries have proceeded more naturally in the rest of the vast musical world.

While it is not surprising to the mathematician that arbitrary formalism is not mathematics, there is also music that has been created using constructions ostensibly based on mathematical elements (with varying levels of seriousness). However, the inevitable insertion of esthetic choices, together with the arbitrary nature of the underlying constructions, conspires to remove any trace of mathematical content from the picture. For instance, examples of "fractal music" range from simply superimposing melodic fragments over themselves at a few increasing multiples of tempo to multiply iterated computer synthesis of sound from 2-dimensional fractal-like shapes that involves numerous parameter choices. The "poorer approximations" of fractals actually tend to sound more musical, but in any event results certainly do not inspire repeated listening and seem unlikely to produce anything nearly as interesting as properties such as fractional dimension, let alone correspond to any more substantial fractal-related mathematics.

The relationships between the motivations and outputs of artists can be subtle and wide ranging. In the case of mathematically inspired composers it's frequently a matter of "a little knowledge being a dangerous thing", and even for the mathematically astute creator of music there remains the problem of extracting correlation from the inspiration. For instance, when a composer claims that the Fibonacci sequence is essential to one piece of music and then turns around and embeds names into the next piece via rhythmic Morse code, the transient nature of any musico-mathematical relationships is apparent [3]. It is possible to be sincere without being serious, but it is also true that in some circles it can be advantageous for a musician to have a supporting "theory" that critics can latch on to.

Unfortunately, I've yet to hear any mathematically inspired music that comes close to providing the substance and lasting impression of even an elementary piece of reasonably interesting mathematics. This reflects a common occurrence in the art world, where the desire to innovate leads to the celebration of "newness for newness' sake", a phenomenon much less prevalent in mathematics, where the value of new work emerges by consensus rather than by press release and both the audience and the reviewers are mathematicians.

Metaphorical Comparisons

So if the physics of sound is mathematical but not musical and music theory is musical but not mathematical, we can still ask if a common musico-mathematical core is reflected in other, perhaps more metaphorical, ways. Attention will be focused on the question of what might be special to mathematics and music rather than science and art in general.

Fundamental Observation

An interesting web of definitions, theorems, proofs, and conjectures does not require an extramathematical application to be satisfying. Similarly, the rhythmic flow of sonic tensions and resolutions in an instrumental music performance can be appreciated without attributing to the sounds any worldly connotations. In this respect mathematics and music seem to share the property that their content—however subjective and time-dependent—*can* be expressed intrinsically, without direct reference to the natural world of human experience.

Whether you agree or disagree with this statement at face value, I believe it is worth trying to adjust your philosophical viewpoint enough to consider the claim, if only to clarify its limitations. (For instance, if you can't separate any significant part of mathematics or music from the natural world, then at least try to recognize the presence of a significant *degree* of intrinsic meaning.) Since I believe that this observation is important, some clarifications are in order.

First of all, there is clearly an emphasis on "can", because both mathematics and music frequently *do* refer directly to the natural world. While the mathematician is well aware of the subtle and symbiotic interactions between the abstract development of theories and applications of mathematics, analogous interactions also occur with music, which besides being appreciated for its own sake can be associated with lyrics, images, dance, ritual, ceremony, commerce, and other extramusical phenomena. Of course external models are enriching and vital to both disciplines, but it can be helpful to be aware of the distinction, and I believe that the claimed observation of intrinsic meaning provides a special link between mathematics and music.

Among human disciplines this form of intrinsic meaning is essentially *unique* to mathematics and nonlyric music: Other sciences are always directly tied to the natural world via their subject matter, and while other art forms may use abstraction, it almost always involves recognizable elements of human experience that have been distorted or used in unexpected ways.

It is true that certain visual art that is completely devoid of any reference to the natural world can have content, but I feel that the *general* comparison is not even close and that the intrinsic natures of music and mathematics are a significant order of magnitude stronger, although I do not know how to measure this. Some fans of extremely abstract visual art will disagree with me here, and admittedly this may be evidence of a "gray area" where meaning emerges self-referentially from patterns, visual or sonic, perhaps suggesting analogies with certain musical works that seem not to even reference recognizable elements of music. Also relevant here is that the visuals used by mathematicians to express mathematics, such as figures, graphs, and diagrams, can have an esthetic impact of their own, as recognized for instance by the sculpture of Helaman Ferguson (`http://www.helasculpt.com/`). Some might suggest that such images provide more effective artistic embodiments of mathematical ideas than the "pseudorigorous" mathematically inspired music composition techniques discussed above. In any event, I stand by the claim of a significant sense of uniqueness and continue with clarifications.

The locations, characters, and actions in literature and dramatic performance provide essential identifications with the natural world, as even the most fantastic settings inevitably mirror recognizable elements in the lives of the audience. And although the art lies in the development of tension and resolution through changes in relationships among the agents, the effect on the audience is always dependent on qualities and expectations that are inferred from these identifications.

And if the avid poetry listener feels that sometimes the message of the poem is being carried entirely by the cadence, phrasing, texture, and tone of voice of the poet without recognition of any semantic content in the words, then I'd say that what is being heard is *music*. Logical philosophy and computer science can similarly intersect mathematics at their extremes.

Note that this claim of uniqueness is not a denial that other disciplines can have meaning that transcends their inherent references to the natural world, just that what is special to mathematics and music is that their content is capable of being expressed entirely in terms of their own raw material, namely, logical thought and audible sound.

Furthermore, no strict formalist mathematical philosophy is being imposed here, just the acceptance that the contemplation of generalized homology theories, transfinite ordinals, moduli spaces, and the like can (and often must) take place outside the usual realm of sensory perception. We believe that our elements are well defined, that our arguments are satisfyingly checkable, and that mathematics is consistent (although we know we can't prove it). Theories are developed by various internal associations of mathematical elements, but we do not *require* confirmation from an embodiment in human experience; and indeed we don't expect to find such confirmation, since even an object as basic as an interval of real numbers does not have a reliable model in the natural world.

Similarly, no banishment of cultural or other associations with music is being proposed, just the observation that as melodies, rhythms, and harmonies unfold in time, it is the relationships among the sounds that speak to you. The sounds repeat, mutate, diverge, return—always in combination with each other but never in *need* of "pointing" to anything outside the music.

Notice that such frequently recognized qualities as beauty, elegance, power, economy, anticipation, surprise, tension, and resolution are certainly *not* unique to music and mathematics. What is remarkable is that such qualities can emerge at all without need of body language, radiant sunsets, death-defying feats, wireless capabilities, expected rates of return, time travel, or love lost and renewed.

Finally, the claimed uniqueness and extreme level of intrinsic meaning is not intended to imply any judgments on the relative *values* of human endeavors, any of which can of course have a wide range of appeal and utility to a variety of people. In particular, nothing is being implied about the relative importance of "pure" and "applied" in both mathematics and music.

What Do Metaphorical Observations Explain?

The fundamental observation seems to provide a possible reason for the enduring attraction of musico-mathematical investigations: Since the ubiquity and power of mathematical and musical applications are a consequence of the strength of their intrinsic constructions, it is only natural to ask the question, Can they model each other?

But this very modeling power can represent obstructions to an in-depth metaphorical discussion with a general public whose musical and mathematical experiences are dominated by applications. (For instance, instrumental jazz and classical music each account for just a few percent of music sales, which is of course still greater than the publishing share of mathematics journals.) It is an important challenge to somehow share the value of abstract thinking with society at large.

An admirably well-intentioned attempt to describe metaphorical connections between the "inner lives" of music and mathematics to a general audience is the recently reprinted bestseller *Emblems of Mind* [12] by *New York Times* journalist Edward Rothstein. On the positive side, this book brings many worthwhile points to light, including the roles of beauty and creativity in mathematics, the emphasis of relationships over objects, and the power of abstraction inherent in both disciplines. Unfortunately, several fundamental problems cripple the coherent development of the many good ideas present: For instance, the occasionally insightful descriptions of music repeatedly fall into all the traps of musical analysis discussed above. A harbinger of the forthcoming distortion appears in the introduction, where after mentioning musical affinities of Galileo, Euclid, Euler, and Kepler, the author includes Schoenberg, Xenakis, and Cage among a short list of examples that seem to point back from music to mathematics. Even most mathematicians with an affinity for these composers would, with all due respect, surely recognize that this juxtaposition is way out of balance. This leads to such contradictions as claiming the existence of "a systematic logic that guides musical systems", but then admitting later that great musical compositions "create their own form of necessity, the binding coming not from logic but from the unfolding of ideas…". And the spurious metaphorical equating of the contrived formalism of twentieth-century atonal "systems" with the discovery of non-Euclidean geometries both fails to recognize the strong and natural role of modern geometry in mathematics and sidesteps the truth that the natures of tonality and dissonance in music are complicated and mysteriously subtle phenomena that have defied satisfactory explanation by any general theory.

The confusion created by mistaking musical form for content is compounded by being interwoven with an informal poetic analysis of music, frequently laced with fancifully chosen mathematical terminology. While the appreciator of well-written romantic prose may enjoy the exposition, those looking for more substance will be disappointed, as the attempt to nail down details makes the metaphors less robust rather than stronger. For instance, the notion that a "composition proceeds to 'prove' itself" or the claim of an analogue of "completeness" (of a logical system) in music are signs that the discussion is deteriorating. This is confirmed when one of the text's central points relates a metaphorical sense of "truth" in music to musical "style".

One fact clearly underscored by the book is that ordinary human language is much better at conveying mathematical ideas than musical ideas. Although the feeling that music is "telling a story" is often intensely felt by both listener and performer, there is no known well-defined "grammar" of music; and if a picture is worth a thousand words, then the relation between music and language must surely be exponential. On the other hand, mathematics has its set-theoretic foundations expressed in the formal languages of logic, and among mathematicians, informal conversation is the most common method of communicating mathematics. Does this suggest that music is in some sense *more* abstract than mathematics?

The popularity of [12] does confirm that there is a healthily curious audience among the general public. One would hope that such readers could be encouraged to pursue their investigation of mathematics in the growing number of expository sources written by mathematicians, such as the recent *Princeton Companion to Mathematics* [7] (although the brief section on mathematics and music in [7] gives too much weight to the type of superficial musical analysis criticized above).

Creative Processes

One might summarize the essence of a very general metaphorical view by the statement that "mathematics and music are the science and art of analogy". Although it appears to be difficult to extract more precision from metaphors, I believe that, by focusing on mathematical and musical *creative processes*, useful conclusions can be drawn.

In fact, the process of creating or discovering mathematics is in many ways analogous to a small-group jazz performance: This is evident in the real-time exchange of ideas among collaborators, spontaneously alternating lead and accompaniment roles, guided by a thematic problem, developing material statement by statement, pursuing tangential ideas, adapting to mistakes, being ready for unexpected results, and never knowing for sure if the original goals will be achieved. I believe that this analogy with musical improvisation is stronger than any picture of the mathematician as the solitary composer (although the most vital composers do capture the spirit of improvisation in their works), as there is a sense in which the nonperforming composer can rework the landscape to "force his theorems to be true" (but not necessarily "interesting"), whereas the improvisor must face the unforgiving judgment of the moment while traveling without a seatbelt. The analogy also extends to the researcher working alone as a solo improvisor, simultaneously playing lead and accompaniment roles as the devil's advocate, and even to the processes of understanding mathematics and interpreting composed music. (Note that the tradition of improvisation in Western classical music, which stretches back through Beethoven, Mozart, and Bach, shows signs of a rebirth [11].)

But this improvisational analogy can apply more generally to processes involved in many human endeavors, not only in the arts and sciences but also including many workplace environments encountered by citizens of today's fast-changing global society. In fact, in the face of turbulent economic conditions, advancing technologies, and increasingly international markets, employers and employees alike are going to be dealing with shifting work flows and new job types and products, as well as interactions with foreign cultures, all of which will require creative problem solving to recognize appropriate skill sets, implement effective training and study methods, and develop new career and employment programs.

The key point here is that the intrinsic nature of mathematics and music suggests that the studies of both research mathematics and improvisational music could play valuable roles in modern education, as their *abstract yet cohesive structures serve as models* for developing flexible skills and the ability to generate spontaneous constructive thought. While the problem-solving techniques and computational powers of mathematics are already well appreciated, the more abstract, creative, and improvisational aspects of human thought are going to be increasingly valuable in twenty-first-century life.

Ideally these studies would be completely integrated into the education system, with the associated musical and mathematical learning processes naturally complementing and reinforcing each other. What is important here is that the *goals of research and improvisation guide the pedagogy.* The challenge is to develop courses, programs, and teaching conceptions with these goals in mind and to incorporate them into the curriculum. (Note that combining mathematics and music in the classroom is not being proposed here.)

That the underlying frameworks of the studies can complement and reinforce each other is apparent at many levels. For instance, the student of musical improvisation uses formalism (music theory) to generate examples (sounds) that are examined esthetically (by listening), while the student of mathematics generates examples (special cases) to understand formalism (general statements) that are considered logically (by proving/disproving). More generally, both studies develop experience with solitary practice, group work, and open-ended learning. Many other such pedagogical frameworks exist at all levels and age groups.

The idea is not to produce more professional mathematicians and musicians (although talent would be more likely to flourish), but rather to provide greater general access and exposure to the relevant abstract skills. Of course some will benefit more from musical study, others from mathematics, and both subjects will still be challenging for almost everyone. But the recognition of the long-term benefits should provide motivation, and effective integration into the education structure would provide support to maximize the positive value for as many as possible. *The almost complete ignorance of the essences of mathematical research and improvisational music that is prevalent in society today means that the initial marginal benefits could be enormous.*

Of course the challenges faced in implementing such an educational vision would be huge, as effective teaching of both research mathematics and improvisational music is already difficult enough, and the skeptic will point to the existing body of inconclusive studies regarding musical and mathematical pedagogical methodology, as well as the apparent lack of supporting circumstantial evidence (where are all the improvisational music groups of mathematical researchers?). But there are good reasons to believe that the obstacles are surmountable and that the vision is valid: First of all, there is a growing consensus supporting educational reform, as well as funding available for innovative ideas. The mathematical research community has shown purposeful commitment to teaching in recent years, while at the same time the many jazz departments in universities and colleges across the country have become increasingly populated with top-level faculty having significant performance experience. (So a pilot program for preparing teachers could involve cross-training of graduate and/or undergraduate students, for example.) And although music has been largely cut from primary and secondary school curricula, the many independent organizations that have been providing music instruction could provide infrastructure for pilot programs on the musical side. On the mathematical side, a new vision is desperately needed to guide a complete reforming of the current generally dreadful state of mathematics education at the primary and secondary school levels. That aspects of this vision have already been accepted is evidenced by the increasing numbers of mathematics Ph.D.s working outside academia [10] and by the direct implementation of jazz conceptions in high-level business consulting [8].

Existing educational data should not be expected to provide insight into the worth of the proposed vision, primarily since such a focus on research and improvisation has not been significantly implemented. I would also expect that direct effects will be difficult to measure, especially in the short term. The problem of correlating success in varying job types is in itself an interesting problem in today's ocean of information and shifting employment patterns. And although I know of various successful external applications of musical and mathematical frames of mind, the satisfying nature of improvisational and research experiences means that those who are good at it are likely to happily stay with it.

Conclusion

It is clear that an in-depth appreciation of both mathematics and music is a prerequisite to the critical consideration of musico-mathematical relationships and their kernels. But to the extent that one appreciates mathematics, one *is* a mathematician, whereas the appreciator of music need not be a musician. It follows that the mathematics community is likely to provide constructive contributors to the dialogue. Expositing and teaching mathematics (independently of music), as well as promoting exposure to all forms of music, will contribute to opening the discussion to a wider audience. Ideally this could be integrated into the entire educational system. At least, one would hope that inviting metaphors might provide motivation for deeper exploration and in particular lead to a wider awareness of the esthetics of mathematics. The danger is that the unconscious readiness with which the mind accepts analogies will allow poetic hand waving to stir up pleasing but shallow illusions, clouding a picture that can only be clarified by thoughtful hard work.

In an ideal world, a marriage of mathematics and music should celebrate the beauty and power of abstraction. But the courtship is thrown off balance by the contrast between the open-access nature of the musical world, in which the listener is free to navigate by ear, and the rigor of the mathematical world, in which the curious mind must temper its imagination with logic. The proliferation of suitors in the natural world further complicates matters, rendering detailed agreements, scientific or metaphorical, elusive. In spite of the voluminous literature inspired by this undeniably intriguing situation, many of the most salient observations on the subject are one-liners, often provided by mathematicians (see e.g., [1]). On that note, I would like to provide an affirmative answer to the title question by offering a punch line of my own: "Mathematics is like music that only musicians can hear."

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The Abdus Salam School of Mathematical Sciences in Pakistan

Loring W. Tu

A critical partner in the fight against terrorism, Pakistan has often been in the news lately; unfortunately much of the news is bad. Beset with political instability, economic inequality, ethnic strife, high-profile assassinations, religious extremism, government corruption, sectarian violence, and natural disasters, the country faces almost insurmountable challenges.

Pakistan shares with India a long and glorious past. Following a succession of ancient empires, Great Britain gained control of the Indian subcontinent in the mid-nineteenth century. In 1947 British India was partitioned along religious lines into two states. The predominantly Muslim areas became the Islamic Republic of Pakistan, which later separated into present-day Pakistan and Bangladesh, and the rest became the secular Republic of India, whose inhabitants are mainly Hindu. Unlike in India, mathematics had long been neglected as an area of research in Pakistan.

In 2003, recognizing the need for training in advanced mathematics, the Higher Education Commission of Pakistan and the provincial government of Punjab, the largest and economically most important province of Pakistan, founded the Abdus Salam School of Mathematical Sciences (ASSMS) at Government College (GC) University in Lahore. The school takes its name from Abdus Salam, a Pakistani Nobel laureate whose Nobel Prize was in physics but who had studied and taught mathematics at GC University. With a population of more than seven million, Lahore is the second largest city in Pakistan and is its intellectual, cultural, and artistic capital. The seat of the Mughal empire in the late sixteenth century, Lahore has mosques and palaces that rival Versailles in their scale (Figure 1).

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Although affiliated with GC University, the Abdus Salam School of Mathematical Sciences is an autonomous unit with its own faculty, funding, and admission of Ph.D. students. Even its building is not on the campus of GC University. Housed in a nondescript, unmarked, low-hung building in a residential area in the heart of Lahore, protected by a large, heavy metal gate behind high walls, the school is hardly noticeable (Figure 2). On my recent visit, the director-general of the school, Dr. A. D. R. Choudary, told me that the anonymity of the building and of the location is intentional, for it contributes to the security of the school.

Faculty

Among research and educational institutions in mathematics, the Abdus Salam School of Mathematical Sciences is unique in many ways. It is a doctoral school in mathematics with no undergraduates. Reflecting the state of mathematical training in Pakistan, its faculty is entirely foreign. Moreover, every professor has a joint appointment either as a regular or as an emeritus faculty member at a foreign university or institute. This fact alone guarantees a level of quality unmatched in other Pakistani institutions. Most of the professors have positions in Eastern Europe, but a few come from France, Germany, Britain, and Norway. In a country where the average per capita income is less than two dollars a day, it is difficult for the school to offer salaries competitive with those of the West. Clearly, for a foreign mathematician to work at the Abdus Salam School, a certain measure of idealism is required. Fortunately, the cost of living in Pakistan is low, and one can live very well on a local professor's salary.

There is no permanent faculty, but many professors come regularly enough that the school not only functions but has achieved an enviable level of success. Some professors discharge their teaching duties at their home institution in one semester and come to the Abdus Salam School in the other semester; others, located at research institutes, have more freedom of movement; still others come during semester breaks or summer months. Those who are emeritus in their own institution can of course accept a full-time appointment at the Abdus Salam School. The research expertise of the forty some faculty members spans all areas of pure and applied mathematics, from algebra and number theory to geometry, topology, analysis, dynamical systems, combinatorics, mathematical physics, probability, and financial mathematics.

Program

The Abdus Salam School provides all of its students with full tuition support and living expenses for five years. Each year twenty students are admitted based on a competitive entrance examination. While some Pakistani students do go abroad for graduate study, most do not. The students at the ASSMS are the cream of the crop of those who stay in Pakistan, a factor that may help explain the high graduation rate at the end of five years at the school. In a male-dominated Muslim society, it is surprising to see a strong contingent of female students. Of the eighty-four full-time students currently pursuing a Ph.D. degree at the school, twenty-five are women (Figure 3).

In their first year, all students take ten required courses, in Linear Algebra, Algebra I and II, Real Analysis I and II, Geometry I and II, Complex Analysis, Number Theory, and Differential Equations. In their second year, the students take more advanced required and elective courses from a large number of choices, depending on the faculty available. One of the more unusual Ph.D. requirements at the school is that a student must have a paper accepted in an internationally recognized journal, such as the ones on the list established by the ISI (Institute for Scientific Information), before the thesis can be presented for the degree. This requirement, which ensures that every thesis meets a minimum internationally recognized standard, is unheard of at American universities but is especially important in a country such as Pakistan for the degree to have credibility.

It is an impressive achievement that, even with this publication requirement, in the short span of eight years since its founding in 2003, the Abdus Salam School has produced fifty-eight Ph.D.s in mathematics, of whom nine are women. Even more remarkable is the fact that, of the fifty-eight, all except one are now employed as faculty at universities and institutes throughout Pakistan. The Abdus Salam School is clearly serving an important societal need in Pakistan. In addition to training Ph.D. students, the school has a postdoctoral program for new Ph.D.s from abroad and a training camp to prepare talented Pakistani high school students for the International Mathematical Olympiad. In a multipronged approach to the promotion of mathematics, the school organizes mathematical contests for young students throughout Pakistan,

Figure 1. Lahore Fort in Lahore, Pakistan.

Figure 2. The courtyard of the ASSMS.

Figure 3. Students enjoying Pakistani treats.

Figure 4. The author in Pakistani garb with Director-General A. D. R. Choudary (fourth man from left, in white) and some of the faculty and students at the Abdus Salam School.

as well as international conferences for research mathematicians.

Crisis

In spite of the school's service to the nation, the outlook for the ASSMS is not rosy. In the summer of 2010, heavy monsoon rains flooded one fifth of Pakistan, creating a humanitarian, medical, and economic crisis of unprecedented proportions. Whether as a response to this or some other crisis, the government cut the budget of the ASSMS by 50 percent. For the first time in its history, the ASSMS did not admit a first-year class. What the future holds is anyone's guess. The fact is, it is difficult to make a case for theoretical mathematics when millions of people, displaced from their homes, lack food, clean water, and medical care.

The 50 percent cut to its budget underscores the precarious financial foundation of the ASSMS and the need for an endowment. By American standards, the amount needed is not large. For example, at the current rate of return in Pakistan, the income from an endowment of $25,000 can provide the annual living expenses for one Ph.D. student.

Visitors

Another way the international mathematical community can help is for eminent mathematicians to give lectures, offer courses, or advise students at the ASSMS.

In hosting international visitors, one obstacle unique to Pakistan is the issue of security. Various Western governments, including those of Australia, Canada, France, and Switzerland, have issued travel warnings advising their citizens against visiting Pakistan except in case of family or professional necessities. The State Department of the United States does not go so far, but it issues a list of risks long enough to scare off potential travelers. During my two-week visit to Lahore in January 2011 (Figure 4), the only Westerners I saw were the foreign faculty at the ASSMS. None of them have ever had a bad experience in Pakistan, nor have they heard of any incidents involving foreigners in Lahore. It may be that the small size of the foreign population in Lahore makes it an unnoticeable or unattractive target.

Whatever the security situation may be, the Abdus Salam School takes good care of its faculty. All the foreign faculty are housed in mansions in a safe neighborhood on the outskirts of Lahore. Both the faculty housing and the school itself are patrolled by armed guards twenty-four hours a day. Every day the school provides vans to transport the faculty between the housing and the school. At the faculty residences, in-house chefs prepare meals for all the faculty, and custodians clean the houses. Laundry can be sent out and will come back cleaned and pressed. With the mundane daily affairs taken care of, if they wish, the faculty can devote all their time to mathematics.

Religion

Religion permeates every aspect of life in Pakistan. Upon arrival at the airport, the luggage goes through a scanner. If the scan shows anything resembling a bottle, the luggage is opened and bottles containing alcohol are confiscated.

I had been warned not to bring alcohol into Pakistan, but I did bring from Paris some expensive chocolates filled with brandy, Cointreau, or cognac. Surely eating liquor-filled chocolates does not count as drinking! My chocolates made it through customs with no problem, but, alas, I could not give them away. On being told the alcohol content of the chocolates, my Pakistani hosts, the Pakistani staff at the school and at the residence, and the

All photographs courtesy of the author.

Figure 5. The mathematics library at the ASSMS.

students all politely declined my offer. In the end, I gave the chocolates to the foreign faculty and the foreign-born non-Muslim mother-in-law of a staff member.

The first morning, at 5 a.m., I was roused from my slumber by a persistent chant that seemed to envelop the entire neighborhood. It was the call to morning prayer. A devout Muslim prays five times a day. In every neighborhood there is a mosque, and the minaret of the mosque is usually fitted with a powerful loudspeaker that broadcasts the call to prayer, or *adhan*. The call can last twenty minutes. I adapted by going to bed early in order to wake up with the call to morning prayer.

The seriousness of religion in Pakistan can be seen in the debate about the blasphemy laws that make insulting Islam a crime punishable by death. In November 2010 a Christian woman was sentenced to death by hanging under the blasphemy laws. She was accused of having made derogatory comments about the prophet Muhammad, but there are those who think that the blasphemy laws are being used to settle personal vendettas. Lawmakers who try to repeal the blasphemy laws run considerable risks. On the second day of my visit, the governor of the Punjab province, Salman Taseer, a reform-minded Muslim, was shot to death by his own bodyguard. Universities and government offices closed, and my lecture for the day was canceled. Within two months, the federal minister of minority affairs was assassinated, also for supporting the reform of the blasphemy laws. The case of the Christian woman is under appeal, but the movement to reform the blasphemy laws is stalled.

Health Concerns

Before my trip to Pakistan, I went to the Travel Clinic at Massachusetts General Hospital and got, at considerable expense, seven different immunization shots, as well as medication against malaria. The malaria medication was to be taken every day while in Pakistan and for seven days after leaving. I also brought with me a can of insect repellant. All of this turned out not to be necessary, at least not in Lahore. None of the foreign faculty at the Abdus Salam School had gotten any immunization, and they have been perfectly fine. Moreover, Lahore has no mosquitos in the winter months. I stopped the malaria medication two days after arrival and experienced no health problems while in Pakistan.

Internet and Library

Wireless Internet works surprisingly well in Lahore. It seems that the entire city is covered with wireless Internet. With a special USB key from the Internet service provider plugged into my personal laptop, I was able to access the Internet from anywhere in the city.

With the availability of the Internet, the library at the Abdus Salam School can dispense with hard copies of journals and rely on online subscriptions to major mathematical journals (Figure 5). As for books, it is a different matter. While the library has most of the standard reference books in each field, its book collection as a whole is small. Moreover, the students simply do not have the means to buy original editions of books published in the West. With more and more books becoming electronic, perhaps the situation will become better in the future.

Power Shedding

In spite of my extensive experience in international travel, it was in Pakistan that I encountered for the first time the phenomenon of "power shedding". On the day of my arrival, I was writing up some lecture notes at 6 p.m., when the room suddenly went pitch black. In fact, the whole neighborhood went dark. My Pakistani caretaker, Fareed, assured me that power would come back at 7 p.m. It turned out that, in an effort to save energy, the government shuts down power five times a day for an

Figure 6. Jahangir's Tomb in Lahore, Pakistan.

hour each time. This is called "power shedding". Power shedding rotates among neighborhoods, with different neighborhoods losing power at different times. Large stores and institutions usually have their own backup generators so that they can go about their business. For a mathematician, it is indispensable to have a battery-powered laptop. Fortunately, wireless Internet continues to be available even during periods of power outage. I was told that power shedding had been going on in Pakistan for thirty years. With the safety of offshore oil rigs in doubt and nuclear power under a cloud, could power shedding be in America's energy future?

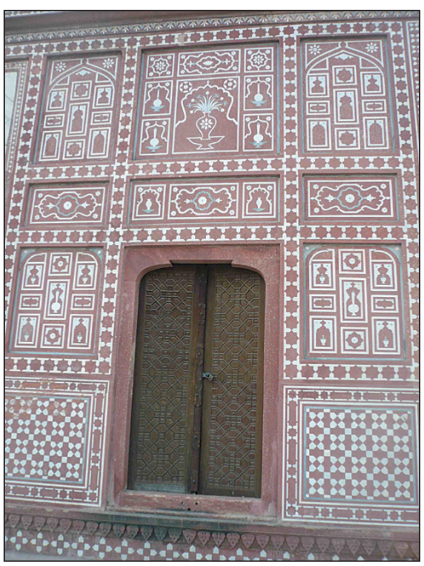


Figure 7. Details of Jahangir's Tomb.

Students

At the Abdus Salam School I gave a series of twelve lectures on equivariant cohomology, assuming a basic knowledge of manifolds and cohomology and ending with a proof and some applications of the equivariant localization theorem of Atiyah-Bott and Berline-Vergne. About two dozen people, mostly students but also some faculty, attended the lectures. From the questions, I could tell that some of the students were following the lectures closely. I spoke with students outside the classroom and had the impression that at least a few are comparable to the best students in a good American graduate program. The problems they work on, say on exceptional Lie algebras or on configuration spaces, seem to me quite mainstream and constitute interesting mathematics. The students seemed motivated and eager to learn, for there was little attrition throughout the twelve lectures.

University of the Punjab

The Abdus Salam School is located not far from the University of the Punjab. One day a graduate student, Waleed Noor, from the Abdus Salam School took me to the University of the Punjab for a visit. In Waleed, I found a perfect guide to Pakistani culture. The first striking fact about the University of the Punjab campus is the preponderance of female students, all with headscarves and in full-body cloaks, some even in niqab that covers most of their face. The university's student body is 70 percent female. One reason may be that girls are more studious and obedient in high school and do better on exams. Since admission to a university is based on an entrance exam, there would be more female undergraduates. At the University of the Punjab, the mathematics department has four hundred mathematics majors, of whom three hundred and fifty are women, a marked departure from the ratios in the United States. However, progressively fewer women pursue advanced studies, and even fewer enter the work force. My Pakistani hosts offered the explanation that most women in Pakistan still prefer the traditional role of a mother and housewife. My own unscientific survey was too limited to conclude if the dearth of women in the

Figure 8. Donkey carts are a common sight in Lahore.

work force was out of preference or due to gender discrimination and peer pressure.

I asked a group of female mathematics majors whether, given the lopsided sex ratio at the university, there is intense competition for a male date. They said, "We don't date. Our parents will find husbands for us." Most marriages in Pakistan, even among the highly educated segment of the population, are still arranged. Both men and women seem content with the arrangement, because "our parents can cast a wider net."

Lahore

Much of Lahore today is not beautiful, but it has breathtakingly beautiful sites that recall its former splendor. Both the Lahore Fort and the Shalimar Garden have been designated as UNESCO World Heritage Sites. The photos I took of the Lahore Fort and of Jahangir's Tomb (Figures 1, 6, and 7) share a common feature—the absence of people. There are no tourists in Lahore to speak of. Foreigners have been scared away, and the locals, for whatever reason, do not throng to their cultural heritage, and so the monuments stand in splendid isolation.

Figure 9. Rickshaws serve as taxis in Lahore.

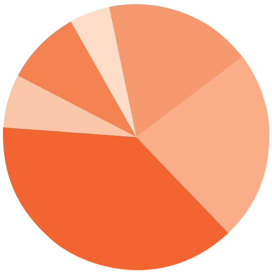
The ubiquity of donkey carts adds an Old World charm to daily life in Lahore (Figure 8). Rickshaws, which are motorized tricycles that serve as taxis in Lahore, weave in and out of traffic (Figure 9). In a city of seven million without a subway, traffic jams are to be expected.

The lack of a tourism industry means that it is not easy to find picture postcards. According to the locals, postcards might be available in the Lahore museum, but no one seemed to have seen one. I never made it to the Lahore museum; the thought of getting caught in traffic jams was enough of a deterrent.

Shortly after I left, an American, Raymond Davis, was arrested in Lahore for killing two Pakistanis. According to Mr. Davis, who turned out to be a CIA contractor, the two Pakistanis were trying to rob him at a traffic jam and he acted in self-defense. Whatever the truth may be, this appeared to be an isolated incident. I felt safe walking freely about the city in January 2011. However, with the tension generated by the killing of bin Laden, the security situation for American visitors in Lahore may have become more fluid.

Conclusion

Terrorism and lawlessness thrive when a population lives in misery. While the development of mathematics cannot be expected to solve all the ills of a society, it is a step in the right direction. The Abdus Salam School of Mathematical Sciences is training mathematicians versed in modern mathematics to serve as future faculty in Pakistani universities. It is an important mission. It would be a pity if its programs were curtailed because the Pakistani government is overwhelmed with competing demands. Those of us fortunate enough to work in the West can lend a helping hand. In the case of the Abdus Salam School, even a small gesture can go a long way. For more information about the school or to make a donation, visit `http://www.sms.edu.pk`.



Report on the 2009-2010 New Doctoral Recipients

Richard Cleary, James W. Maxwell, and Colleen Rose

This report presents a statistical profile of recipients of doctoral degrees awarded by departments in the mathematical sciences at universities in the United States during the period July 1, 2009, through June 30, 2010. All information in the report was provided over the summer and fall of 2010 by the departments that awarded the degrees with information provided by the individual new doctoral recipients. The report includes an analysis of the fall 2010 employment plans of 2009–2010 doctoral recipients and a demographic profile summarizing characteristics of citizenship status, sex, and racial/ethnic group. This report provides a more extensive look at the 2009–2010 new doctorates and includes information about 2009-2010 doctoral recipients that were not included in the preliminary report.

Detailed information, including tables which traditionally appeared in this report, is available on the AMS website at `www.ams.org/annual-survey/survey-reports.`

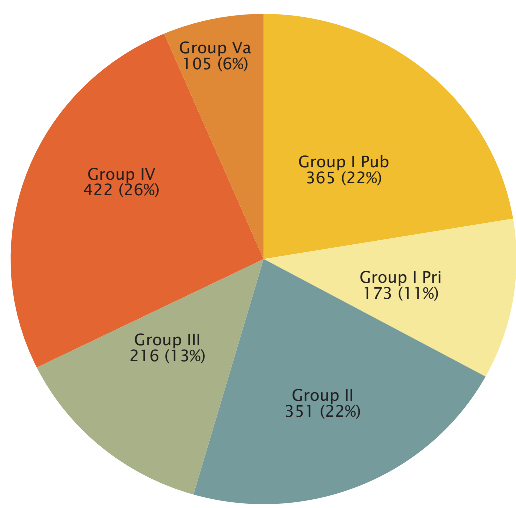
Doctoral Degrees Awarded

1,632 Ph.D.s were awarded by the 299 doctoral-granting departments that we surveyed. For the first time ever we had a 100% response rate. The 292 departments responding both this year and last year reported a total of 1,625 new doctoral recipients, an increase of 20 over the 1,605 new doctoral recipients they reported last year.

Again considering only the 292 departments responding both years, the twenty-three departments in Group 1 Private responding to both surveys reported 52 fewer new doctoral recipients for 2010, 225 for 2009-2010 compared to 173 for 2008-2009. (See page 954 for a description of the department groupings.)

35% (568) of the new Ph.D.s had a dissertation in statistics/biostatistics, followed by algebra/number theory (230) and applied mathematics (229) both with 14%.

Figure A.1: Number and Percentage of Degrees Awarded by Department Groupings



Total Degrees Awarded: 1,632

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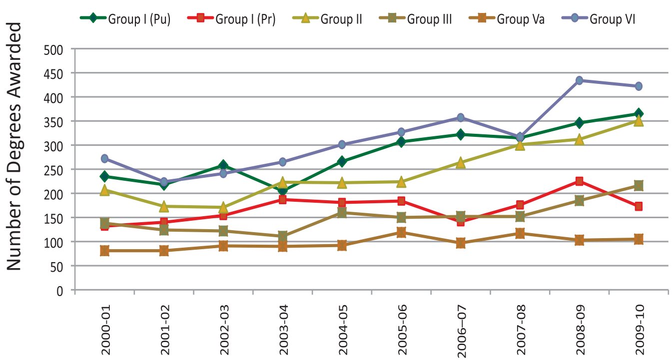
Doctoral Degrees Awarded

Figure A.2: New Ph.D.s Awarded by Group



Comparing Ph.D.s awarded this year to last year, the number of Ph.D.s awarded:

- Increased 2% overall.
- Groups I (Pr) and IV awarded 23% and 3% fewer degrees.
- Groups II and III awarded 13% and 17% more degrees.

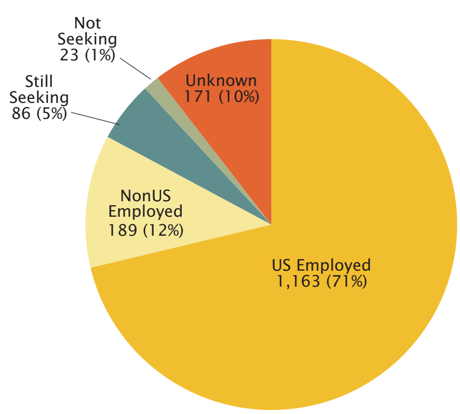
Looking at Ph.D.s awarded this year with those awarded in 2000–2001:

- Ph.D.s awarded have increased more than 53% over the last 10 years in all groups combined.
- Groups I (Pu), II, and III continue to report record numbers each year.

Employment

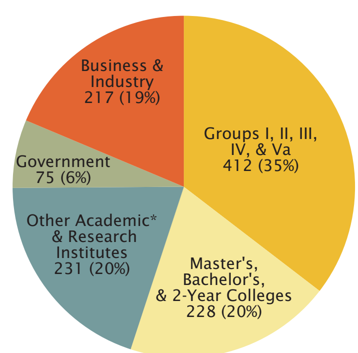
The overall unemployment rate is 6.9%, up from 4.9% last year. (Details on the calculations are on page 954.) The employment plans are known for 1,461 of the 1,632 new doctoral recipients. The number of new doctoral recipients employed in the U.S. is 1,163, down slightly from last year's number of 1,166. Employment in the U.S. increased in all employer types except Groups I and Va which decreased 1%. The number of new Ph.D.s taking positions in government has increased to 75 this year. Academic hiring of new doctoral recipients increased to 871, compared to 741 last year.

Figure E.1: Employment Status



- 53% (621) of those employed in the U.S. are U.S. citizens, up from 51% last year.
- 75% (542) of non-U.S. citizens known to have employment are employed in the U.S., the remaining 178 non-U.S. citizens are either employed outside of the U.S. or are unemployed.
- 8% of new Ph.D.s are working at the institution which granted their degree, up from 7% last year.

Figure E.2: U.S. Employed by Type of Employer

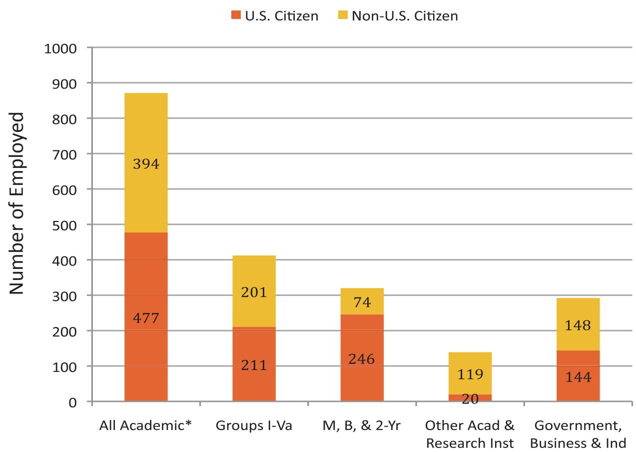


*Other Academic consists of departments outside the mathematical sciences including numerous medical related units.

- Total U.S. employed: 1,163
- U.S. Academic hiring increased 18% overall, all groups except M&B reported increases.
- Business & Industry hiring decreased 29% (from 305 to 217); all groups showed a decrease in the number of Ph.D.s taking positions in this sector.

Employment

Figure E.3: Employment in the U.S. by Type of Employer and Citizenship Total: 1,163

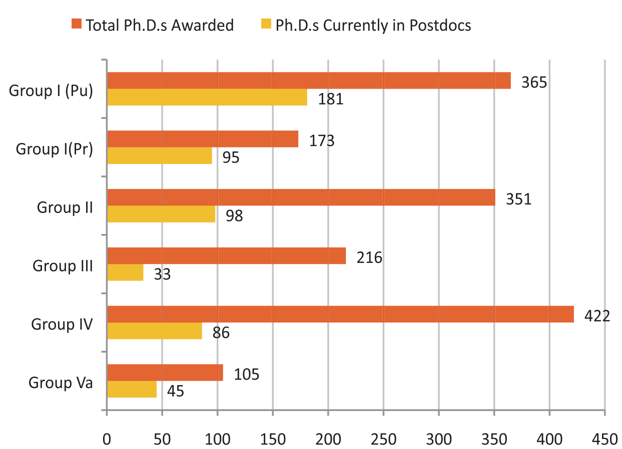


*Includes Groups I-Va, M, B, 2-Yr, other academic and research institutes/nonprofit.

Looking at U.S. citizens whose employment status is known:

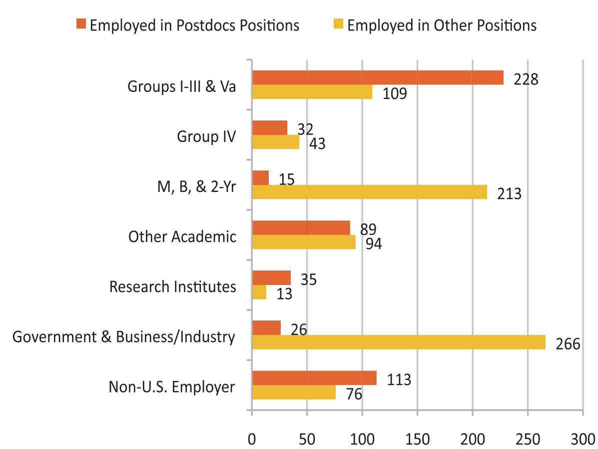
- 85% (621) are employed in the U.S., of these:
  - 34% are employed in Ph.D.-granting departments
  - 43% are employed in all other academic positions
  - 23% are employed in government, business and industry positions

Figure E.4: New Ph.D.s Employed in Postdocs by Degree-Granting Department



- 40% (538) of the new Ph.D.s are reported to be in postdoc positions, up 10% from last year.
- 20% of the new Ph.D.s in postdoc positions are employed outside the U.S.
- 49% of the new Ph.D.s having U.S. academic employment are in postdocs; last year this percentage was 43%.
- 55% of the new Ph.D.s awarded by Group I (Pr) are employed in postdocs, while only 15% of new Ph.D.s awarded by Group III are in postdocs.

Figure E.5: Postdoc vs Non-Postdoc Employment by Type of Employer



- Total known to be employed: 1,352
- 63% of the new Ph.D.s employed in Groups I-Va are in postdoc positions. The analogous percent for Group I is 80%.

Employment

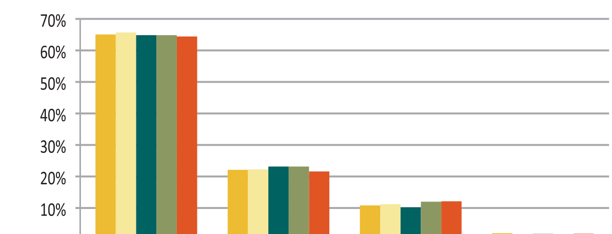
Figure E.1 displays the U.S. unemployment rate for new doctorates, details on the calculations are on page 954.

Figure E.1: Percentage of New Doctoral Recipients Unemployed 2001–2010*

*The difficult employment years of the 1990's are not show here but are located on the AMS website at www.ams.org/annual-survey/2010Survey-NewDoctorates.

- Unemployment among those whose employment status is known is 6.9%, up from 4.9% for fall 2009.
- Group II reported highest unemployment at 11.6%.
- Group IV reported the lowest unemployment at 2.3%.
- 7% of U.S. citizens are unemployed, compared to 8% in fall 2009.
- 6.7% of non-U.S. citizens are unemployed; the rates by visa status are
    - 10.1% for those holding a permanent visa.
    - 8.1% for those holding a temporary visa, almost double last year's figure of 4.4%.

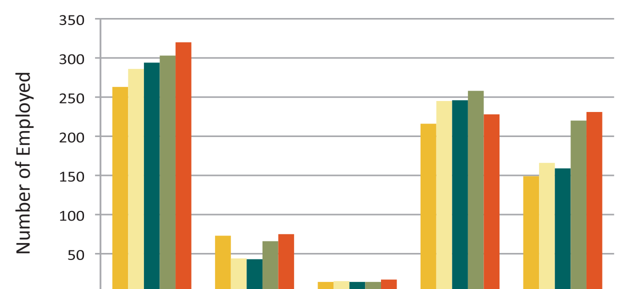
Figure E.7: Percentage of Employed New Ph.D.s by Type of Employer



	U.S. Academic*	U.S. Noncademic	Non-U.S. Academic	Non-U.S. Nonacademic
Fall 2006	65%	22%	11%	2%
Fall 2007	66%	22%	11%	1%
Fall 2008	65%	23%	10%	2%
Fall 2009	65%	23%	12%	1%
Fall 2010	64%	22%	12%	2%

* Includes research institutes and other non-profits.

Figure E.8: New Ph.D.s Employed in U.S. Academic Positions by Hiring Department Group[1]



	Groups I-III	Group IV	Group Va	Groups M, B & 2-Yr	Other[2]
Fall 2006	263	73	14	216	149
Fall 2007	286	44	15	245	166
Fall 2008	294	43	14	246	159
Fall 2009	303	66	14	258	220
Fall 2010	320	75	17	228	231

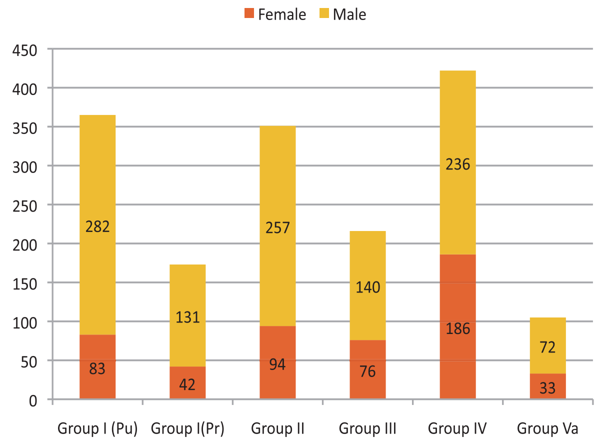
1 For definitions of groups see page 954.
2 Includes other academic departments and research institutes/other nonprofits.

- Hiring of new Ph.D.s has increased in all groups except Groups M&B which hired 13% fewer new Ph.D.s than last year.
- Comparing the last 5 years we see that:
    - The percentage of Ph.D.s hired into academic and nonacademic positions shows little variability over the years.
    - Groups I-III and Other have showed an increasing trend in the hiring of new Ph.D.s, hiring 22% and 54% more new Ph.D.s than for Fall 2006.
    - Groups IV, Va, and M&B all show some variability over the years, but all groups hired a few more new Ph.D.s this year than they did in Fall 2006.
    - Detailed information on new Ph.D.s employed in the U.S. by degree-granting department group is available on the website at www.ams.org/annual-survey/2010Survey-NewDoctorates.

Demographics

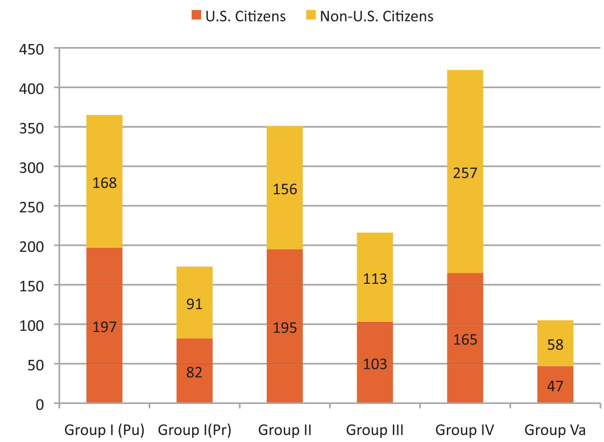
Gender and citizenship was known for all 1,632 new Ph.D.s reported for 2009-2010. The number of U.S. citizens is 789 (48%) (up from 46% last year). The number of females accounted for 29% of the U.S. citizen total (down from 31% last year). The number of non-U.S. citizens receiving a Ph.D decreased to 52% from 54% last year.

Figure D.1: Gender of Doctoral Recipients by Degree-Granting Department



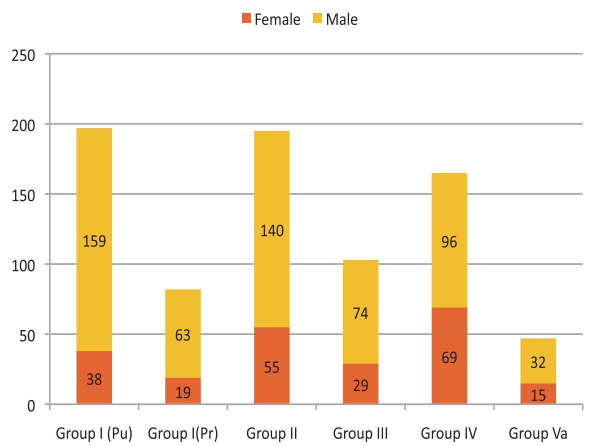
- Females account for 31% (514) of the 1,632 Ph.D.s, down from last year's figure of 33%.

Figure D.2: Citizenship of Doctoral Recipients by Degree-Granting Department



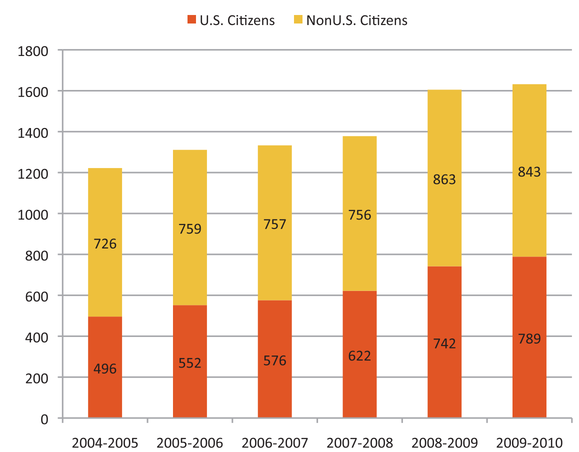
- All groups reported awarding more degrees to non-U.S. citizens than U.S. citizens, with the exception of Groups I (Pr) and III, which awarded 54% and 56% of their Ph.D.s to U.S. citizens.

Figure D.3: Gender of U.S. Citizen Doctoral Recipients by Degree-Granting Department



- 50% of the males and 44% of the females are U.S. citizens.
- Females accounted for 29% of the U.S. citizens,
- Among the U.S. citizens: 2 are American Indian or Alaska Native, 42 are Asian, 28 are Black or African American, 24 are Hispanic or Latino, 6 are Native Hawaiian or Other Pacific Islander, 668 are White, and 19 are of unknown race/ethnicity.

Figure D.4: Citizenship of New Ph.D. Recipients, 2004–2010



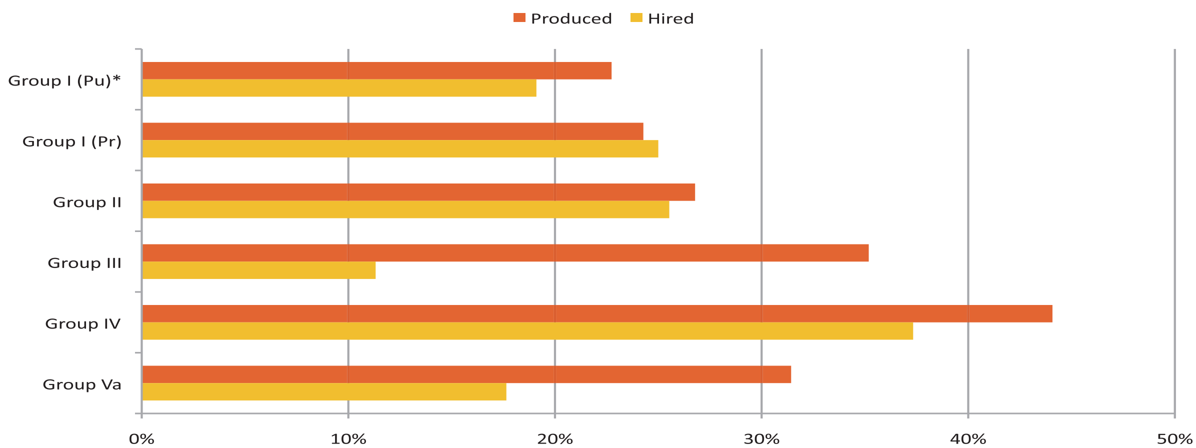
Looking at the last six years we see that:

- U.S. citizen counts have been increasing steadily, reaching a high of 789 this year. This is a 59% increase from Fall 2004–2005.
- Non-U.S. citizen counts which had been hovering around 750, jumped to 863 last year before dropping to 843 this year. While this is a 16% increase from Fall 2004–2005, it represents a 2% decrease from last year.

Female New Doctoral Recipients

After increasing to 33% last year, the number of female new doctoral recipients decreased to 31% this year. Of the 871 new Ph.D.s hired into academic positions 33% (287) were women, up from 29% last year. 20% of those hired into postdoc positions were women, with 57% of those being U.S. citizens. The U.S. unemployment rate for females is 5.6%, compared to 7.5% for males and 6.9% overall.

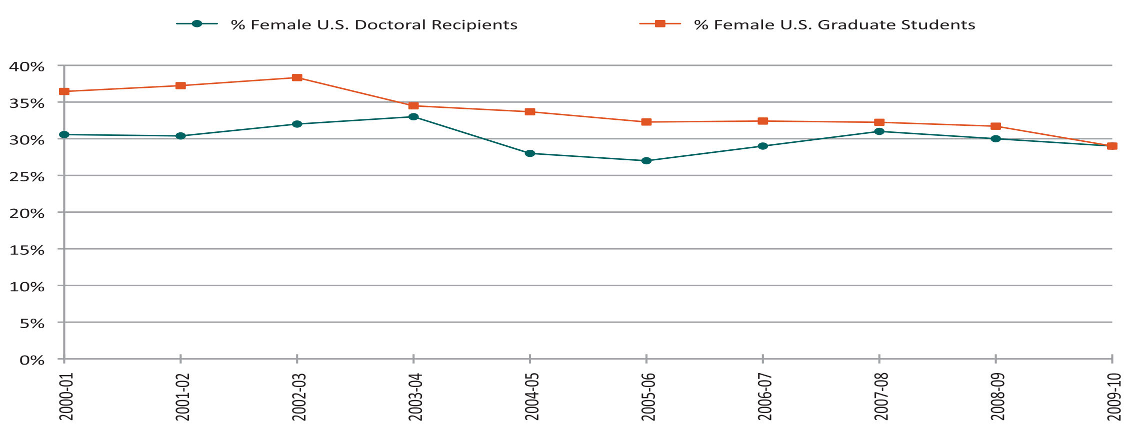
Figure F.1: Females as a Percentage of New Doctoral Recipients Produced by and Hired by Doctoral-Granting Department



* For definitions of groups see page 954.

- 43% of those hired by Group B were women (the same as last year) and 39% of those hired by Group M were women (down from 40% last year).
- 35% of those hired into Research Institutes/Other non-profit positions were women.
- 36% of those hired into Government positions were women.
- 61% of the women employed in Groups I-Va are in postdoc positions, compared to 64% of the men employed in postdocs in these groups.

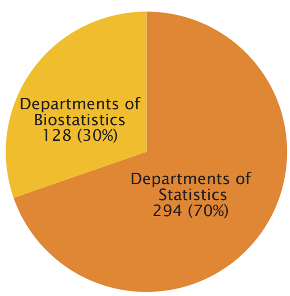
Figure F.2: Females as a Percentage of U.S. Citizen Doctoral Recipients



Ph.D.s Awarded in Group IV (Statistics/Biostatistics)

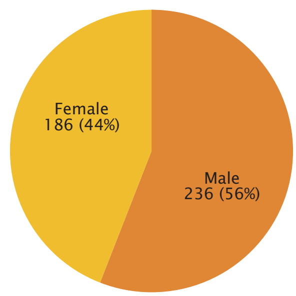
This section contains information about new doctoral recipients in Group IV. Group IV produced 422 new doctorates, of which all but 5 had dissertations in statistics/biostatistics. This is a 3% decrease in the number reported for fall 2009 of 434. In addition, Groups I–III and Va combined had 152 Ph.D. recipients with dissertations in statistics. In Group IV, 165 (39%) of the new doctoral recipients are U.S. citizens (while in the other groups combined 52% are U.S. citizens). The 89 departments responding last year and this year reported a total of 416 new doctoral recipients, a decrease of 4% from last year. While the unemployment rate for new Ph.D.s with dissertations in statistics or probability has increased to 3.4%, the unemployment among the Group IV new Ph.D.s is 2.3%.

Figure S.1: Ph.D.s Awarded in Group IV



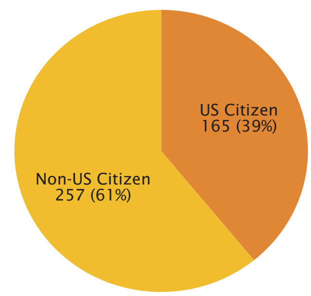
- 26% of all Ph.D.s awarded were in Group IV.
- Females account for 39% of statistics and 55% of biostatistics Ph.D.s awarded.

Figure S.2: Gender of Group IV Ph.D. Recipients



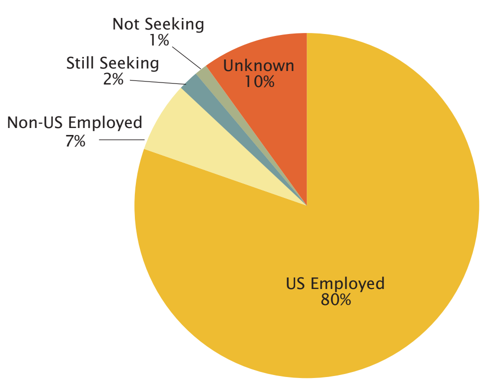
- Females accounted for 44% of the 422 Ph.D.s in Group IV, compared to all other groups combined, where 27% (328) are female.

Figure S.3: Citizenship of Group IV Ph.D. Recipients



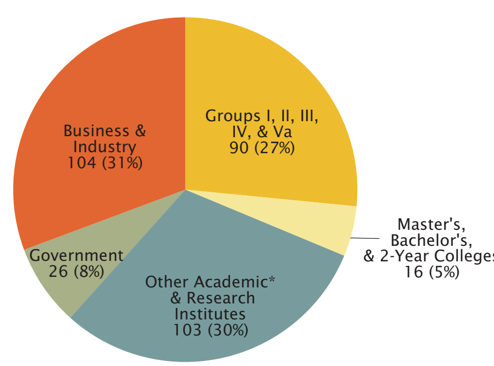
- 42% of Group IV U.S. citizen Ph.D. recipients are females, while in all other groups combined 25% of the U.S. citizens are females.

Figure S.4: Employment Status of Group IV Ph.D. Recipients



- 2.3% of Group IV Ph.D.s are unemployed compared to 8.6% among all other groups. This is up from 1.8% last year.
- Unemployment among new Ph.D.s with dissertations in statistics/probability is 3.4%, up from 2.9%. Among all other dissertation groupings 7.2% are unemployed.

Figure S.5: U.S. Employed Group IV Ph.D. Recipients by Type of Employer



*Other Academic consists of departments outside the mathematical sciences including numerous medical related units.

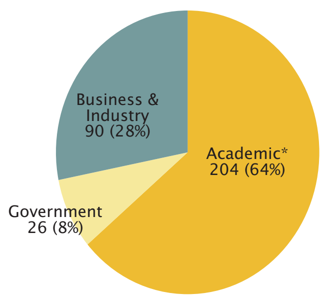
- Group IV total U.S. employed: 339
- 31% of Group IV Ph.D.s are employed in Business/Industry, compared to 14% in all other groups.
- 37% of those hired by Group IV were females, compared to 21% in all other groups.

Information from the Employment Experiences of New Doctorates (EENDR) Survey

This section contains additional information on employment gathered from a subset of the 2009–2010 new Ph.D.s on the EENDR Survey. It expands on the details of employment which are not available through the departments.

The 1,476 new Ph.D.s reported in our Preliminary Report were sent this survey; of those individuals 802 (54%) responded. The employment status is known for 792 of these individuals, the U.S. unemployment among this group is less than 2.6%. 33% of EENDR respondents who are employed reported they are actively looking for another position. The median age among this group of respondents is 30.

Figure EE.1: EENDR Respondents Reporting Permanent U.S. Employment by Sector

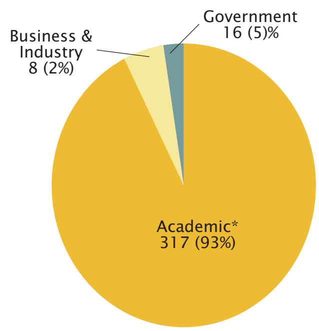


* Includes research institutes and other non-profits.

Of the 320 permanently employed:

- 38% are women.
- 51% were unable to find a suitable permanent position.
- 73% of those reporting academic employment hold tenured/tenure-track positions.

Figure EE.2: EENDR Respondents Reporting Temporary U.S. Employment by Sector

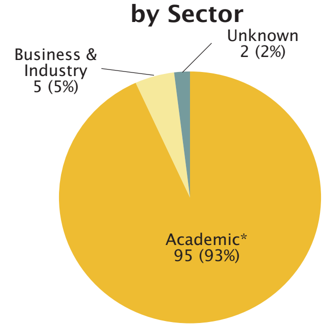


* Includes research institutes and other non-profits.

Of the 341 temporarily employed:

- 31% are women.
- 51% were unable to find a suitable permanent position.
- 72% are employed in postdocs and 28% of these reported they could not find a suitable permanent position.

Figure EE.3. EENDR Respondents Employed Outside the U.S. by Sector



* Includes research institutes and other non-profits.

Of the 102 employed outside the U.S.:

- 25% are women.
- 26% are U.S. Citizens.
- 96% of the U.S. Citizens are employed in postdocs and 72% of these reported they could not find a suitable permanent position.

Table EE.1: Number and Percentage of EENDR Respondents Employed in the U.S. by Job Status

					Temporary		Temporary Postdocs				
Year	Perm Total	%	Temp Total	%	Perm Not Avail	%	Total	%	Perm Not Avail	%	Unkown
Fall 2006	289	51%	274	49%	98	36%	209	76%	57	27%	0
Fall 2007	259	53%	227	47%	88	39%	172	76%	57	33%	0
Fall 2008	245	49%	222	45%	74	33%	172	77%	47	27%	0
Fall 2009	318	49%	326	51%	146	45%	234	72%	68	29%	0
Fall 2010	320	48%	341	52%	140	41%	246	72%	68	28%	0

Comparing the employment status of EENDR respondents over the last five years we see that:

- Permanent positions have dropped to 48%, but the number has increased to a high of 320.
- Temporary positions have increased to 52% (341), reaching a five-year high.
- 41% of those holding temporary positions were unable to find suitable permanent positions, a 4% decrease from Fall 2009.
- Postdoc postions have reached a five-year high (246) this year. Although, the highest percentage of postdoc positions reported was 77% for Fall 2008.

Information from the Employment Experiences of New Doctorates (EENDR) Survey

Table EE.2: Percentage of EENDR Respondents Employed in the U.S. by Employment Sector within Job Status

Year	Permanent			Temporary		
	Acad	Govn	B/I	Acad	Govn	B/I
Fall 2006	66%	4%	30%	93%	5%	2%
Fall 2007	68%	3%	29%	93%	4%	3%
Fall 2008	63%	6%	31%	95%	4%	1%
Fall 2009	64%	6%	29%	91%	5%	4%
Fall 2010	64%	8%	28%	93%	5%	2%

Looking at at Table EE.2 we see that

- Permanent academic employment has remained steady at 64%, although it is down 2% from Fall 2006. While temporary employment in this sector tends to be around 93%.
- Permanent government employment has steadily increased, reaching 8% this year.
- Business/Industry shows a decreasing trend in permanent employment, while temporary positions shows some variability.

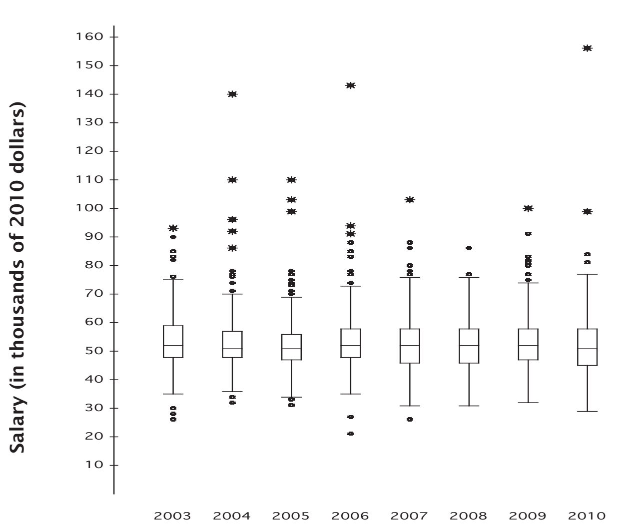
Starting Salaries of the 2009-2010 Doctoral Recipients

The starting salary figures were compiled from information gathered on the EENDR questionnaires sent to 1,476 individuals using addresses provided by the departments granting the degrees; 802 individuals responded between late October and April. Responses with insufficient data or from individuals who indicated they had part-time or non-U.S. employment were excluded. Numbers of usable responses for each salary category are reported in the following tables.

Readers should be warned that the data in this report are obtained from a self-selected sample, and inferences from them may not be representative of the population.

Academic Teaching/Teaching and Research 9–10-Month Starting Salaries* (in thousands of dollars)

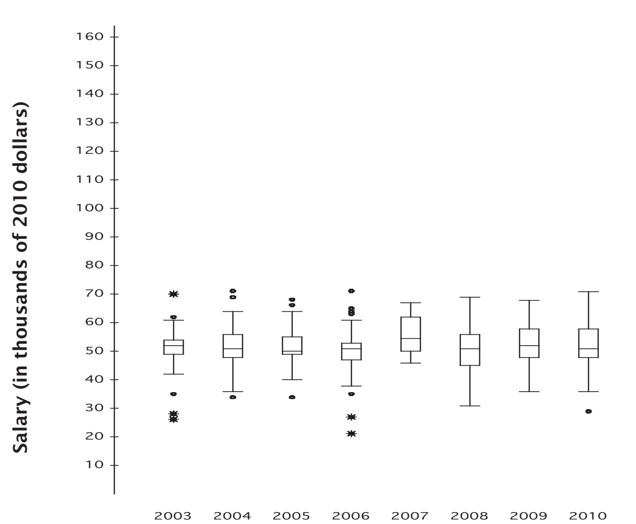
Ph.D. Year	Min	Q_1	Median	Q_3	Max
Total (183 male/96 female)					
2010 M	29.0	45.4	51.0	58.0	157.0
2010 F	30.0	45.0	52.2	57.3	85.0
One year or less experience (162 male/83 female)					
2010 M	29.0	45.0	50.3	58.0	157.0
2010 F	30.0	45.0	52.8	58.0	85.0



* Includes postdoctoral salaries.

Academic Postdoctorates Only* 9–10-Month Starting Salaries (in thousands of dollars)

Ph.D. Year	Min	Q_1	Median	Q_3	Max
Total (68 male/19 female)					
2010 M	29.0	48.0	50.6	57.3	72.0
2010 F	36.0	47.0	52.0	56.0	72.0
One year or less experience (66 male/17 female)					
2010 M	29.0	48.0	51.0	57.8	72.0
2010 F	36.0	49.0	52.4	56.0	72.0

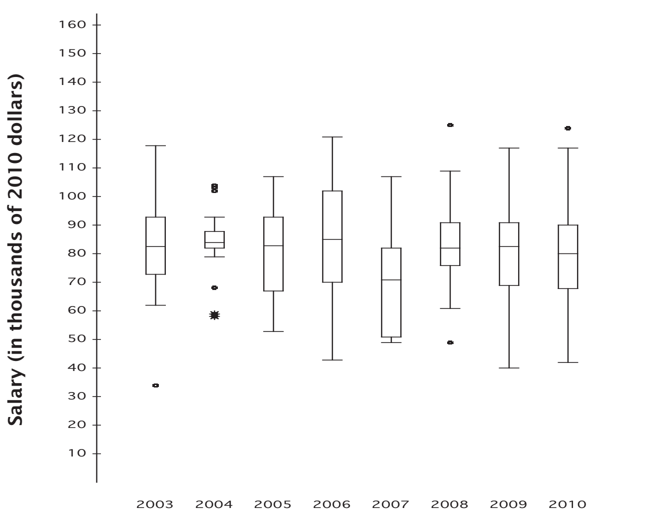


* A postdoctoral appointment is a temporary position primarily intended to provide an opportunity to extend graduate training or to further research experience.

Starting Salaries of the 2009-2010 Doctoral Recipients

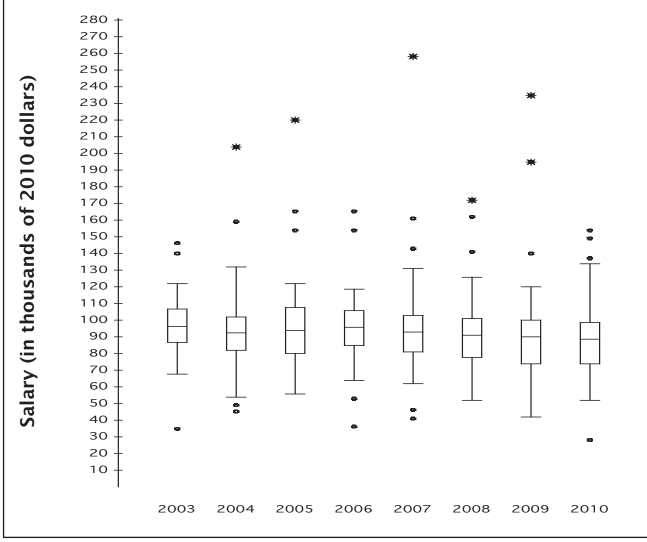
Government
11–12-Month Starting Salaries
(in thousands of dollars)

Ph.D. Year	Min	Q_1	Median	Q_3	Max
Total (23 male/16 female)					
2010 M	62.0	70.5	80.0	89.0	124.5
2010 F	42.0	66.0	73.7	90.0	117.0
One year or less experience (22 male/12 female)					
2010 M	62.0	70.3	80.6	89.0	125.4
2010 F	42.0	65.3	71.6	81.3	100.0



Business and Industry
11–12-Month Starting Salaries
(in thousands of dollars)

Ph.D. Year	Min	Q_1	Median	Q_3	Max
Total (56 male/28 female)					
2010 M	52.0	77.6	90.0	100.0	155.0
2010 F	28.0	72.9	90.0	96.8	120.0
One year or less experience (47 male/24 female)					
2010 M	52.0	77.3	90.0	100.0	155.0
2010 F	28.0	71.9	88.9	92.8	120.0



Remarks on Starting Salaries

Key to Tables and Graphs. Salaries are those reported for the fall immediately following the survey cycle. Years listed denote the survey cycle in which the doctorate was received—for example, survey cycle July 1, 2009–June 30, 2010, is designated as 2010. Salaries reported as 9–10 months exclude stipends for summer grants or summer teaching or the equivalent. M and F are male and female respectively. Male and female figures are not provided when the number of salaries available for analysis in a particular category was five or fewer. All categories of "Teaching/Teaching and Research" and "Research Only" contain those recipients employed at academic institutions only.

Graphs. The graphs show standard boxplots summarizing salary distribution information for the years 2003 through 2010. Values plotted for 2003 through 2010 are converted to 2010 dollars using the implicit price deflator prepared annually by the Bureau of Economic Analysis, U.S. Department of Commerce. These categories are based on work activities reported in EENDR. Salaries of postdoctorates are shown separately. They are also included in other academic categories with matching work activities.

For each boxplot the box shows the first quartile (Q1), the median (M), and the third quartile (Q3). The interquartile range (IQR) is defined as Q3–Q1. Think of constructing invisible fences 1.5 IQR below Q1 and 1.5 IQR above Q3. Whiskers are drawn from Q3 to the largest observation that falls below the upper invisible fence and from Q1 to the smallest observation that falls above the lower invisible fence. Think of constructing two more invisible fences, each falling 1.5 IQR above or below the existing invisible fences. Any observation that falls between the fences on each end of the boxplots is called an outlier and is plotted as ● in the boxplots. Any observation that falls outside of both fences either above or below the box in the boxplot is called an extreme outlier and is marked as ✳ in the boxplot.

Other Information

Survey Response Rates

Doctorates Granted
Departmental Response Rates

Group I (Pu)	25 of 25 including	0 with no degrees
Group I (Pr)	23 of 23 including	0 with no degrees
Group II	56 of 56 including	2 with no degrees
Group III	81 of 81 including	9 with no degrees
Group IV	92 of 92 including	11 with no degrees
Statistics	57 of 57 including	4 with no degrees
Biostatistics	35 of 35 including	7 with no degrees
Group Va	22 of 22 including	4 with no degrees

Group Descriptions

Group I is composed of 48 departments with scores in the 3.00–5.00 range. Group I Public and Group I Private are Group I departments at public institutions and private institutions, respectively.

Group II is composed of 56 departments with scores in the 2.00–2.99 range.

Group III contains the remaining U.S. departments reporting a doctoral program, including a number of departments not included in the 1995 ranking of program faculty.

Group IV contains U.S. departments (or programs) of statistics, biostatistics, and biometrics reporting a doctoral program.

Group V contains U.S. departments (or programs) in applied mathematics/applied science, operations research, and management science which report a doctoral program.

Group Va is applied mathematics/applied science; Group Vb, which was no longer surveyed as of 1998–99, was operations research and management science.

Group M contains U.S. departments granting a master's degree as the highest graduate degree.

Group B contains U.S. departments granting a baccalaureate degree only.

Listings of the actual departments which compose these groups are available on the AMS website at `www.ams.org/annual-survey/groups_des`.

U.S. Unemployment Rate Calculations

In the unemployment calculations provided in this report the individuals employed outside the U.S. have been removed from the denominator used in the calculation of the rate, in addition to the routine removal of all individuals whose employment status is unknown. This is a change from Annual Survey Reports prior to 2009. As a consequence, the unemployment rate now being reported more accurately reflects the U.S. labor market experienced by the new doctoral recipients. This change tends to increase the rate of unemployment over that reported in prior years.

In a further small change from prior years, those individuals reported as not seeking employment have also been removed from the denominator. The number of individuals so designated is small each year, and the impact of this change is to produce a slight increase in the rate over that reported in prior years.

The unemployment rates for years prior to 2009 shown in this report have been recalculated using this new method. One can view a comparison of the unemployment rates using the traditional method and the new method by visiting the AMS website at `www.ams.org/annual-survey/surveyreports.html`.

About the Annual Survey

The Annual Survey series, begun in 1957 by the American Mathematical Society, is currently under the direction of the Data Committee, a joint committee of the American Mathematical Society, the American Statistical Association, the Mathematical Association of America, and the Society of Industrial and Applied Mathematics. The current members of this committee are Pam Arroway, Richard Cleary (chair), Steven R. Dunbar, Susan Geller, Abbe H. Herzig, Ellen Kirkman, Joanna Mitro, James W. Maxwell (ex officio), Bart S. Ng, Douglas Ravanel, and Marie Vitulli. The committee is assisted by AMS survey analyst Colleen A. Rose. In addition, the Annual Survey is sponsored by the Institute of Mathematical Statistics. Comments or suggestions regarding this Survey Report may be directed to the committee.

Other Sources of Data

Visit the AMS website at `www.ams.org/annual-survey/other-sources` for a listing of additional sources of data on the Mathematical Sciences.

WHAT IS... a Derived Stack?

Gabriele Vezzosi

Derived stacks are the "spaces" studied in derived algebraic geometry, a relatively new theory in which algebraic geometry meets homotopy theory—or higher category theory, depending on one's taste. Just as a scheme is locally modeled on commutative rings, derived schemes or stacks are modeled on some kind of *derived commutative rings*, a homotopy version of commutative rings. In order to define derived stacks more precisely, it will be useful to reexamine briefly the functorial point of view in (underived) algebraic geometry.

Let k be a *base* commutative ring. In algebraic geometry, a k-scheme may be given at least two equivalent definitions. The first one is as a special kind of pair $(X, \mathcal{O}_X)$, where X is a topological space and $\mathcal{O}_X$ is a sheaf of commutative k-algebras on X (this is the so-called *ringed space* approach). The second one is as a special kind of functor from the category $\mathbf{CommAlg}_k$ of commutative k-algebras to the category of sets (this is the *functor of points* approach). For example, the n-dimensional projective space $\mathbb{P}^n_k$ over k may be identified with the functor sending $A \in \mathbf{CommAlg}_k$ to the set of surjective maps of A-modules $A^{n+1} \to A$, modulo the equivalence relation generated by multiplication by units in A. In the following, we will concentrate on the functor-of-points description.

Prompted by the study of moduli problems (e.g., classifying families of elliptic curves or vector bundles on a given algebraic variety), algebraic geometers have long been led to enlarge the *target* category of the functor of points from sets to *groupoids* (i.e., categories whose morphisms are all invertible) in order to classify objects *together with* their isomorphisms instead of just objects *modulo* isomorphisms. These functors are called *stacks,* and aficionados of the WHAT IS column already have met this notion ("What is a stack?" by Dan Edidin, *Notices*, April 2003). More recently, *higher stacks* came into play; they arise naturally when one is interested in classifying geometric objects (say, over a given scheme) for which the natural notion of *equivalence* is broader than just isomorphisms. Example: perfect complexes over a given scheme with equivalences given by quasi-isomorphisms, i.e., maps inducing isomorphisms on cohomology. In such cases it is natural to enlarge the target category for the corresponding moduli functors to the category of *simplicial sets* or, equivalently, to the category of *topological spaces.* A stack may be viewed as a higher stack via the *nerve* construction: the nerve of a groupoid is the simplicial set whose n-th level is the set of n composable morphisms in the groupoid. This simplicial set has homotopy groups only in degrees ≤ 1, with π_1 roughly corresponding to automorphisms of a given object. General simplicial sets or topological spaces are needed in order to accommodate "higher autoequivalences" of the objects being classified.

Another example of a higher stack is given by iterating the so-called *classifying stack* construction. For a k-group scheme G, there is a stack $\mathrm{B}G \equiv K(G,1)$ classifying principal G-bundles; by taking the nerve, we may view $K(G,1)$ as a functor to simplicial sets. If G is *abelian*, this functor is equivalent to a functor to simplicial abelian groups, and the classifying stack construction may then be applied to any simplicial level again to get $\mathrm{BB}G \equiv K(G,2)$. And so on. For any $n \geq 2$, $K(G,n)$ is not a stack but a higher stack (classifying

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"higher" principal G-bundles); it is the algebro-geometric analog of the Eilenberg-Mac Lane space in topology, from which we borrowed the notation.

It is useful to draw a diagram summarizing the still underived situation we have just discussed.

$$\begin{tikzcd}
\mathbf{CommAlg}_k \arrow[r, "\text{schemes}"] \arrow[dr, "\text{stacks}"] \arrow[ddr, "\text{higher stacks}"'] & \mathbf{Sets} \arrow[d, "i_0"] \\
 & \mathbf{Grpds} \arrow[d, "\text{Nerve}"] \\
 & \mathbf{SimplSets}
\end{tikzcd}$$

Here i_0 is the functor identifying a set with the groupoid having that set of objects and only identities as arrows.

The main point of derived algebraic geometry *is to enlarge* (also) *the source category*, i.e., to replace commutative algebras with a more flexible notion of commutative rings serving as new or *derived rings*. Why? I could list here, among some of the actual historical motivations, the Kontsevich *hidden smoothness philosophy* and a geometrical definition of *universal elliptic cohomology* (aka *topological modular forms*). For expository reasons, I will concentrate instead on two more down-to-earth and classical instances that naturally lead to building a geometry based on these derived rings rather than on the usual commutative rings.

Derived Intersections

In algebraic geometry, the so-called *intersection multiplicities* are given by Serre's formula. Here is one form of it. Let X be an ambient complex smooth projective variety, and let Z, T be possibly singular subvarieties of X whose dimensions sum up to $\dim X$ and which intersect on a 0-dimensional locus. If $p \in Z \cap T$ is a point, its "weight" in the intersection, i.e., its intersection multiplicity, is given by

$$\mu_p(X; Z, T) = \sum_{i \geq 0} \dim_{\mathbb{C}} \mathrm{Tor}_i^{\mathcal{O}_{X,p}}(\mathcal{O}_{Z,p}, \mathcal{O}_{T,p}),$$

where $\mathcal{O}_{Y,p}$ denotes the local ring of a variety Y at $p \in Y$ and the Tors are computed in the category of $\mathcal{O}_{X,p}$-modules. One can easily prove that the sum is finite and much less easily that it is nonnegative. But here we are interested in another aspect of this formula. In the lucky case of a flat intersection, i.e., when either $\mathcal{O}_{Z,p}$ or $\mathcal{O}_{T,p}$ are flat $\mathcal{O}_{X,p}$-modules, this formula tells us that the multiplicity is given by the dimension of the tensor product $\mathcal{O}_{Z,p} \otimes_{\mathcal{O}_{X,p}} \mathcal{O}_{T,p}$, which, for our purposes, has two peculiar features: it is a commutative ring, and it is the local ring of the scheme-theoretic intersection $Z \cap T$ at p. In other words, it carries a nice geometrical interpretation.

What about the general case? By definition, in order to compute such multiplicities, i.e., the Tor-groups, one has to resolve $\mathcal{O}_{Z,p}$ (or $\mathcal{O}_{T,p}$) via a complex of projective or flat $\mathcal{O}_{X,p}$-modules, tensor this resolution with $\mathcal{O}_{T,p}$ (or $\mathcal{O}_{Z,p}$), and compute the cohomology of the resulting complex. This is very much homological algebra, but where has the geometry gone? We started with three varieties and a point on each of them, and we ended up computing the cohomology of a rather geometrically obscure complex. Is there a way to reconcile the general case with the flat intersection case in a possibly wider geometrical picture? A possible answer is the following: we can still keep the two peculiar geometric features of the flat intersection case mentioned above, provided we are willing to contemplate a notion of commutative rings that is more general than the usual one. More precisely, one can first observe that it is possible to choose the resolution of, say, $\mathcal{O}_{Z,p}$ (as an $\mathcal{O}_{X,p}$-module) in such a way that it has the structure of a nonpositively *commutative differential graded $\mathcal{O}_{X,p}$-algebra* with the differential increasing the degree (a *cdga*, for short) or equivalently of a simplicial commutative $\mathcal{O}_{X,p}$-algebra. This gives us an extension of the first feature of the flat intersection case. Then we can force the second feature by insisting that the tensor product of this cdga resolution with $\mathcal{O}_{T,p}$ does give the "scheme structure" of $Z \cap T$ (locally at the point p). Of course this is not a usual scheme structure, but rather a new kind of scheme-like structure that we will call a *derived structure*, the name coming from the fact that what we are computing is the derived tensor product $\mathcal{O}_{Z,p} \otimes^{\mathbb{L}}_{\mathcal{O}_{X,p}} \mathcal{O}_{T,p}$ (whose cohomology groups are the Tor-groups appearing in Serre's intersection formula). But we may, and therefore we do, view $\mathcal{O}_{Z,p} \otimes^{\mathbb{L}}_{\mathcal{O}_{X,p}} \mathcal{O}_{T,p}$ as a *derived* commutative ring, i.e., a cdga or a simplicial commutative algebra.

Deformation Theory

Another more or less classical topic in algebraic geometry that also leads to considering these kinds of derived rings is the theory of the *cotangent complex*. This object dates back to Quillen, Grothendieck, and Illusie (see L. Illusie, *Complexe cotangent et déformations. I*, Lecture Notes in Math. 239, Springer-Verlag, 1971) and is too technical to be carefully defined here. Let me just say that in the affine case $X = \operatorname{Spec} A$, for A a commutative k-algebra, it is defined as the classical module of Kähler differentials, but only after having replaced A itself by a resolution that is a simplicial commutative k-algebra that is free at each simplicial level (in characteristic 0, one might as well resolve using cdga's). Recall that a simplicial commutative algebra is a simplicial set that is at each level a commutative algebra and whose structural maps (face and degeneracies) are required to be morphisms of algebras. Even with such a sketchy definition, it will not perhaps be too surprising that most topics in the deformation theory of schemes, and more generally of moduli stacks, are handled through this cotangent complex. Although this was confirmed and deepened several times in the course of the explosive development of moduli theory, this relationship with deformation theory was already clear to Quillen, Illusie, and Grothendieck. It was Grothendieck himself, back in 1968, who asked whether it was possible to give some geometrical interpretation of the cotangent complex, say of a scheme X (see p. 4 of *Catégories cofibrées additives et complexe cotangent relatif*, LNM 79, Springer-Verlag, 1968). Derived algebraic geometry offers a possible answer to this question: if one is willing to build algebraic geometry using derived rings, then in this new world the cotangent complex $\mathbb{L}_X$ of a scheme X *is* the actual cotangent space of X. As a consequence, in derived algebraic geometry the full cotangent complex (and not only some truncation thereof) has a deformation-theoretic interpretation: this might be considered as the main reason derived algebraic geometry is interesting for studying moduli problems.

The upshot of the previous discussion is that we are interested in enlarging the previous diagram to the following one:

$$\begin{tikzcd}
\mathbf{CommAlg}_k \arrow[r, "\text{schemes}"] \arrow[dr, "\text{stacks}"] \arrow[ddr, "\text{higher stacks}"] \arrow[dd, "j_0"'] & \mathbf{Sets} \arrow[d, "i_0"] \\
& \mathbf{Grpds} \arrow[d, "\text{Nerve}"] \\
\mathbf{DerivedCommAlg}_k \arrow[r, "\text{derived stacks}"'] & \mathbf{SimplSets}
\end{tikzcd}$$

Here $\mathbf{DerivedCommAlg}_k$ is either the category of simplicial commutative k-algebras or, when the base ring k has characteristic 0, the category of cdga's over k. We will freely pass from one description to the other whenever this is possible and will contribute to conciseness. The functor j_0 then sends a commutative algebra R to the corresponding constant simplicial commutative algebra (having R in each simplicial level and with identities as face and degeneracies) or to the cdga having R in degree 0, and 0 elsewhere.

An *equivalence* $f : A \to B$ between simplicial commutative algebras is a map inducing isomorphisms $\pi_i(A; a) \simeq \pi_i(A; f(a))$ between homotopy groups, for any base point $a \in A_0$ (A_0 being the 0-th level of the simplicial set A) and any $i \geq 0$. The corresponding notion for cdga's is given by *quasi-isomorphisms*, i.e., maps inducing isomorphisms on every cohomology group. Derived rings together with this notion of equivalences give rise to a *homotopy theory* (technically speaking, a Quillen model category structure); the same is true, with weak homotopy equivalences as equivalences, for the target category **SimplSets**. It is a basic rule of derived algebraic geometry that all constructions should be, in an appropriate sense, invariant under all these equivalences. This is exactly the point where derived algebraic geometry becomes a blend of algebraic geometry and homotopy theory, borrowing techniques and intuitions from both areas.

We are now ready to fulfill the aim of this column and give a definition. A *derived stack* over k is a functor $\mathbf{DerivedCommAlg}_k \to \mathbf{SimplSets}$ sending equivalences to weak homotopy equivalences and satisfying a *descent* or *gluing condition* with respect to some chosen "topology" on derived rings.

The descent condition mentioned here is just a derived (or homotopy) version of the usual sheaf condition with respect to an appropriate (i.e., invariant under equivalences) notion of *topology* on derived rings. Here is one example of such a topology, the so-called *strong étale topology*. We will assume we are working in characteristic 0 and are taking cdga's as our model for derived rings. A covering family for such a topology is a family $\{A \to B_i\}$ such that $\{H^0(A) \to H^0(B_i)\}$ is an étale covering family (in the sense of usual algebraic geometry) and the canonical maps $H^i(A) \otimes_{H^0(A)} H^0(B) \to H^i(B)$ are isomorphisms for any $i \geq 0$. A derived version of the Yoneda lemma gives us, for any derived ring A, a derived stack denoted as $\mathbb{R}\mathrm{Spec}\, A$ and called the *derived spectrum* of A. Any stack may be faithfully viewed as a derived stack, and conversely any derived stack $\mathcal{F}$ has a *truncation* $\mathrm{t}_0(\mathcal{F})$ that is a stack, e.g., $\mathrm{t}_0(\mathbb{R}\mathrm{Spec}\, A) \simeq \mathrm{Spec}(H^0(A))$. Passing to the truncation should be thought of as passing to the classical or underived part. And, intuitively speaking, $\mathcal{F}$ behaves much like a formal thickening of its truncation or as a scheme with respect to its reduced subscheme.

In the section "Deformation Theory" I hinted that derived algebraic geometry might be a natural framework for deformation theory in algebraic geometry. Let me try to push this point further. The idea is that derived rings allow for more general deformation directions, but not so general that the usual geometrical intuition is completely lost.

Let $\mathrm{char}(k) = 0$ and $i \in \mathbb{N}$ and $k[i]$ be the k-dg-module having just k in degree $-i$. We can then consider the trivial square zero extension k-cdga

$$k[\varepsilon_i] := k \oplus k[i].$$

Note that $k[\varepsilon_i]$ is concentrated in nonpositive degrees (with a degree-increasing differential) and that its only nontrivial cohomology groups are concentrated in degrees 0 and $-i$, where they both equal k. $k[\varepsilon_i]$ is called the *derived ring of*

i-th order dual numbers over k, and its derived spectrum $\mathbf{D}_i := \mathbb{R}\mathrm{Spec}\, k[\varepsilon_i]$ is called the *derived i-th order infinitesimal disk* over k. Note that for odd i, $k[\varepsilon_i]$ is the free cdga on the k-dg module $k[i]$, i.e., on one generator in degree $-i$.

A useful intuitive way of thinking about $k[\varepsilon_i]$ is as the universal derived affine scheme carrying *generalized nilpotents* of order i. Here is one typical result explaining how derived stacks allow for a natural and geometrical reinterpretation of usual deformation theory.

Proposition. *Let X be a scheme over k and let $\mathbb{L}_X$ be its cotangent complex. If $x \in X(k)$ is a k-rational point in X, then for each $i \in \mathbb{N}$, there is a canonical group isomorphism*

$$\mathrm{Ext}^i_k(\mathbb{L}_{X,x}, k) \simeq \mathbb{R}\mathrm{Hom}_*(\mathbf{D}_i, (X,x)),$$

where $\mathbb{R}\mathrm{Hom}_*$ denotes the set of morphisms in the homotopy category of Spec *k-pointed derived stacks.*

In other words, for any $i \in \mathbb{N}$, the functor from Spec k-pointed schemes to abelian groups

$$\mathbf{Sch}_{*,k} \longrightarrow \mathbf{Ab} \;:\; (X,x) \longmapsto \mathrm{Ext}^i_k(\mathbb{L}_{X,x}, k),$$

while *not* corepresentable in $\mathbf{Sch}_{*,k}$, is indeed co-represented by $\mathbf{D}_i$ in the larger category of pointed derived stacks. Therefore, the full cotangent complex has a moduli-theoretic interpretation in the world of derived algebraic geometry.

A *derived extension* of a stack F is a derived stack $\mathcal{F}$ together with an identification of F with the truncation $\mathrm{t}_0(\mathcal{F})$ of $\mathcal{F}$. Given a stack F, there is always a trivial derived extension (just viewing F itself as a derived stack), but in most cases there are other derived extensions. For example, the stack $\mathbf{Vect}_n(X)$ classifying rank n vector bundles over a smooth and proper scheme X has another *natural* and nontrivial derived extension $\mathbb{R}\mathbf{Vect}_n(X)$, obtained as the derived stack of maps from X to the classifying stack $\mathrm{B}GL_n$. One can prove that $\mathbb{R}\mathbf{Vect}_n(X)$ classifies a fairly natural derived version of rank n vector bundles on X. The choice of a derived extension of a given stack F endows F itself with important *additional* geometric structure. One interesting example of this further structure, still in the thread of deformation theory, arises when one starts with a Deligne-Mumford stack F (e.g., the stack of stable maps to a fixed smooth complex projective variety) and considers a derived Deligne-Mumford extension $\mathcal{F}$ of it. If this derived extension is *quasi-smooth* (i.e., its cotangent complex is of perfect amplitude $[-1,0]$), then the closed immersion $j : F \hookrightarrow \mathcal{F}$ induces a map of cotangent complexes $j^*\mathbb{L}_{\mathcal{F}} \to \mathbb{L}_F$ that is a $[-1,0]$-*perfect obstruction theory* in the sense of Behrend-Fantechi (*Invent. Math.* 128 (1997)). Moreover, it is true in all known cases, and expected to be true in general, that *any* such obstruction theory can be obtained as above from some derived extension. So, as already seen in the case of the cotangent complex of a scheme, obstruction theories are also classical ways of (partially) encoding derived geometric structures.

A Quick Guide to the Literature

The approach to derived algebraic geometry sketched above is contained essentially in [HAG-II], of which [Toën-2005] is a very readable overview. Due to some overlap in the topics, [V-2010] might be a useful complement to the present text. Another approach to derived geometry is in Jacob Lurie's book [H-Algebra], where the emphasis is on higher categorical aspects from the very beginning and whose spectrum of applications is broader.

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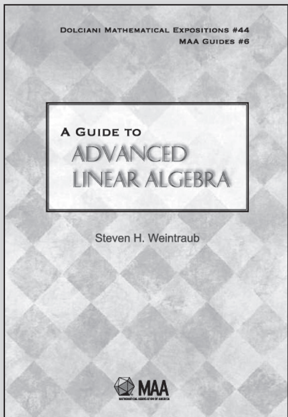

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Topics treated in this book include: vector spaces and linear transformations; dimension counting and applications; representation of linear transformations by matrices; duality; determinants and their uses; rational and especially Jordan canonical form; bilinear forms; inner product spaces; normal linear transformations and the spectral theorem; and an introduction to matrix groups as Lie groups.

The book treats vector spaces in full generality, though it concentrates on the finite dimensional case. Also, it treats vector spaces over arbitrary fields, specializing to algebraically closed fields or to the fields of real and complex numbers as necessary.

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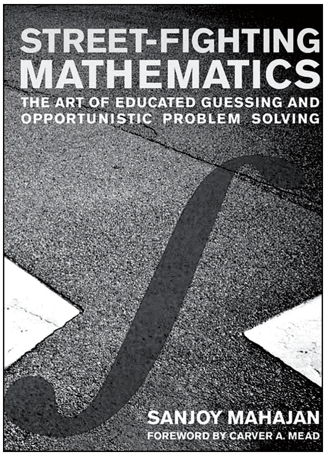

Street-Fighting Mathematics

Reviewed by Brent Deschamp

Street-Fighting Mathematics: The Art of Educated Guessing and Opportunistic Problem Solving
Sanjoy Mahajan
The MIT Press, 2010
US$25.00, 134 pages
ISBN 0-262-51429-3

I have read *Street-Fighting Mathematics* twice and most of the sections five or six times. I find myself working, and struggling with, problems from this book as much as I did with homework problems when I was a student. It is not that the material in this book is difficult; in fact the aim of the book is to provide simple tools for approximating solutions to complicated problems. The difficulty lies in the fact that the ideas this book presents are at times completely foreign to my way of thinking. Learning to see problems the way Mahajan sees them takes deep thought, time, and practice, but that is what makes *Street-Fighting Mathematics* an enjoyable read that provides an enlightening look at solving problems.

At only 134 pages in length, the book is small and covers only six major topics, but those topics have kept me busy for months. They are dimensional analysis, easy cases, lumping, pictorial proofs, taking out the big part, and reasoning by analogy. Along the way, Mahajan, a physicist by training, solves problems involving everyday calculations, geometry, calculus, differential equations, topology, and physics. He even finds a solution for the Navier-Stokes equations involving falling cones using nothing more than dimensional analysis and easy cases. The list of topics is short, but those topics are powerful. To illustrate some of these ideas, I present a few examples.

Consider the integral

$$\int \sqrt{1-\alpha x^2}\, dx.$$

The most common method for solving this integral would be to use a trigonometric substitution such as $x = (1/\sqrt{\alpha})\cos\theta$. Instead, Mahajan shows how dimensional analysis can be used to see how the parameter α influences the solution. In order to simplify notation, assign the dimension of length, L, to x. Since everything under the radical must have the same dimension and since 1 is dimensionless, it must be that α has dimension L^{-2}.

We now need to determine the dimension of the entire integral. The integrand is dimensionless, and the differential dx, which represents a small quantity of x, will have dimension L. Finally, the integral symbol represents both a limit and a sum, which are both dimensionless, and thus summing terms of dimension L yields a quantity with dimension L. Also, the integral will produce a function of α, $f(\alpha)$, and the only way for $f(\alpha)$ to have the dimension L is if $f(\alpha) \sim \alpha^{-1/2}$.

Using the trigonometric substitution mentioned earlier and a lot more work, we find the exact solution to the integral is

$$-\frac{1}{2\sqrt{\alpha}}\left[\cos^{-1}(x\sqrt{\alpha}) - (x\sqrt{\alpha})\sqrt{1-\alpha x^2}\right] + C.$$

Note that both terms inside the brackets are dimensionless and that the leading coefficient combines $\alpha^{-1/2}$ with a dimensionless constant. If learning how α influences the solution is all that is needed, then using dimensional analysis provides the same result with considerably less effort.

Another example involves "taking out the big part". Students often complain about having to remember the shortcuts for derivatives. Does the de-

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This book is available for download through MIT Press at http://mitpress.mit.edu.

rivative of b^x involve $\ln b$ or its reciprocal? Which inverse trig functions have square roots in their derivatives? The issue is that the students remember the pieces of the answer but not how those pieces go together. Mahajan calls answers of this type "high-entropy" expressions. A solution that uses a "low-entropy" expression is one that has a few pieces that go together in a memorable way so there is little confusion when the method is used long after the exact process has been forgotten.

Consider the product 2.08×5.25. To estimate the product we could simply take out the big part and consider $2.08 \times 5.25 \approx 2 \times 5 = 10$, but what if we wanted a better approximation? We could use a correction factor to improve our estimate. Our first attempt is to try

$$(x + \Delta x)(y + \Delta y) = xy + x\Delta y + y\Delta x + \Delta x\Delta y,$$

but remembering which Δ term is multiplied with which whole term is not obvious until we return to the formula and complete the multiplication. This is a "high-entropy" expression.

Instead, consider the dimensionless correction factor

$$\frac{\Delta(xy)}{xy} = \frac{(x + \Delta x)(y + \Delta y)}{xy} = \frac{x + \Delta x}{x}\frac{y + \Delta y}{y} = \left(1 + \frac{\Delta x}{x}\right)\left(1 + \frac{\Delta y}{y}\right).$$

The result has an apparent meaning. It is easy to interpret that $(\Delta x)/x$ and $(\Delta y)/y$ represent the fractional change in x and y, respectively. Moreover, we see that

$$\frac{\Delta(xy)}{xy} = \left(1+\frac{\Delta x}{x}\right)\left(1+\frac{\Delta y}{y}\right) - 1 = \frac{\Delta x}{x}+\frac{\Delta y}{y}+\frac{\Delta x}{x}\frac{\Delta y}{y},$$

and if Δx and Δy are relatively small, then

$$\frac{\Delta(xy)}{xy} \approx \frac{\Delta x}{x} + \frac{\Delta y}{y}.$$

Thus we can improve our estimate by multiplying by a correction factor that consists of summing the fractional change of x and the fractional change in y, which is easy to remember. Therefore

$$2.08\times5.25 \approx 10\times(1+0.04+0.05) = 10\times1.09 = 10.9.$$

The exact answer is 10.29, which means our approximation is within 0.18 percent of the exact value.

Two other topics in the book that warrant explanation are lumping and reasoning by analogy. The former involves such ideas as approximating an integral by a single, well-chosen rectangle. The latter is used to answer such questions as, "Into how many regions do five planes divide space?" The approach is to first determine how many regions are created by five lines in a plane and then use analogy to reason the three-dimensional case.

My biggest issue with *Street-Fighting Mathematics* is that in applying these ideas I do not know what I am doing. I was a structural engineer before I was a mathematician, and so approximating is nothing new to me, but as a mathematician I do not think of approximating unless I am using numerical methods, and even then the algorithm does the heavy lifting. So, I can estimate my time of arrival on a long drive based on a rough estimate of my average speed without giving it much thought, but it never occurs to me to approximate a formula for the solution to a differential equation using dimensionless factors.

Additionally, I do not think as Mahajan does. He spends a chapter on guessing formulas by considering easy cases. What is the volume of a frustum or truncated pyramid with a square base? Three easy cases present themselves: the length of the side of the top square is 0, which yields a pyramid; the length of the side of the bottom square is 0, which yields an inverted pyramid; the lengths of the sides of both squares are equal, which yields a cube. Fine, but now we need to determine the volume of a pyramid. Mahajan points out that six pyramids with height equal to half the length of the base, with their vertices located over the center of the square base, when joined at their vertices, form a cube. Thus the volume of a pyramid with a square base is one-sixth the volume of the cube. This is not so much an easy case as a clever trick.

Later we are asked to derive a formula for the period of a pendulum. The easy cases in this situation are when the pendulum is released from an angle of 0 or 90 degrees. When these cases do not provide enough information, Mahajan turns to an extreme case: when the pendulum is released from 180 degrees. Again, this is not obvious, and so it is more clever than easy.

My complaint is that this book can be too clever, and how to be clever is not always obvious. I cannot fault Mahajan for this. I remember sitting in my advisor's office and often thinking, "How does he get these ideas?" Years later, one of my master's advisees told me she often had the same thoughts sitting in my office. Being clever comes from deep thought and experience, and you cannot teach that in a book. But you can help people get started, and that is what *Street-Fighting Mathematics* does.

And so I have read parts of this book many times, and I have tried every problem, and I have learned a great deal. This book is based on a short course at MIT, and I have even visited the course website to find new problems and solutions as a way to gain further insight. But there are enough problems that I could not solve that I found myself wishing that the book had a solutions section. I suspect that without the correct trick some of these problems are genuinely difficult to solve.

Mahajan, though, is upfront about the difficulty of learning a new technique, and he often returns to Pólya's statement that a tool is a trick we use twice. Mahajan shows a trick once (or several times), but recognizing when that trick can be used in a new setting is often difficult to see. I do not want to sound like my students who complain that they cannot see how to do a problem when all they need to do is spend more time thinking, but after trying unsuccessfully for a week to solve a problem, I would at least like a hint. It would not have taken much effort to add a few pages to this 134-page book to give hints about or solutions to the more difficult problems. Like I said, I do not think as Mahajan does, and so it would be helpful if there were a way to peek inside his head every once in a while and gain a better understanding of how to pull a problem apart.

My other issue with this book lies in the Foreword by noted computer scientist Carver Mead. His opening line irks me: "Most of us took mathematics courses from mathematicians—Bad Idea!" He goes on to state that since mathematics courses are taught as their own subject, most courses "are seldom helpful and are often downright destructive." I agree that mathematics should not be taught in a vacuum, but I do not understand how any in-depth study of a subject can be "downright destructive".

I do not know the intent behind Mead's statement—it may have just been an attempt to promote the book that wound up using hyperbole; and if I did not encounter this sentiment regularly, I could simply ignore Mead's remarks. I mentioned I was a structural engineer before I was a mathematician, and I have encountered this prejudice for years. My engineering advisors always chastised me for "wasting my time on more useless math courses". My fellow engineers never understood why I spent time learning more math, and the engineering students in my calculus classes perpetually complain that none of what they are learning will ever be useful.

And yet Mahajan uses a wider range of math in this book than I ever would have expected. He doesn't take time to explain derivatives or integrals or series or operators. He simply uses them when they are the correct tool or shows how to estimate their value. The very courses people are decrying as useless teach the material that forms the backbone of this book.

For instance, several times Taylor series is used to simplify a problem. This tells me two things: First, Taylor series is useful. Second, since Mahajan is not explaining what a Taylor series is, he is assuming we already learned this concept somewhere else.

I get tired of engineers telling me I waste my time with mathematics, and I am equally tired of mathematicians looking at me like I grew a second head when I use an engineering-style thought process to solve a problem. Both modes of thinking have their place, but we teach a single approach to a single audience when both approaches would be useful.

A better statement about what this book represents is that it fills a void for those who do not think in approximations and back-of-the-envelope calculations. If you are someone who has been trained in theory and brute-force calculations, then this book would provide insight into a new way of thinking. If you do such things on a regular basis, then this book will provide you with more tools.

But the ideas presented in this book will never replace more exacting methods of mathematics. It is one thing to run a sequence of estimates and back-of-the-envelope calculations at the beginning of a project. It saves time and provides a framework for the future development of the project, and this book teaches such methods. But it would be another thing to base a final design on a sequence of quick approximations, and those "useless" courses that emphasize rigor and precision will be what provide the tools to calculate those final results.

A group of students recently approached me wanting to know how to design a catapult. I did not use any of the tools described in this book—I ran straight to free-body diagrams and calculus. I do not know if I did this because those are the tools with which I am most comfortable or because I felt my students, who were taking calculus, needed to practice using calculus or because street-fighting mathematics simply did not provide the right tools. This book has taught me a great deal. Am I comfortable with this material? Some of it, yes. So why did it not occur to me to try out some of these techniques? I don't know.

What I do know is that *Street-Fighting Mathematics* is an engaging, well-written, insightful book. I do know that the book will provide any reader with new tools for making quick estimates and will introduce new ways of viewing problem solving. And I do know that I will read this book again. And again. And again. And maybe one day I will take the leap and actually use these methods to solve a problem.

Is Moore Better (in Precalculus)?

Karen S. Briggs, Brad Bailey, and Thomas E. Cooper

Have you ever thought, "The Moore Method is appropriate for a class like topology or real analysis" but wondered, "Would it ever work in a class like precalculus or college algebra?" The advantages of the Moore Method and other "minimal-guidance" teaching techniques over traditional lecture-style teaching is much debated among mathematics education experts, especially with regard to introductory-level mathematics courses. Intrigued by these debates, the authors of this paper considered using a modification of the Moore Method (commonly known as Modified Moore Method or MMM)[1] for an honors section of precalculus. We searched for resources to use in an MMM precalculus class and discovered Mahavier's "Trigonometry" notes in the *Journal of Inquiry-Based Learning* [9]. However, we came up empty-handed in our search for the advanced algebra portion of our precalculus course. We also found no empirical studies on the effectiveness of MMM in introductory mathematics classes. Without the appropriate resources or research, we decided not to use MMM in our honors precalculus. Nevertheless, we continued to wonder if an MMM could work for a class like precalculus.

With the approval of our department, we designed a quasi experiment [4] using three sections of precalculus (none of which was an honors section). One treatment section would be taught using an MMM, while the two control sections would receive traditional lectures. It should be noted that while all three instructors involved in the study were experienced lecturers, none had experience teaching precalculus with an MMM. In undertaking this study, we wanted not only to satisfy our own curiosities but also to join an existing debate on the Moore Method and perhaps provide a perspective on the use of an MMM in a type of course that had not yet been formally studied. In particular, we wanted to investigate the following:

1. Would there be a significant difference in scores on a common assessment between the MMM students and the traditional lecture students?
2. Would MMM be better (or worse) at teaching particular topics?
3. How would the self-efficacy of MMM students compare to that of the students taught by traditional lectures?
4. Would an MMM trigger changes in the students' attitudes about mathematics and the teaching and learning of mathematics?

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This research was supported by a grant from the Educational Advancement Foundation.

[1]*An MMM is any teaching style that is driven by students' deriving and presenting solutions to a carefully crafted sequence of problems. Several such Modified Moore Methods have been described in the literature, including by Chalice [2], Cohen [3], and Mahavier [8].*

To assess students' grade self-efficacy, task-specific self-efficacy, and intent to take and feelings of preparedness for calculus, we developed an Attitudes, Beliefs and Self-Efficacy (ABSE) survey that included twenty questions from Schoenfeld [11]. The ABSE survey was administered in all three sections the first class day after the drop/add period had ended and again during the last full week of classes. At midsemester the instructors coauthored a common final exam and developed a detailed grading rubric. The common final exam was administered to all three sections at the end of the semester, and the students' scores for each of the thirty-six items on the final exam were recorded.

In our MMM section, the instructor did not use a textbook but instead a set of course notes that included basic definitions and axioms together with a problem sequence through which the students discovered the course content. These notes, written by the treatment instructor throughout the course of the semester, included problems on advanced algebra topics together with problems from Mahavier's "Trigonometry" [9]. Each day the instructor assigned a set of problems from the course notes for the students to complete outside of class. Students were assigned to groups of three and were allowed to discuss the problems only with their group members. They were not allowed to seek assistance from friends, family, tutors, other instructors, the Internet, or a textbook. Each class period began with the instructor calling upon students to present solutions to one of the assigned problems at the board, while the remainder of the class evaluated the accuracy of the solutions and discussed any differences in their own solutions. Because these presentations affected the students' final grades, the instructor kept an up-to-date record of the number of times a student presented a problem and the quality of the student's solutions. Students who had the least number of "quality" presentations to date were given the first opportunity to present. The instructor would occasionally present a required definition or axiom, but the students presented the majority of the content.

The MMM students outperformed the traditional lecture students by about 10 percent on the 200-point common final exam. The mean, standard deviation, and sample sizes were, respectively, 136.5, 27.74, and 32 for the treatment section and 116.5, 35.68, and 67 for the control sections. When a two-sample t-test was performed, the difference in average final exam scores was statistically significant at the 0.005 level. We also compared the performances of the three sections on all thirty-six final exam items using ANOVA and post-hoc tests. Neither of the control sections did significantly better than the treatment section on any of the thirty-six final exam items. On the other hand, the treatment section did score significantly higher ($p < .05$) or marginally significantly higher ($p < .10$) than did at least one control section on twelve items.

Due to the survey's Likert-type scale,[2] we used a series of Mann-Whitney U tests[3] to compare the responses of the control and treatment sections with a 0.05 significance level. The analysis of the first round of the ABSE survey showed that after roughly one week of class, the students in the treatment section felt significantly less confident about their grades and mathematical abilities than the students in the control sections. When the students completed the survey again at the end of the semester, the differences between the responses of the treatment and control sections on the grade-efficacy items were no longer statistically significant.

At the beginning of the semester, the only significant difference between the treatment and control sections on the attitudes and beliefs items was that the control group was less likely than the treatment group to agree with the statement "In mathematics, something is either right or wrong." This particular difference did not exist at the end of the semester. For the treatment students, four items on the attitudes portion of the survey showed shifts over the semester that reflected an increase in mathematical maturity and awareness. Perhaps most interesting among these changes was that the treatment students were less likely than they were at the beginning of the semester to agree with the statement "Everything important in math is already known by mathematicians." Since many students have the misconception that nothing new is currently being discovered in mathematics, their unwillingness to agree with this statement was encouraging. Finally, the responses to the question about intent to take calculus showed through a sign test[4] that the treatment group was less likely to take calculus at the end of the semester than at the beginning. A statistical analysis of these results appears in [1] and [4].

The question remains, is Moore better? In our study, an MMM produced mathematically mature and aware students who performed nearly 10 percent better than the traditional students on a common assessment but who also reported that they were less likely to take calculus after experiencing an MMM. As with most things in life,

[2]*A scale used in survey research to measure the level at which a respondent agrees or disagrees with a statement [6].*

[3]*A nonparametric test used in statistics for assessing whether two independent samples of observations come from the same distribution* [7].

[4]*A nonparametric statistical test used to analyze the signs of differences of scores between matched pairs of subjects under two experimental conditions [5].*

any teaching method will have its advantages and disadvantages. Enhanced mathematical ability and increased maturity are wonderful advantages that the MMM appears to offer. However, the MMM seems a bit humbling to some students and may discourage them from taking further math classes. The purpose of reporting these results is twofold. First, knowing the effects that our implementation of the MMM had on our students might enable others to decide whether or not to use the method. Second, modifications to our method based on our results might help overcome the result that a smaller percentage were likely to take calculus. We hope that this article has inspired you the reader to consider if Moore would be better for your students in your introductory classes.

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Mathematics People

Helfgott and Sanders Awarded Adams Prize

HARALD HELFGOTT of the University of Bristol and TOM SANDERS of the University of Cambridge have been awarded the 2011 Adams Prize. This year's topic was "Discrete Mathematics or Number Theory". According to the citation, "the work of both this year's winners has transformed our understanding of important topics in analytic number theory. They have each introduced new methodologies and techniques in applying deep tools from analysis in number theory; their results have already fostered much new research." Helfgott's work "is a major breakthrough in understanding expanders in general groups, a major problem in additive combinatorics." Sanders "employed deep harmonic analysis to understand arithmetic progressions and answer long-standing conjectures in number theory."

The Adams Prize is awarded each year jointly by the Faculty of Mathematics at the University of Cambridge and St. John's College to a young researcher or researchers based in the United Kingdom doing first-class international research in the mathematical sciences. The prize is named after the mathematician John Couch Adams and was endowed by members of St. John's College. It carries a cash prize of approximately £14,000 (about US$22,500), of which one-third is awarded to the prizewinner on announcement of the prize, one-third is provided to the prizewinner's institution (for research expenses of the prizewinner), and one-third is awarded to the prizewinner on acceptance for publication in an internationally recognized journal of a substantial (normally at least twenty-five printed pages) original survey article of which the prizewinner is an author.

—From a University of Cambridge announcement

Butcher Receives Jones Medal

A new medal for lifetime achievement in the mathematical sciences, the Jones Medal, has been established by the Royal Society of New Zealand and has been awarded to JOHN BUTCHER, professor emeritus at the University of Auckland. The award consists of a medal designed by Marian Fountain, a New Zealand sculptor living in France, and a cash award of US$4,000. It will be awarded biennially for lifetime achievement in pure or applied mathematics or statistics by a person with substantial connections to New Zealand.

The medal is named after and honors Sir Vaughan Jones, who was born in New Zealand and studied at the University of Auckland and the University of Geneva. Since 1985 he has been a professor at the University of California, Berkeley. His work on subfactors of von Neumann algebras led to his discovery of the Jones polynomial invariant of knots and links and to his Fields Medal award in 1990 and his knighthood in 2002. (This work involved the golden ratio, which appears on the medal.) He has also worked on statistical mechanics, low-dimensional topology, and planar algebras. He has maintained a strong connection to New Zealand, including serving as codirector of the New Zealand Institute of Mathematics and Its Applications since its founding in 2002.

John Butcher is without doubt one of the leading world experts on numerical methods for the solution of ordinary differential equations (ODEs) and the world expert on Runge-Kutta methods. When he began work on Runge-Kutta methods in 1963, the area of numerical methods for ODE initial value problems was hardly considered fashionable, yet alone ripe for revolution. Yet that is what Butcher brought about in a series of papers over the following decades. The entire subject today is organized around the concept of B-series, named after John, the expansion of the integrator as a power series in the time step, with coefficients that are polynomial in the Runge-Kutta coefficients and in the vector field appearing in the ODE and its derivatives; the combinatorial aspects are handled by rooted trees.

The algebraic structure of B-series, whose study Butcher launched in 1972, was rediscovered twenty-five years later by Alain Connes and Dirk Kreimer for applications in quantum field theory. Connes and Kreimer applauded this work: "We regard Butcher's work on the classification of numerical integration methods as an impressive example that concrete problem-oriented work can lead to far-reaching conceptual results." Butcher has also worked on general linear methods, a simultaneous generalization of linear multistep and Runge-Kutta methods that led, for example, to his 2009 proof of the 1992 Butcher-Chipman conjecture on generalized Padé approximants of the exponential function.

Both mathematical and human elements are incorporated into the design of the medal. Marian Fountain says that the design "has been an interesting voyage for me and I spent a few weeks having too many possibilities and touching on the frustration of infinity, the feeling of not having quite found the right answer. I tried to keep thinking of the wonder of discovery in mathematics, and of the aspect of proof, so it had to stay a perfect circle, which was an interesting but important restraint." The knot design shows the simplest link that the Jones polynomial cannot distinguish from the unlink. Despite much effort, it is still unknown whether there exists a nontrivial knot that the Jones polynomial cannot distinguish from the unknot.

Additional information about the Jones Medal, including pictures of the medal itself, is available at `http://www.royalsociety.org.nz/programmes/awards/jones-medal`.

—Robert I. McLachlan, Massey University

Oberman and Tropp Awarded Monroe H. Martin Prize

Adam Oberman of Simon Fraser University and Joel A. Tropp of the California Institute of Technology have been awarded the eighth Monroe H. Martin Prize. The prize is awarded every five years by the Institute for Physical Science and Technology to honor outstanding sole-authored papers by junior mathematicians. The prize carries a cash award of US$5,000 to each awardee.

Oberman was honored for his paper "A convergent difference scheme for the infinity Laplacian: Construction of absolutely minimizing Lipschitz extensions", which appeared in *Mathematics of Computation*, Volume 74 (2005), pp. 1217–1230. In this paper Oberman discusses building effective approximation methods for a class of nonlinear elliptic partial differential equations. These equations have applications in diverse areas: differential geometry, stochastic control, mathematical finance, and homogenization. Typical examples include Hamilton-Jacobi equations, the Monge-Ampère equation, and the equation for the convex envelope.

Tropp was honored for his paper "On the conditioning of random subdictionaries", which appeared in *Applied and Computational Harmonic Analysis*, Volume 25 (2008), pp. 1–24. In this paper Tropp observes that computer scientists have long known that randomness can be used to improve the performance of algorithms. A familiar application is the process of dimension reduction, in which a random map transports data from a high-dimensional space to a lower-dimensional space while approximately preserving some geometric properties. By operating with the compact representation of the data, it is theoretically possible to produce approximate solutions to certain large problems very efficiently.

The Monroe H. Martin Prize was established to honor the outstanding contributions of the late Monroe H. Martin, professor emeritus at the University of Maryland, College Park. He was chair of the Department of Mathematics from 1942 until 1954 and the founding director of the Institute for Fluid Dynamics and Applied Mathematics (a forerunner of the Institute for Physical Science and Technology) from 1952 until 1968. Previous prizewinners are Neil Berger (1975), Marshall Slemrod (1980), Jonathan Goodman (1985), Marek Rychlik (1990), Andrew Stuart (1995), Zhihong Xia (1995), Yury Grabovsky (2000), Robert McCann (2000), C. Sinan Gunturk (2005), and Jared Tanner (2005).

—Frank W. J. Olver, cochair,
Monroe H. Martin Prize Committee

2010 Prize for Achievement in Information-Based Complexity

Boleslaw Z. Kacewicz of the AGH University of Science and Technology, Cracow, Poland, has been awarded the 2010 Prize for Achievement in Information-Based Complexity. The award consists of US$3,000 and a plaque.

—IBC announcement

ACM Newell Award

Takeo Kanade of Carnegie Mellon University has been awarded the 2010 Allen Newell Award of the Association for Computing Machinery (ACM) for "fundamental contributions to research in computer vision and robotics, for applications to driving, 3D vision and quality of life technology, and for promoting the interaction between computer science and other disciplines, most notably robotics."

The Allen Newell Award is presented to an individual selected for career contributions that have breadth within computer science or that bridge computer science and other disciplines. This endowed award is accompanied by a prize of US$10,000 and is supported by the Association for the Advancement of Artificial Intelligence and by individual contributions.

—From an ACM announcement

Daubechies Awarded Franklin Medal

Ingrid Daubechies of Duke University has been awarded the 2011 Benjamin Franklin Medal in Electrical Engineering "for fundamental discoveries in the field of compact representations of data, leading to efficient image compression as used in digital photography." The Franklin Awards, given by the Franklin Institute, "identify individuals whose great innovation has benefited humanity, advanced science, launched new fields of inquiry, and deepened our understanding of the universe."

—From a Franklin Institute announcement

Lapidus Awarded Anassilaos Prize

Michel Lapidus, professor of mathematics at the University of California, Riverside, has been awarded an international prize in mathematics by the Associazione Culturale Anassilaos. The prize is named after the Italian geometer Renato Calapso (1901–1976). Lapidus serves as AMS associate secretary for the western section.

The prize citation says that Lapidus is being honored for "distinguished contributions to mathematical physics, as well as to spectral and fractal geometry, including the mathematical theory of Feynman integrals and the vibrations of fractal drums and strings, with applications to the study of the propagation of waves in rough media, the search for the origin of fractality in nature, the development of the theory of complex fractal dimensions, and the establishment of new connections between fractal geometry and number theory, arithmetic and noncommutative geometry." Lapidus will receive a plaque during a November 2011 ceremony and celebration in southern Italy. An international conference is being planned in southern Italy around his work.

—Allyn Jackson

Kannan Awarded Knuth Prize

Ravi Kannan of Microsoft Research Labs India has been awarded the 2011 Knuth Prize of the Association for Computing Machinery's (ACM) Special Interest Group on Algorithms and Computation Theory (SIGACT) for developing influential algorithmic techniques aimed at solving long-standing computational problems. Kannan's contributions address the challenges of computation with massive data that characterize today's information-driven environment. His foundational work spans many areas of theoretical computer science, including lattices and their applications, geometric algorithms, machine learning, and computational linear algebra.

The Knuth Prize, named in honor of Donald Knuth of Stanford University, is given every eighteen months by ACM SIGACT and the Institute of Electrical and Electronics Engineers (IEEE) Technical Committee on the Mathematical Foundations of Computer Science. It includes a cash award of US$5,000.

—From an ACM announcement

USA Mathematical Olympiad

The 2011 USA Mathematical Olympiad (USAMO) was held April 27–28, 2011. The students who participated in the Olympiad were selected on the basis of their performances on the American High School and American Invitational Mathematics Examinations. This year 293 high school students qualified for the competition. The twelve highest scorers in the USAMO, listed in alphabetical order, were: Wenyu Cao (Phillips Academy, Andover, Massachusetts); Zijing (Michael) Gao (Cary Academy, Cary, North Carolina); Benjamin Gunby (Georgetown Day School, Washington, DC); Xiaoyu He (Acton-Boxborough Regional High School, Acton, Massachusetts); Ravi Jagadeesan (Phillips Exeter Academy, Exeter, New Hampshire); Yong Wook Kwon (Phillips Exeter Academy, Exeter, New Hampshire); Mitchell Lee (Thomas Jefferson High School for Science and Technology, Alexandria, Virginia); Ray Li (Phillips Exeter Academy, Exeter, New Hampshire); Evan O'Dorney (Berkeley Math Circle); Mark Sellke (William Henry Harrison High School, West Lafayette, Indiana); David Yang (Phillips Exeter Academy, Exeter, New Hampshire); Shijie (Joy) Zheng (Phillips Exeter Academy, Exeter, New Hampshire).

The twelve USAMO winners will attend the Mathematical Olympiad Summer Program (MOSP) at the University of Nebraska, Lincoln. Ten of the twelve will take the team selection test to qualify for the U.S. team. The six students with the highest combined scores from the test and the USAMO will become members of the U.S. team and will compete in the International Mathematical Olympiad (IMO) to be held in Amsterdam, The Netherlands, July 16–24, 2011.

—Elaine Kehoe

Moody's Mega Math Challenge Winners Announced

The winners of the 2011 Mega Math Challenge for high school students have been announced. The topic for this year's competition was "Colorado River Water: Good to the Last Acre-Foot". A team from Pine View High School in Osprey, Florida, was awarded the Summa Cum Laude Team Prize of US$20,000 in scholarship money. The members of the team were Caroline Bowman, Patrick Braga, Anthony Grebe, Alex Kiefer, and Jason Oettinger. Their coach was Ann Hankinson.

The Magna Cum Laude Team Prize of US$15,000 was awarded to a team from Ridgefield High School in Ridgefield, Connecticut. The team members were Kimberly Cohen, Allison Collins, Andrew Klutey, Sean Scott, and Will Yolen. They were coached by David Yolen.

The Cum Laude Team Prize of US$10,000 was awarded to a team from High Technology High School in Lincroft, New Jersey. The team members were Sidney Buchbinder, Stephen Guo, Channing Huang, Matthew Tsim, and Angela Zhou. Their coach was Ellen LeBlanc.

The Meritorious Team Prize of US$7,500 went to a team from T. R. Robinson High School of Tampa, Florida. The team members were Kennon Bittick, James Gibson, Erin Seligsohn, Steven Seligsohn, and Aaron Warwick. They were coached by Judi Charley-Sale.

The Exemplary Team Prize of US$5,000 was awarded to a team from Eastside High School, Gainesville, Florida. The team members were Peishi Cheng, Yi Fan, Alexander Geoffroy, Hohyun Jeon, and Medha Ranka. Their coach was Carl Henriksen.

Another team from High Technology High School, Lincroft, New Jersey, was awarded the First Honorable Mention Team Prize of US$2,500. The team members were Vinay Ayyala, Robert Hale, Brittany Ko, Neil Rangwani, and James Ting. They were coached by Raymond Eng.

The Mega Math Challenge invites teams of high school juniors and seniors to solve an open-ended, realistic, challenging modeling problem focused on real-world issues. The top five teams receive awards ranging from US$5,000 to US$20,000 in scholarship money. The competition is sponsored by the Moody's Foundation, a charitable foundation established by Moody's Corporation, and organized by the Society for Industrial and Applied Mathematics (SIAM).

—From a Moody's Foundation/SIAM announcement

Klotz and Krulik Receive NCTM Lifetime Achievement Awards

The National Council of Teachers of Mathematics (NCTM) has presented Mathematics Education Trust Lifetime Achievement Awards for Distinguished Service to Mathematics Education to Eugene A. Klotz and Stephen Krulik. Klotz, retired from Swarthmore College, was among the first to realize the potential of technology to support mathematics learning. He launched the multimedia Visual Geometry Project, which eventually expanded to become the Math Forum. Krulik taught at Temple University for more than forty years, sharing his passion for and knowledge of mathematics through hundreds of presentations and in numerous publications spanning five decades.

—From NCTM announcements

National Academy of Sciences Elections

The National Academy of Sciences (NAS) has elected seventy-two new members and eighteen foreign associates for 2011. Following are the new members whose work involves the mathematical sciences: James W. Demmel, University of California Berkeley; David Gabai, Princeton University; Stuart Geman, Brown University; Joseph Harris, Harvard University; Jon M. Kleinberg, Cornell University; Leslie Lamport, Microsoft Research; and Andrew Strominger, Harvard University. Elected as a foreign associate was Jean Bourgain of the Institute for Advanced Study.

—From an NAS announcement

AAAS Elects New Members

The American Academy of Arts and Sciences (AAAS) has chosen 212 new members and 16 foreign honorary members for 2011. Following are the names and affiliations of the new members who work in the mathematical sciences or whose work involves considerable mathematics: Marsha Berger, Courant Institute of Mathematical Sciences, New York University; Edmund M. Clarke, Carnegie Mellon University; Alex Eskin, University of Chicago; Sylvester James Gates Jr., University of Maryland; Thomas Y. Hou, California Institute of Technology; Michael I. Jordan, University of California Berkeley; Kazuya Kato, University of Chicago; Gregory W. Moore, Rutgers University; Laurent Saloff-Coste, Cornell University; Peter Shor, Massachusetts Institute of Technology; Avi Wigderson, Institute for Advanced Study; and Shou-Wu Zhang, Columbia University.

—From an AAAS announcement

Mathematics Opportunities

Call for Entries for Balaguer Prize

The Ferran Sunyer i Balaguer Foundation invites entries for the 2012 Ferran Sunyer i Balaguer Prize. The prize will be awarded for a mathematical monograph of an expository nature presenting the latest developments in an active area of research in mathematics. The prize consists of 15,000 euros (approximately US$21,500) and publication of the winning monograph in Birkhäuser-Verlag's series Progress in Mathematics. The deadline for submission is **December 2, 2011**. For more information see the website `http://ffsb.iec.cat`.

—From a Ferran Sunyer i Balaguer Foundation announcement

Call for Nominations for Otto Neugebauer Prize

The European Mathematical Society (EMS) is seeking nominations for the Otto Neugebauer Prize for the History of Mathematics. The prize will be awarded "for highly original and influential work in the field of history of mathematics that enhances our understanding of either the development of mathematics or a particular mathematical subject in any period and in any geographical region." The award comprises a certificate including the citation and a cash prize of 5,000 euros (approximately US$7,000). The deadline for nominations is **December 31, 2011**. For further information see the website `http://www.euro-math-soc.eu/node/995`.

—From an EMS announcement

Call for Nominations for Raymond J. Carroll Young Investigator Award

The Department of Statistics at Texas A&M University is seeking nominations for the Raymond J. Carroll Young Investigator Award. The award is presented every two years to an outstanding young researcher in statistical science. The awardee must have completed his or her Ph.D. within the ten years preceding the award and must have demonstrated outstanding scholarly contributions in statistical methodology and applications. Nominations must be written and must include a curriculum vitae. Nominators are encouraged to supply supporting documents such as letters of recommendation. Self-nominations are invited and encouraged. Correspondence by email is preferred but not required. The deadline for award submissions is **August 15, 2011**. Nominations and supporting documents should be sent to Professor Jeff Hart, Chair, Raymond J. Carroll Young Investigator Award, Department of Statistics, Texas A&M University, 3143 TAMU, College Station, Texas 77843-3143; email: hart@stat.tamu.edu.

—From a Texas A&M University announcement

NSF Focused Research Groups

The Focused Research Groups (FRG) activity of the Division of Mathematical Sciences (DMS) of the National Science Foundation (NSF) supports small groups of researchers in the mathematical sciences.

The DMS has announced deadline dates for the 2011 competition for FRG grants. The deadline for receipt of the required letters of intent to submit FRG proposals is **August 19, 2011**. The deadline date for full proposals is **September 16, 2011**. The FRG solicitation may be found on the Web at http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5671.

—From an NSF announcement

NSF Mathematical Sciences Postdoctoral Research Fellowships

The Mathematical Sciences Postdoctoral Research Fellowship program of the Division of Mathematical Sciences (DMS) of the National Science Foundation (NSF) awards fellowships each year that are designed to permit awardees to choose research environments that will have maximal impact on their future scientific development. Awards of these fellowships are made for appropriate research in areas of the mathematical sciences, including applications to other disciplines. Fellows may opt to choose either a research fellowship or a research instructorship. The deadline for this year's applications is **October 19, 2011**. Applications must be submitted via FastLane on the World Wide Web. For more information see the website http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5301.

—From an NSF announcement

NSA Mathematical Sciences Grants and Sabbaticals Program

As the nation's largest employer of mathematicians, the National Security Agency (NSA) is a strong supporter of the academic mathematics community in the United States. Through the Mathematical Sciences Program, the NSA provides research funding and sabbatical opportunities for eligible faculty members in the mathematical sciences.

Grants for Research in Mathematics. The Mathematical Sciences Program (MSP) supports self-directed, unclassified research in the following areas of mathematics: algebra, number theory, discrete mathematics, probability, and statistics. The Research Grants program offers three types of grants: the Young Investigators Grant, the Standard Grant, and the Senior Investigators Grant. The program also supports conferences and workshops (typically in the range of US$15,000–$20,000) in these five mathematical areas. The program does not entertain research or conference proposals that involve cryptology. A Special Situation Proposal category is for research experience for undergraduates or events that do not fall within the typical "research" conference format. In particular, MSP is interested in supporting efforts that increase broader participation in the mathematical sciences, promote wide dissemination of mathematics, and promote the education and training of undergraduates and graduate students. Principal investigators, graduate students, and all other personnel supported by NSA grants must be U.S. citizens or permanent residents of the United States at the time of proposal submission. Proposals should be submitted **electronically** by **October 15, 2011**, via the program website: http://www.nsa.gov/research/math_research/index.shtml.

Sabbatical Program. NSA's Mathematics Sabbatical Program offers mathematicians, statisticians, and computer scientists the unique opportunity to develop skills in directions that would be nearly impossible anywhere else. Sabbatical employees work side by side with other NSA scientists on projects that involve cryptanalysis, coding theory, number theory, discrete mathematics, statistics and probability, and many other subjects. Visitors spend 9–24 months at NSA, and most find that within a very short period of time they are able to make significant contributions.

NSA pays 50 percent of salary and benefits during academic months and 100 percent of salary and benefits during summer months of the sabbatical detail. A monthly housing supplement is available to help offset the cost of local lodging. On average, three sabbatical positions are available per year.

Applicants must be U.S. citizens and must be able to obtain a security clearance. A complete application includes a cover letter and curriculum vitae with list of significant publications. The cover letter should describe the applicant's research interests, programming experience and level of fluency, and how an NSA sabbatical would affect teaching and research upon return to academia. Additional information is available about the Sabbatical Program at the following website: http://www.nsa.gov/research/math_research/sabbaticals/index.shtml.

For more information about the Grants or Sabbatical Program, please contact the program office at 301-688-0400. You may also send email correspondences to mspgrants@nsa.gov.

—Mathematical Sciences Program announcement

Research Experiences for Undergraduates

The Research Experiences for Undergraduates (REU) program supports active research participation by undergraduate students in any of the areas of research funded by the National Science Foundation (NSF). Student research may be supported in two forms: REU supplements and REU sites.

REU supplements may be requested for ongoing NSF-funded research projects or may be included in proposals for new or renewal NSF grants or cooperative agreements.

REU sites are based on independent proposals to initiate and conduct undergraduate research participation projects for a number of students. REU site projects may be based in a single discipline or academic department or on interdisciplinary or multidepartment research opportunities with a strong intellectual focus. Proposals with an international dimension are welcomed. A partnership with the Department of Defense supports REU sites in research areas relevant to defense. Undergraduate student participants supported with NSF funds in either supplements or sites must be citizens or permanent residents of the United States or its possessions.

Students may not apply to NSF to participate in REU activities. Students apply directly to REU sites and should consult the directory of active REU sites on the Web at `http://www.nsf.gov/crssprgm/reu/reu_search.cfm`. The deadline for full proposals for REU sites is **August 24, 2011**. Deadline dates for REU supplements vary with the research program; contact the program director for more information. The full program announcement can be found at the website `http://www.nsf.gov/pubs/2009/nsf09598/nsf09598.htm`.

—From an NSF announcement

Call for Nominations for 2011 Sacks Prize

The Association for Symbolic Logic (ASL) invites nominations for the 2011 Sacks Prize for the most outstanding doctoral dissertation in mathematical logic. The Sacks Prize consists of a cash award and five years' free membership in the ASL. Dissertations must have been defended by **September 30, 2011**.

General information about the prize is available at `http://www.aslonline.org/info-prizes.html`. For details about nomination procedures, see `http://www.aslonline.org/Sacks_nominations.html`.

—From an ASL announcement

PIMS Postdoctoral Fellowships

The Pacific Institute for the Mathematical Sciences (PIMS) invites nominations of outstanding young researchers in the mathematical sciences for postdoctoral fellowships for the year 2012–2013. **Please note that the deadline for receipt of applications has been changed to December 1**. Candidates must be nominated by at least one scientist or by a department (or departments) affiliated with PIMS. The fellowships are intended to supplement support provided by the sponsor and are tenable at any of its Canadian member universities: Simon Fraser University, the University of Alberta, the University of British Columbia, the University of Calgary, the University of Victoria, University of Regina, and the University of Saskatchewan, as well as at the PIMS affiliates, the Universities of Lethbridge and Northern British Columbia.

For the 2012–2013 competition, to be held in January of 2012, the amount of the award will be C$20,000 (approximately US$20,400) and the sponsor(s) is (are) required to provide additional funds to finance a minimum total stipend of C$40,000 (approximately US$41,000). Rankings of candidates are made by the PIMS PDF Review Panel based on the qualifications of the candidate, his or her potential for participation in PIMS programs, and his or her potential involvement with PIMS partners. PIMS postdoctoral fellows will be expected to participate in all PIMS activities related to the fellow's area of expertise and will be encouraged to spend time at more than one site. To ensure that PIMS postdoctoral fellows are able to participate fully in institute activities, they may not teach more than two single-term courses per year.

Nominees must have a Ph.D. or equivalent (or expect to receive a Ph.D. by December 31, 2012) and be within three years of the Ph.D. at the time of the nomination (i.e., the candidate must have received her or his Ph.D. on or after January 1, 2009). The fellowship may be taken up at any time between September 1, 2012, and January 1, 2013. The fellowship is for one year and is renewable for at most one additional year.

The PIMS PDF nomination/application process takes place entirely online, utilizing the MathJobs service provided by the American Mathematical Society. Having selected their nominees, sponsors direct them to apply online at `mathjobs.org/jobs/PIMS`. Nominees are required to upload two letters of reference, a curriculum vitae, and a statement of research interests. Sponsors must upload their own reference letters (these are in addition to the two reference letters mentioned above) and a statement of financial support. They will receive instructions as to how to proceed from their nominees via email from MathJobs. Detailed instructions regarding all aspects of the MathJobs application procedure may be found in the online MathJobs user guides. Please note that application is by nomination only; unsolicited applications will not be considered. Please note that all nominees must apply through MathJobs; this includes nominees from PIMS Collaborative Research Groups.

Complete applications must be uploaded to MathJobs by **December 1, 2011**. (Note that this date is two weeks earlier than in previous years.) For further information, visit the website `http://www.pims.math.ca/scientific/postdoctoral` or contact: `assistant.director@pims.math.ca`.

—PIMS announcement

Reference and Book List

*The **Reference** section of the* Notices *is intended to provide the reader with frequently sought information in an easily accessible manner. New information is printed as it becomes available and is referenced after the first printing. As soon as information is updated or otherwise changed, it will be noted in this section.*

Contacting the *Notices*

The preferred method for contacting the *Notices* is electronic mail. The editor is the person to whom to send articles and letters for consideration. Articles include feature articles, memorial articles, communications, opinion pieces, and book reviews. The editor is also the person to whom to send news of unusual interest about other people's mathematics research.

The managing editor is the person to whom to send items for "Mathematics People", "Mathematics Opportunities", "For Your Information", "Reference and Book List", and "Mathematics Calendar". Requests for permissions, as well as all other inquiries, go to the managing editor.

The electronic-mail addresses are `notices@math.wustl.edu` in the case of the editor and `notices@ams.org` in the case of the managing editor. The fax numbers are 314-935-6839 for the editor and 401-331-3842 for the managing editor. Postal addresses may be found in the masthead.

Upcoming Deadlines

July 19, 2011: Full proposals for NSF Research Training Groups in the Mathematical Sciences. See `http://tinyurl.com/3v9urpd`.

July 20, 2011: Full proposals for NSF Mentoring through Critical Transition Points in the Mathematical Sciences program. See `http://tinyurl.com/3eh8m73`.

August 1, 2011: Applications for August review for National Academies Research Associateship Programs. See the National Academies website at `http://sites.nationalacademies.org/PGA/RAP/PGA_050491` or contact Research Associateship Programs, National Research Council, Keck 568, 500 Fifth Street, NW, Washington, DC 20001; telephone 202-334-2760; fax 202-334-2759; email `rap@nas.edu`.

August 15, 2011: Nominations for Raymond J. Carroll Young Investigator Award. See "Mathematics Opportunities" in this issue.

August 15, 2011: Nominations for SASTRA Ramanujan Prize. See `http://www.math.ufl.edu/sastra-prize/nominations-2011.html`.

August 19, 2011: Letters of intent for NSF Focused Research Groups. See "Mathematics Opportunities" in this issue.

Where to Find It

A brief index to information that appears in this and previous issues of the *Notices*.

August 24, 2011: Full proposals for REU sites. See "Mathematics Opportunities" in this issue.

August 31, 2011: Contributions to BSM study, "The Mathematical Sciences in 2025". See www.nas.edu/mathsci2025.

September 15, 2011: Nomination for Sloan Research Fellowships. See http://www.sloan.org/fellowships.

September 16, 2011: Full proposals for NSF Focused Research Groups. See "Mathematics Opportunities" in this issue.

September 30, 2011: Nominations for 2011 Sacks Prize. See "Mathematics Opportunities" in this issue.

October 1, 2011: Nominations for Emanuel and Carol Parzen Prize for Statistical Innovation. Contact Thomas Wehrly, Department of Statistics, 3143 TAMU, Texas A&M University, College Station, Texas 77843-3143.

October 1, 2011: Proposals for MSRI Hot Topic Workshops for 2012. See http://www.msri.org/msri-htw.

October 1, 2011: Proposals for MSRI Summer Graduate Schools for 2012. See http://www.msri.org/msri-sgw.

October 1, 2011: Applications for AWM Travel Grants. See http://www.awm-math.org/travelgrants.html#standard.

October 15, 2011: Proposals for NSA Mathematical Sciences Grants. See "Mathematics Opportunities" in this issue.

October 19, 2011: Proposals for NSF Postdoctoral Research Fellowships. See http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5301.

October 30, 2011: Nominations for ICTP Ramanujan Prize. See http://prizes.ictp.it/Ramanujan/.

November 1, 2011: Applications for November review for National Academies Research Associateship Programs. See the National Academies website at http://sites.nationalacademies.org/PGA/RAP/PGA_050491 or contact Research Associateship Programs, National Research Council, Keck 568, 500 Fifth Street, NW, Washington, DC 20001; telephone 202-334-2760; fax 202-334-2759; email rap@nas.edu.

December 1, 2011: Applications for PIMS postdoctoral fellowships. See "Mathematics Opportunities" in this issue.

December 2, 2011: Entries for the 2012 Ferran Sunyer i Balaguer Prize. See "Mathematics Opportunities" in this issue.

December 21, 2011: Nominations for the Schauder Medal. Contact Lech Gorniewicz, tmna@mat.uni.torun.pl.

December 31, 2011: Nominations for Otto Neugebauer Prize for the History of Mathematics. See "Mathematics Opportunities" in this issue.

January 1, 2012: Proposals for MSRI Hot Topic Workshops for 2012. See http://www.msri.org/msri-htw.

January 1, 2012: Proposals for MSRI Summer Graduate Schools for 2012. See http://www.msri.org/msri-sgw.

Contact Information for Mathematics Institutes

American Institute of Mathematics
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Telephone: 650-845-2071
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Stefan Banach International Mathematical Center

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Fax: 48 22 622-57-50
email: Banach.Center.Office@impan.pl
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c/o The Banff Centre
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http://www.birs.ca

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http://www.cscamm.umd.edu/

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Telephone: 45 8942 3432
email: ctqm@imf.au.dk
http://www.ctqm.au.dk/

Centre International de Rencontres Mathématiques (CIRM)

163, avenue de Luminy Case 916
F-13288 Marseille Cedex 09, France
Telephone: 33 04 91 83 30 00
Fax: 33 04 91 83 30 05
http://www.cirm.univ-mrs.fr

Centre de Recerca Matemática (CRM)

Campus de Bellaterra, Edifici C 08193
Bellaterra

Barcelona, Spain
Telephone: 34 93 581 1081
Fax: 34 93 581 2202
email: crm@crm.cat
http://www.crm.cat

Centre for Mathematics and Its Applications (CMA)
Building 27
Australian National University
ACT 0200
Australia
Telephone: 61 2 6125 2897
Fax: 61 2 6125 5549
email: admin.research.msi@anu.edu.au
http://www.maths.anu.edu.au/CMA/

Centre de Recherches Mathématiques (CRM)
Université de Montréal
P.O. Box 6128, Centre-ville Station
Montréal, Quebec H3C 3J7, Canada
Telephone: 514 343 7501
Fax: 514 343 2254
email: CRM@CRM.UMontreal.ca
http://www.crm.umontreal.ca

Centro de Investigación en Matemáticas (CIMAT)
Jalisco S/N, Col. Valenciana, CP: 36240 Guanajuato, Gto
México
Telephone: +52 473 732 7155/735 0800
Fax: +52 473 732 5749
email: laura@cimat.mx
http://www.cimat.mx

Centro di Ricerca Matematica Ennio De Giorgi
Collegio Puteano
Scuola Normale Superiore
Piazza dei Cavalieri, 3
I-56100 Pisa, Italy
Telephone: 39 (050) 509256
Fax: 050 509177
email: crm@crm.sns.it
http://www.crm.sns.it/index_02.html

Centro Internazionale per la Ricerca Matematica
Fondazione Bruno Kessler
Via Sommarive, 14 Povo
38100 Trento, Italy
Telephone: 39-0461-881628
Fax: 39-0461-810629
email: michelet@science.unitn.it
http://www.science.unitn.it/cirm/

Chennai Mathematical Institute
Plot H1, SIPCOT IT Park
Padur PO, Siruseri 603103
India
Telephone: 91-44-3298-3441, 91-44-3298-3442
Fax: 91-44-2747-0225
email: office@cmi.ac.in
http://www.cmi.ac.in

Chern Institute of Mathematics
Nankai University
Tianjin 300071, China
Telephone: 86-22-2350-8228
Fax: 86-22-2350-1532
email: cim@nankai.edu.cn
http://www.nim.nankai.edu.cn/nim_e/index.htm

Euler International Mathematical Institute
nab. Fontanki, 27
St. Petersburg 191023
Russia
Telephone: 7 960 279 10 37
Fax: 7 812 234 05 74
email: admin@euler.pdmi.ras.ru
http://www.pdmi.ras.ru/EIMI/index.html

Fields Institute for Research in Mathematical Sciences
222 College Street, 2nd Floor
Toronto, Ontario M5T 3J1 Canada
Telephone: 416 348 9710
Fax: 416 348 9714
email: geninfo@fields.utoronto.ca
http://www.fields.utoronto.ca/

Forschungsinstitut für Mathematik (FIM)
HG G 44.1
Rämistrasse 101
8092 Zurich, Switzerland
Telephone: 41 44 632 3598
Fax: 41 44 632 1614
email: admin@fim.math.ethz.ch
http://www.fim.math.ethz.ch/

Institut des Hautes Études Scientifiques (IHÉS)
Le Bois Marie 35, route de Chartres
F 91440 Bures sur Yvette, France
Telephone: 33 1 60 92 66 00
Fax: 33 1 60 92 66 69
http://www.ihes.fr

Institut Henri Poincaré
11, rue Pierre et Marie Curie
75231 Paris Cedex 05, France
Telephone: 33 01 44 27 67 89
Fax: 33 01 44 07 09 37
http://www.ihp.jussieu.fr/

Institut Mittag-Leffler
Auravägen 17
SE-182 60 Djursholm, Sweden
Telephone: 46 8 622 05 60
Fax: 46 8 622 05 89
email: info@mittag-leffler.se
http://www.mittag-leffler.se/

Institute for Advanced Study (IAS)
School of Mathematics
Einstein Drive
Princeton, NJ 08540
Telephone: 609-734-8100
Fax: 609-951-4459
email: math@math.ias.edu
http://www.math.ias.edu/

Institute for Mathematical Sciences
National University of Singapore
3 Prince George's Park
Singapore 118402, Republic of Singapore
Telephone: 65 6516 1897
Fax: 65 6873 8292
email: ims@nus.edu.sg
http://www2.ims.nus.edu.sg/

Institute of Mathematical Sciences
Chinese University of Hong Kong
Unit 601
Academic Building No. 1
Shatin, N. T., Hong Kong
Telephone: 852 2609 8038
Fax: 852 2603 7636
email: ims@ims.cuhk.edu.hk
http://www.ims.cuhk.edu.hk

Institute for Mathematics and its Applications (IMA)
University of Minnesota
114 Lind Hall
207 Church Street, SE
Minneapolis, MN 55455-0134
Telephone: 612-624-6066
Fax: 612-626-7370
email: staff@ima.umn.edu
http://www.ima.umn.edu/

Institute for Pure and Applied Mathematics (IPAM)
IPAM Building
460 Portola Plaza
Box 957121
Los Angeles, CA 90095-7121
Telephone: 310-825-4755
Fax: 310-825-4756
email: ipam@ucla.edu
http://www.ipam.ucla.edu

Institute for Research in Fundamental Sciences
School of Mathematics
P. O. Box 19395-5746
Tehran, Iran
Telephone: 98 21 2228 7013
Fax: 98 21 2229 0151
email: ipminfo@ipm.ir
http://math.ipm.ac.ir

Instituto Nacional de Matemática Pura e Aplicada (IMPA)
Estrada Dona Castorina, 110
Rio de Janeiro, Brazil 22460-320
Telephone: 55 21 2529 5000
Fax: 55 21 2512 4115
email: diretor@impa.br
http://www.impa.br

International Center for Theoretical Physics (ICTP)
Strada Costiera 11
I-34151 Trieste, Italy
Telephone: 39 040 2240111
Fax: 39 040 224163
email: sci_info@ictp.it
http://www.ictp.it

International Centre for Mathematical Sciences (ICMS)
15 South College Street
Edinburgh EH8 9AA
United Kingdom
Telephone: 0131 650 9831
email: enquiries@icms.org.uk
http://www.icms.org.uk/index.php

Isaac Newton Institute for Mathematical Sciences
20 Clarkson Road
Cambridge CB3 0EH
United Kingdom
Telephone: 44 0 1223 335999
Fax: 44 0 1223 330508
email: info@newton.ac.uk
http://www.newton.ac.uk/

Korea Institute for Advanced Study (KIAS)
85 Hoegiro (Cheongnyangni-dong 207-43)
Dongdaemun-gu
Seoul 130-722, Korea
Telephone: 82 2 958 3711
Fax: 82 2 958 3770
http://www.kias.re.kr/en/index.jsp

Liu Bie Ju Centre for Mathematical Sciences
City University of Hong Kong
Tat Chee Avenue
Kowloon, Hong Kong
Telephone: 852 3442 9816
Fax: 852 3442 0250
email: mclbj@cityu.edu.hk
http://www.cityu.edu.hk/rcms

Mathematical Biosciences Institute
The Ohio State University
Jennings Hall, 3rd Floor
1735 Neil Avenue
Columbus, Ohio 43210
Telephone: 614-292-3648
Fax: 614-247-6643
email: rebecca@mbi.osu.edu
http://www.mbi.osu.edu

Mathematical Sciences Research Institute (MSRI)
17 Gauss Way
Berkeley, CA 94720 5070
Telephone: 510-642-0143
Fax: 510-642-8609
email: msri-inquiries@msri.org
http://www.msri.org/

Mathematisches Forschungs Institut Oberwolfach
Schwarzwaldstr. 9-11 (Lorenzenhof)
D 77709 Oberwolfach Walke, Germany
Telephone: 49 7834 979 0
Fax: 49 7834 979 38
email: admin@mfo.de
http://www.mfo.de

Max Planck Institut für Mathematik
Vivatsgasse 7
53111 Bonn, Germany
Telephone: 49 0 228 402 0
Fax: 49 0 228 402 277
email: admin@mpim-bonn.mpg.de
http://www.mpim-bonn.mpg.de

Max Planck Institut für Mathematik in den Naturwissenschaften
Inselstrasse 22
04103 Leipzig, Germany
Telephone: 49 0 341 9959 50
Fax: 49 (0) 341 9959 658
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http://www.mis.mpg.de/

New Zealand Institute of Mathematics and Its Applications (NZIMA)
University of Auckland
Private Bag 92019
Auckland, New Zealand
Telephone: 64 (0)9 373 7599
ext. 82025
Fax: 64 (0)9 373 7457
email: nzima-admin@nzima.auckland.ac.nz
http://www.nzima.org

Pacific Institute for the Mathematical Sciences (PIMS)
University of British Columbia
1933 West Mall, Room 200
Vancouver, BC, V6T 1Z2, Canada
Telephone: 604-822-3922
Fax: 604-822-0883
email: reception@pims.math.ca
http://www.pims.math.ca

Alfréd Rényi Institute of Mathematics
Hungarian Academy of Sciences
POB 127
H-1364 Budapest, Hungary
Telephone: 36 1 483 8302
Fax: 36 1-483 8333
email: math@renyi.hu
http://www.renyi.hu

Research Institute for Mathematical Sciences (RIMS)
Kyoto University
Kyoto, 606 8502, Japan
Telephone: 81 75 753 7245
Fax: 81 75 753 7272
http://www.kurims.kyoto-u.ac.jp/

Erwin Schrödinger International Institute for Mathematical Physics
Boltzmanngasse 9
A-1090 Vienna, Austria
Telephone: 43 1 4277 28282
Fax: 43 1 4277 28299
email: secr@esi.ac.at
http://www.esi.ac.at/

Sobolev Institute of Mathematics

Russian Academy of Sciences,
Siberian Branch
4 Acad. Koptyug Avenue
630090 Novosibirsk Russia
Telephone: 383 333 28 92
Fax: 383 333 25 98
email: `im@math.nsc.ru`
`http://math.nsc.ru`

Statistical and Applied Mathematical Sciences Institute (SAMSI)

19 T. W. Alexander Drive
P.O. Box 14006
Research Triangle Park, NC 27709-4006
Telephone: 919-685-9350
Fax: 919-685-9360
email: `info@samsi.info`
`http://www.samsi.info/`

Steklov Institute of Mathematics

Russian Academy of Sciences
Gubkina str. 8
119991, Moscow, Russia
Telephone: 7 499 135 22 91
Fax: 7 499 135 05 55
email: `steklov@mi.ras.ru`
`http://www.mi.ras.ru`

Steklov Institute of Mathematics

27, Fontanka
St. Petersburg 191023, Russia
Telephone: 7 812 312 40 58
Fax: 7 812 310 53 77
email: `admin@pdmi.ras.ru`
`http://www.pdmi.ras.ru`

Tata Institute of Fundamental Research

School of Mathematics
Homi Bhabha Road
Mumbai 400 005, India
Telephone: 91 22 22782000
Fax: 91 22 22804610; 91 22 22804611
`http://www.math.tifr.res.in`

T. N. Thiele Centre for Applied Mathematics in Natural Science

University of Aarhus
Department of Mathematical Sciences
Ny Munkegade 118, Building 1530
DK-8000 Aarhus C, Denmark
Telephone: 45 89 42 35 15
Fax: 45 86 13 17 69
email: `thiele@imf.au.dk`
`http://www.thiele.au.dk`

Warwick Mathematics Research Centre

University of Warwick
Zeeman Building Coventry CV4 7AL,
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Telephone: +44 (0)24 7652 8317
Fax: +44 (0)24 7652 3548
email: `mrc@maths.warwick.ac.uk`
`http://www.maths.warwick.ac.uk/mrc/index.html`

Weierstrass Institute for Applied Analysis and Stochastics

Mohrenstrasse 39
10117 Berlin, Germany
Telephone: 49 30 20372 0
Fax: 49 30 2044975
email: `contact@wias-berlin.de`
`http://www.wias-berlin.de/`

Book List

The Book List highlights books that have mathematical themes and are aimed at a broad audience potentially including mathematicians, students, and the general public. When a book has been reviewed in the Notices, *a reference is given to the review. Generally the list will contain only books published within the last two years, though exceptions may be made in cases where current events (e.g., the death of a prominent mathematician, coverage of a certain piece of mathematics in the news) warrant drawing readers' attention to older books. Suggestions for books to include on the list may be sent to* `notices-booklist@ams.org`.

*Added to "Book List" since the list's last appearance.

**The Adventure of Reason: Interplay Between Philosophy of Mathematics and Mathematical Logic, 1900-1940,* by Paolo Mancosu. Oxford University Press, January 2011. ISBN-13: 978-01995-465-34.

Apocalypse When?: Calculating How Long the Human Race Will Survive, by Willard Wells. Springer Praxis, June 2009. ISBN-13: 978-03870-983-64.

At Home with André and Simone Weil, by Sylvie Weil. (Translation of *Chez les Weils*, translated by Benjamin Ivry.) Northwestern University Press, October 2010. ISBN 978-08101-270-43. (Reviewed May 2011.)

**The Autonomy of Mathematical Knowledge: Hilbert's Program Revisited,* by Curtis Franks. Cambridge University Press, December 2010. ISBN-13: 978-05211-838-95.

The Best Writing on Mathematics: 2010, edited by Mircea Pitici. Princeton University Press, December 2010. ISBN-13: 978-06911-484-10.

The Big Questions: Mathematics, by Tony Crilly. Quercus, April 2011. ISBN: 978-18491-624-01.

The Black Swan: The Impact of the Highly Improbable, by Nassim Nicholas Taleb. Random House Trade Paperbacks, second edition, May 2010. ISBN-13: 978-08129-738-15. (First edition reviewed March 2011.)

The Calculus Diaries: How Math Can Help You Lose Weight, Win in Vegas, and Survive a Zombie Apocalypse, by Jennifer Ouellette. Penguin, reprint edition, August 2010. ISBN 978-01431-173-77.

The Calculus of Selfishness, by Karl Sigmund. Princeton University Press, January 2010. ISBN-13: 978-06911-427-53.

Chasing Shadows: Mathematics, Astronomy, and the Early History of Eclipse Reckoning, by Clemency Montelle. Johns Hopkins University Press, April 2011. ISBN-13: 978-08018-969-10.

The Clockwork Universe: Isaac Newton, the Royal Society, and the Birth of the Modern World, by Edward Dolnick. Harper, February 2011. ISBN-13: 978-00617-195-16. (Reviewed April 2011.)

Complexity: A Guided Tour, by Melanie Mitchell. Oxford University Press, April 2009. ISBN-13: 978-01951-244-15. (Reviewed April 2011.)

Crafting by Concepts: Fiber Arts and Mathematics, by Sarah-Marie Belcastro and Carolyn Yackel. A K Peters/CRC Press, March 2011. ISBN-13: 978-15688-143-53.

Duel at Dawn: Heroes, Martyrs, and the Rise of Modern Mathematics, by Amir Alexander. Harvard University Press, April 2010. ISBN-13: 978-06740-466-10. (Reviewed November 2010.)

Euler's Gem: The Polyhedron Formula and the Birth of Topology, by David S. Richeson. Princeton University Press, September 2008. ISBN-13: 978-06911-267-77. (Reviewed December 2010.)

**The Evolution of Logic,* by W. D. Hart. Cambridge University Press, August 2010. ISBN: 978-0-521-74772-1

The Grand Design, by Stephen Hawking and Leonard Mlodinow. Bantam, September 2010. ISBN-13: 978-05538-053-76.

Hidden Harmonies (The Lives and Times of the Pythagorean Theorem), by Robert and Ellen Kaplan. Bloomsbury Press, January 2011. ISBN-13:978-15969-152-20.

Hot X: Algebra Exposed, by Danica McKellar. Hudson Street Press, August 2010. ISBN 978-15946-307-05.

I Want to Be a Mathematician: A Conversation with Paul Halmos. A film by George Csicsery. Mathematical Association of America, March 2009. ISBN: 978-08838-590-94. (Reviewed June/July 2011.)

Le Operazioni del Calcolo Logico, by Ernst Schröder. Original German version of *Operationskreis des Logikkalkuls* and Italian translation with commentary and annotations by Davide Bondoni. LED Online, 2010. ISBN 978-88-7916-474-0.

Logicomix: An Epic Search for Truth, by Apostolos Doxiadis and Christos Papadimitriou. Bloomsbury USA, September 2009. ISBN-13: 978-15969-145-20. (Reviewed December 2010.)

Loving + Hating Mathematics: Challenging the Myths of Mathematical Life, by Reuben Hersh and Vera John-Steiner. Princeton University Press, January 2011. ISBN-13: 978-06911-424-70.

The Math Book: From Pythagoras to the 57th Dimension, 250 Milestones in the History of Mathematics, by Clifford A. Pickover. Sterling, September 2009. ISBN-13: 978-14027-579-69.

A Mathematician's Lament: How School Cheats Us Out of Our Most Fascinating and Imaginative Art Form, by Paul Lockhart. Bellevue Literary Press, April 2009. ISBN-13:978-1-934137-17-8.

Mathematicians Fleeing from Nazi Germany: Individual Fates and Global Impact, by Reinhard Siegmund-Schultze. Princeton University Press, July 2009. ISBN-13: 978-06911-4041-4. (Reviewed November 2010.)

**Mathematics and Reality,* by Mary Leng. Oxford University Press, June 2010. ISBN-13: 978-01992-807-97.

Mathematics Education for a New Era: Video Games as a Medium for Learning, by Keith Devlin. A K Peters/CRC Press, February 2011. ISBN: 978-1-56881-431-5.

A Motif of Mathematics: History and Application of the Mediant and the Farey Sequence, by Scott B. Guthery. Docent Press, September 2010. ISBN-13:978-4538-105-76.

Mysteries of the Equilateral Triangle, by Brian J. McCartin. Hikari, August 2010. ISBN-13: 978-954-91999-5-6. Electronic copies available for free at `http://www.m-hikari.com/mccartin-2.pdf`.

Nonsense on Stilts: How to Tell Science from Bunk, by Massimo Pigliucci. University of Chicago Press, May 2010. ISBN-13: 978-02266-678-67. (Reviewed April 2011.)

Number Freak: From 1 to 200—The Hidden Language of Numbers Revealed, by Derrick Niederman. Perigee Trade, August 2009. ISBN-10: 03995-345-98.

Numbers: A Very Short Introduction, by Peter M. Higgins. Oxford University Press, February 2011. ISBN 978-0-19-958405-5.

Numbers Rule: The Vexing Mathematics of Democracy, from Plato to the Present, by George G. Szpiro. Princeton University Press, April 2010. ISBN-13: 978-06911-399-44. (Reviewed January 2011.)

Origami Inspirations, by Meenakshi Mukerji. A K Peters, September 2010. ISBN-13: 978-1568815848.

Perfect Rigor: A Genius and the Mathematical Breakthrough of the Century, by Masha Gessen. Houghton Mifflin Harcourt, November 2009. ISBN-13: 978-01510-140-64. (Reviewed January 2011.)

Plato's Ghost: The Modernist Transformation of Mathematics, by Jeremy Gray. Princeton University Press, September 2008. ISBN-13: 978-06911-361-03. (Reviewed February 2010.)

Problem-Solving and Selected Topics in Number Theory in the Spirit of the Mathematical Olympiads, by Michael Th. Rassias. Springer, 2011. ISBN-13: 978-1-4419-0494-2.

Proofiness: The Dark Arts of Mathematical Deception, by Charles Seife. Viking, September 2010. ISBN 978-06700-221-68.

Proofs from THE BOOK, by Martin Aigner and Günter Ziegler. Expanded fourth edition, Springer, October 2009. ISBN-13: 978-3-642-00855-9.

The Quants: How a New Breed of Math Whizzes Conquered Wall Street and Nearly Destroyed It, by Scott Patterson. Crown Business, January 2011. ISBN 978-03074-533-89. (Reviewed May 2011.)

Recountings: Conversations with MIT Mathematicians, edited by Joel Segel. A K Peters, January 2009. ISBN-13: 978-15688-144-90.

**Roads to Infinity: The Mathematics of Truth and Proof,* by John C. Stillwell. A K Peters/CRC Press, July 2010. ISBN-13: 978-15688-146-67.

The Shape of Inner Space: String Theory and the Geometry of the Universe's Hidden Dimensions, by Shing-Tung Yau (with Steve Nadis). Basic Books, September 2010. ISBN-13: 978-04650-202-32. (Reviewed February 2011.)

The Solitude of Prime Numbers, by Paolo Giordano. Pamela Dorman Books, March 2010. ISBN-13: 978-06700-214-82. (Reviewed September 2010.)

The Strangest Man, by Graham Farmelo. Basic Books, August 2009. ISBN-13: 978-04650-182-77.

**Street-Fighting Mathematics: The Art of Educated Guessing and Opportunistic Problem Solving,* by Sanjoy Mahajan. MIT Press, March 2010. ISBN: 978-0-262-51429-3. (Reviewed in this issue.)

Survival Guide for Outsiders: How to Protect Yourself from Politicians, Experts, and Other Insiders, by Sherman Stein. BookSurge Publishing, February 2010. ISBN-13: 978-14392-532-74.

Symmetry in Chaos: A Search for Pattern in Mathematics, Art, and Nature, by Michael Field and Martin Golubitsky. Society for Industrial and Applied Mathematics, second revised edition, May 2009. ISBN-13: 978-08987-167-26.

Train Your Brain: A Year's Worth of Puzzles, by George Grätzer. A K Peters/CRC Press, April 2011. ISBN-13: 978-15688-171-01.

What's Luck Got to Do with It? The History, Mathematics and Psychology of the Gambler's Illusion, by Joseph Mazur. Princeton University Press, July 2010. ISBN: 978-069-113890-9.

**Why Beliefs Matter: Reflections on the Nature of Science*, by E. Brian Davies. Oxford University Press, June 2010. ISBN13: 978-01995-862-02.

Doctoral Degrees Conferred

2009–2010

ALABAMA

Auburn University (8)

Department of Mathematics and Statistics

Allagan, Julian, Choice numbers, Ohba numbers and Hall numbers of some complete k-partite graphs

Delgado Ortiz, Abel, Intersection problem for the class of quaternary Reed-Muller codes

Fuller, Chris, Constructive aspects of the generalized orthogonal group

Greiwe, Regina, Properties of nonmetric hereditarily indecomposable subcontinua of finite products of lexicographic arcs

Prier, David, The inverse domination number problem, DI-pathological graphs and fractional analogues

Secor-Hutchinson, Jennifer, Thin-type dense sets and related properties

Spadaro, Santi, Discrete sets, free sequences and cardinal properties of topological spaces

Tiemeyer, Michael, C_4-factorizations with two associate classes

University of Alabama-Birmingham (4)

Department of Biostatistics

Gao, Hong-Jiang, Hypothesis testing based on pool screening with unequal pool sizes

Hamilton, Kiya, Extension of the predictive power method with multiple endpoints

Sun, Yanhui, Methods for estimating mediation effects in survival analysis: Does weight loss mediate the undernutrition-mortality relationship in the older adults?

Department of Mathematics

Curry, Clinton, Topological models of Julia sets

University of Alabama-Huntsville (1)

Department of Mathematical Sciences

Igor, Savin, Numerical methods for singularly perturbed boundary value problems and singularly perturbed equations

University of Alabama-Tuscaloosa (8)

Department of Information, Systems Statistics, and Management Science

Michaelson, Gregory, On the identification of statistically significant network topology

Department of Mathematics

Kidane, Berhanu, The corona theorem for the multiplier algebras on weighted Dirichlet spaces

Ryle, Julie, A corona theorem for certain subalgebras of $H^\infty(D)$

Taylor, Patrick, A graph theoretical model for the analysis of the game of football and a discussion of applications thereof

Thagunna, Karan, Three assets model for portfolio selection under a constrained consumption rate process

Upton, Julia, The hidden subgroup problem for generalized quaternions

Yu, Chunhui, Managing risk with short term futures contracts

Zheng, Xiaohua, Volatility analysis for high frequency financial data

ALASKA

University of Alaska Fairbanks (2)

Department of Mathematics and Statistics

Bulanova, Anna, Control theoretic approach to sampling and approximation problems

Mikhailov, Victor, Control and inverse problems for one dimensional systems

ARIZONA

Arizona State University (4)

Mathematical, Computational and Modeling Sciences Center

Flores, Kevin, Multiscale modeling of cancer

Ortiz Nieves, Angela, Modeling the transmission of Vancomyncin-resistant Enterococcus in hospitals: A case study

Rios-Doria, Daniel, Modeling transient and sustained epidemic dynamics: Cholera, influenza and rubella as case studies

Torre, Carlos A., Deterministic and stochastic metapopulation models for Dengue fever

University of Arizona (12)

Department of Mathematics

Chesler, Joshua, Interactions with algebra across the disciplinary fields of mathematics, education, and mathematics education

Dyhr, Benjamin, The chordal Loewner equation driven by Brownian motion with a linear drift

Hystad, Grethe, Periodic Ising correlations

Kennedy, Bridget, Modelling pulse propagation in loss-compensated materials that exhibit the negative refreactive index property

Kerl, John, Critical behavior for the model of random spatial permutations

LaGatta, Thomas, Geodesics of random Riemannian metrics

Lamb, McKenzie, Ginzburg-Weinstein isomorphisms for pseudo-unitary Lie groups

Occhipinti, Thomas, Mordell-Weil groups of large rank in towers

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The above list contains the names and thesis titles of recipients of doctoral degrees in the mathematical sciences (July 1, 2009, to June 30, 2010) reported in the 2010 Annual Survey of the Mathematical Sciences by 266 departments in 177 universities in the United States. Each entry contains the name of the recipient and the thesis title. The number in parentheses following the name of the university is the number of degrees listed for that university.

Wasielak, Aramian, Various limiting criteria for multidimensional diffusion processes

Program in Applied Mathematics

Graff, Christian, Parameter estimation in magnetic resonance imaging

McMahon, Joseph, Geometry and mechanics of growing, nonlinearly elastic plates and membranes

Sun, Zhiying, Pattern formation and evolution on plants

ARKANSAS

University of Arkansas at Fayetteville (1)

Department of Mathematical Sciences

Rea, Garrett, A Harnack inequality for solutions to second order divergence form operators over Hörmander vector fields

CALIFORNIA

California Institute of Technology (10)

Department of Applied and Computational Mathematics

Buzi, Gentian, Control theoretic analysis of autocatalytic networks in biology with applications to glycolysis

Chu, Chia-Chieh, Multiscale methods for elliptic partial differential equations and related application

Du Toit, Philip, Transport and separatrices in time-dependent flows

Maynard Gayme, Dennice, A robust control approach to understanding nonlinear mechanisms in shear flow turbulence

Department of Mathematics

Cheon, Wan Keng, Gromov-Witten invariants: Crepant resolutions and simple flops

Gadre, Vaibhav, Dynamics of non-classical interval exchanges

Kozhan, Rostyslav, Asymptotics for orthogonal polynomials, exponentially small perturbations, and meromorphic continuations of Herglotz functions

Maltsev, Anna, Universality limits of a reproducing kernel for a half-line Schrödinger operator and clock behavior of eigenvalues

Schroeder, Brian, On elliptic semiplanes, an algebraic problem in matrix theory, and weight enumeration of certain binary cyclic codes

Torres-Ruiz, Rafael, Geography and botany of irreducible symplectic 4-manifolds with abelian fundamental group

Claremont Graduate University (12)

School of Mathematical Sciences

Angly, Florent, A computational workflow for the estimation of environmental viral diversity in metagenomes

Aven, John, Stochastic dynamics in coupled bistable systems with applications to sensor devices

Bergmann, Frank, An integrative approach to modeling in systems biology

Coburn, Todd, Optimization: Nurbs and the quasi-Newton method

Isayan, Vigen, t-copula based credit risk modeling in a network economy

Marhadi, Kum, Investigation of progressive failure robustness and alternative load paths for damage tolerant structures

Nam, Hai Ah, Ab initio nuclear shell model calculations of some light nuclei with a three-nucleon force

Negreiros, Rodrigo, Numerical study of the properties of compact stars

Nolan, Kieran, Meta-scheduling of level-set methods in a grid computing environment

Rodriguez-Brito, Beltran, A metagenomic examination of a solar saltern in Southern California

Rojas Ulacio, Otilio, Modelling of rupture propagation under different friction laws using high-order mimetic operators

Zhou, Ming, A mathematical analysis of vesicle shapes

Stanford University (18)

Department of Mathematics

Kloke, Jennifer Novak, Methods and applications of topological data analysis

Koytcheff, Robin Michael John, A homotopy-theoretic view of Bott-Taubes integrals and knot spaces

Lo, Chieh-Cheng, Moduli spaces of PT-stable objects

Mathews, Daniel, Chord diagrams, contact-topological quantum field theory, and contact categories

Rabinoff, Joseph, Higher-level canonical subgroups for p-divisible groups

Schoenfeld, Eric, Higher symplectic field theorey invariants for cotangent bundles of surfaces

Tzeng, Yu-jong, A proof of the Göttsche-Yau-Zaslow formula

Wickelgren, Kirsten, Lower central series obstructions to homotopy sections of curves over number fields

Zhang, Ziyu, On singular moduli spaces of sheaves on $K3$ surfaces

Department of Statistics

Allen, Genevera, Transposable regularized covariance models with applications to high-dimensional data

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Group in Biostatistics

Bullard, James, Statistical methods and software for high-throughput gene expression experiments

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Polley, Eric, Super learner

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University of California, Irvine (12)

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Carlo, Chan, Scaffold facilitated multisite phosphorylation can induce biostability

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University of California, Los Angeles (40)

Department of Biostatistics, School of Public Health

Altstein, Lily, Accelerated failure time models to estimate treatment efficacy among unobserved subgroups of a randomized clinical trial

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Department of Mathematics

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Department of Statistics

Chen, Gong, Modeling and analysis of multiple alignments, ChIP-seq, and gene expression data for finding transcription factor binding sites

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Ferrari, Denise, Multi-fidelity data fusion for aerodynamic metamodel design

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Nesbitt, Tess, Cost-sensitive tree-stacking: Learning with variable prediction error costs

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University of California, Riverside (5)

Department of Mathematics

Burke-Loftus, Jennifer, Gaussian bonds of an equation derived from the Navier-Stokes equations

Hoffnung, Alex, Foundations of categorified representation theory

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Lee, Hwa Young, The flat Hilbert scheme of points of nodal curves and the punctual Hilbert scheme of points of the cusp curve

Sarhad, Jonathan, Spectral geometries on the Sierpinski gasket and a Newton embedding procedure for the nonlinear Poisson problem

University of California, San Diego (8)

Department of Mathematics

Budreau, Daniel J., Curve enumeration on the quintic threefold using tropical methods

Cooper, Benjamin, 3-dimensional topological field theory and Harrison homology

D'Adderio, Michele, Isoperimetric profile of algebras

Lust, Jaime, Verifying depth-zero supercuspidal L-packets for inner forms of GSp(4)

McGown, Kevin, Norm-Euclead Galois fields

Shopple, John, An interface-fitted finite element based level set method: Algorithm, implementation, analysis and applications

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Tressler, Eric, Integral and Euclidean Ramsey theory

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Liptrap, Jesse, From hypergroups to anyonic twines

Nahas, Joules, A decay property of solutions to the mKdV equation

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Ramirez-Rosas, Teresita, Quadrisecants and the ropelength of knots

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Jiang, Yihua, Marcov chain Monte Carlo stochastic approximation algorithms smoothing spline ANOVA frailty models and applications

Montoya, Eduardo, Constrained functional data models with environmental applications

University of California, Santa Cruz (2)

Department of Applied Mathematics and Statistics

Graham, Rishi, Information-driven cooperative sampling strategies for spatial estimation by robotic sensor networks

Pignotti, Angela, Validation of lateral boundary conditions for regional climate models

University of Southern California (7)

Department of Mathematics

Golovko, Roman, The sutured embedded contact homology of $S^1 \times D^2$

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Pehlivan, Lerna, On top to random shuffles, no feedback card guessing and fixed points of permutations

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COLORADO

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Colorado State University (13)

Department of Mathematics

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James, Rodney, Linear systems and Riemann-Roch theory on graphs

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Sonderegger, Derek, Nonparametric function smoothing: Fiducial inference of free knot splines and ecological applications

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DEPARTMENT OF MATHEMATICS AND STATISTICAL SCIENCES

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SCHOOL OF MATHEMATICAL SCIENCES

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Wheeler, Ann, Traditional and nontraditional preservice elementary teachers' perceptions about mathematics and mathematics teaching

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University of Connecticut, Storrs (16)

DEPARTMENT OF MATHEMATICS

Axtell, Jonathan, Vector operator algebras for type G affine Lie algebras

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DEPARTMENT OF STATISTICS

Gaioni, Elijah, Semiparametric functional estimation and extreme estimation and extreme value modeling using mixture distributions and limited quantile information

Joyce, Patrick, A multivariate spatial point process model: Theory, simulation and application

Raman, Balaji, On Gaussian HJM framework for eurodollar futures

Wang, Xia, Generalized link functions for binary response data

Zou, Jian, Volatility estimation and option pricing

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DEPARTMENT OF MATHEMATICS AND COMPUTER SCIENCE

Khorami, Mehdi, Twisted K-theory

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BIOSTATISTICS DIVISION

Wu, Zhenyang, Model selection methods for high-dimensional data and their applications to genome-wide association studies

DEPARTMENT OF MATHEMATICS

Lu, Dan, Howe duality correspondence of $(O(p,q)\mathrm{osp}(2,2))$

Previdi, Luigi Claudio, Generalized Tate spaces

DEPARTMENT OF STATISTICS

Hu, Xing (James), False discovery rate control with groups

DELAWARE

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DEPARTMENT OF MATHEMATICAL SCIENCES

Green, Patrice, Adiabatic dynamics and integrability of optical solitons

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DEPARTMENT OF MATHEMATICAL SCIENCE

Culbert, Craig, Spreads of three-dimensional and five-dimensional finite projective space

Kosick, Pamela, Commutative semifields of odd order and planar Dembowski-Ostrom polynomials

Vasilic, Ana, Homogenizing acoustic properties of cancellous bone

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George Washington University (8)

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Chubb, Jennifer, Ordered structures and computability

Sazdanovic, Radmila, Categorification of knot and graph polynomials and the polynomial ring

Department of Statistics

Liu, Zhenyu, Triangle test and triangle data depth in nonparametric multivariate analyis

Markitsis, Anastasios, The proportion of true null hypotheses in microarray gene expression data

Qin, Min, Some contributions to the theory of unbiased statistical prediction

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Warren, Susan, Evaluating the value of adding diagnostic symptoms using posterior probability and sensitivity/specificity procedures

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McNeal, George D., Spectral analysis for rank-one perturbations of diagonal operators in non-Archimedean Hilbert space

FLORIDA

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Caliskan, Cafer, On projective planes

Chiorescu, Marcela, Minimal zero-dimensional extensions

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Marshall, Mario, Polynomials that are integer-valued on the image of an integer-valued polynomial

Moore, Audrey, Auslander-Reiten theory for systems of submodule embeddings

Perera, Sandun, Stochastic optimal impulse control of jump diffusions with application to exchange rates

Villanyi, Viktoria, Signature schemes in single and multi-user settings

Florida Institute of Technology (3)

Department of Mathematical Sciences

Ke, Hao-Jan, Layers of stochastic games

Miller-Kermani, Donn, Women-owned small businesses in the US: Overcoming hurdles in federal procurement

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Florida State University (15)

Department of Mathematics

Bayazit, Dervis, Sensitivity analysis of options under Levy processes via Malliavin calculus

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Gutierrez, Juan B., Mathematical analysis of the use of Trojan sex chromosomes as means of eradication of invasive species

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Striegel, Deborah, Modeling the folding pattern of the cerebral cortex

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Thompson, Warren, Variable selection of correlated predictors in logistic regression: Investigating the diet-heart hypothesis

University of Central Florida (2)

Department of Mathematics

Shi, Qiling, Weighted L^p-stability for localized infinite matrices

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University of Florida (14)

Department of Mathematics

Arslan, Ogul, Some algebraic problems from coding theory

Bonner, Timothy, The characters and commutators of finite groups

Debhaumik, Anales, The hidden subgroup problem

Dung, Phan, Topics in global optimization: Ellipsoidal bisection, graph partitioning and sparse reconstruction

Fisher, Andrew, Hyperkähler manifolds

Luo, Jiangtao, Functional mapping of dynamic systems

Morofushi, Yuri, p-adic theory of exponential sums on the affine line

Oh, Minah, Efficient solution techniques for axisymmetric problems

Tan, Shuguang, Iterative solvers for hybridized finite element methods

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Department of Statistics

Li, Qin, Statistical models for haplotyping complex inherited diseases in humans

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Department of Mathematics

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University of South Florida (6)

Department of Mathematics

Angeleska, Angela, Combinatorial models for DNA rearrangements in ciliates

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Lynch, O'Neil L., Mixture distributions with application to microarray data analysis

Manandhar Shrestha, Nabin K., Statistical learning and Behrens-Fisher distribution methods for heteroscedastic data in microarray analysis

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GEORGIA

Emory University (11)

Department of Biostatistics

Chen, Jian, Multiple roots in logistic regression with errors in covariates

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Department of Mathematics and Computer Science

Gehrke, Silke, Hamiltonicity and pancyclicity of 4-connected, claw- and net-free graphics

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Georgia Institute of Technology (9)

School of Mathematics

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Shi, Kunyang, Power and sample size determination for dose finding and multiple endpoints

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Department of Mathematics

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Department of Mathematics

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Lynch, Phillip, Locally mean reverting processes

Wang, Dan, Displaced lognormal and displaced Heston volatility skews: Analysis and applications to stochastic volatility simulations

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University of Illinois at Chicago (19)

Public Health - Epidemiology and Biostatistics Division

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Broz, Dita, Transitions to injection and risk of HIV, HBV and HCV among young non-injecting heroin users in Chicago

Chapple, Theresa, Effects of interpregnancy intervals immediately following a fetal death on maternal and perinatal health

Gawel, Susan, The immunological and virologic evolution of human immunodeficiency and hepatitis C viruses among women

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Manolov, Petar, Brauer trees in finite special linear groups

Shkop, Ahuva, On pseudoexponential fields and Schanuel's conjecture

Sohn, Eunju, Storage allocation under processor sharing and infinite server models

Tang, Yuqing, A comparison model for measuring individual agreement

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Zang, Weitian, Complete topological classification of complete intersection weakly elliptic singularities

Zhang, Zhilong, Enumeration of general t-ary trees and universal types

University of Illinois, Urbana-Champaign (22)

Department of Mathematics

Carlisle, Sylvia, Model theory of real trees and their isometries

Chasman, Laura, An isoperimetric inequality for the fundamental tone of the free plate

Dewar, Michael, Congruences in modular, Jacobi, Siegel, and mock modular forms with applications

Eckhardt, Caleb, Local structure of nuclear C^*-algebras

Goldbring, Isaac, Nonstandard methods in Lie theory

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Kim, Byung Chan, Arithmetic of partition functions and q-combinatorics

Kim, Sun, Bijective proofs of partition identities and covering systems

Koukoulopoulos, Dimitrios, Generalized and restricted multiplication tables of integers

Lee, Christopher, Folded symplectic toric four-manifolds

McCullough, Jason, The strong direct summand conjective

Peterson, Valerie, State complexes and special cube complexes

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Walker, Barry, Multiplicative orientations of K-theory and p-adic analysis

Zaki, Mohammad, Analytic continuation and natural boundaries of a family of Dirichlet series

Department of Statistics

Feng, Xingdong, Dimensionality of data matrices with applications to gene expression profiles

Hong, Feng, Contributions to statistical problems related to microarray data

Lin, Guixian, Quantile regression with censored data

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Indiana University, Bloomington (9)

Department of Mathematics

Contreras, Andrés, Gamma convergence and the first critical field for Ginzburg-Landau on thin shells and manifolds

Holmes, William, A 3-D model of the cochlea with numerical simulation and asymptotics

Jhwueng, Dwueng-Chwuan, Some problems in phylogenetics comparative methods

Liu, Lihuei, On the smoothness of horocycle foliation on smooth compact surfaces without focal points

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Shonia, Giorgi, A cross section from dinovariant in h-spaces to inner function in higher dimensions

Su, Zhixu, Rational homotopy type of manifolds

Swanson, Rebecca, Relationships between shellability, vertex decomposability, and h-vectors of simplicial complexes

Yazinski, Jonathan, Construction of small exotic smooth 4-manifolds

Indiana University-Purdue University Indianapolis (4)

Department of Mathematical Sciences

Bieth, Bruno, Developing fast and accurate parallel solver for multi-scales biochemical reacting systems

Hemphill, Rachel, Robust equilibria: Normal-form, extensive-form, and repeated games

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Niles, David, The Riemann-Hilbert-Birkhoff inverse monodromy problem and connection formulae for the third Painlevé transcendents

Purdue University (26)

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Berkesch, Christine, Euler-Koszul homology in algebra and geometry

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Gerberry, David, Mathematical models of tuberculosis and childhood diseases: Very different approaches for very different diseases

Jang, Bogume, Transfer from $GSO(4)$ to $GO(4)$ and L-functions

Kim, Ha Young, Lyapunov exponents for stochastic Anderson models with non-Gaussian noise; portfolio optimization in discrete time with proportional transaction costs under stochastic volatility

Lee, Hyun Ho, Some examples in the non-stable K-theory of C^*-algebras

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Masagutov, Vakhid, Infinitely generated analytic sheaves

Sandeep Varma, Vadakkumkoor, Descent and the generic packet conjecture

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Wang, Yusun, Variant reflected BSDE with application to finance

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Yang, Shan, Credit risk modeling under incomplete information

Zhang, Shun, Recovery based a posteriori error estimators for finite element methods

Department of Statistics

Chronopoulou, Alexandra, Variations and Hurst index estimation for self-similar processes

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Hua, Lanqing, Statistical inference of protein structure using small-angle x-ray scattering data

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Martin, Ryan, Fast nonparametric estimation of a mixing distribution with application to high-dimensional inference

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Paul, Sudeshna, Estimation of interatomic distance distribution of protein molecules from small angle scattering (SAS) images

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Zhao, Yang, Local likelihood modeling of the concept drift phenomenon

University of Notre Dame (10)

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Axon, Logan, Algorithmically random closed sets and probability

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Alturk, Ahmet, Boundary functions for wavelets and their properties

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Wells, Andrew, Zorn vector matrices over commutative rings and the loops arising from their construction

Department of Statistics

Bancroft, Timothy, Estimating the number of true null hypotheses and the false discovery rate from multiple discrete non-uniform permutation P-values

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Wei, Fengrong, High-dimensional regression with grouped variables

Department of Biostatistics

Breheny, Patrick, Regularized methods for high-dimensional and bi-level variable selection

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Sparks, JonDavid, Model selection criteria in the presence of missing data based on the Kullback-Leibler discrepancy

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Willis, Paulette, C^*-algebras of labeled graphs and $*$-commuting endomorphisms

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DEPARTMENT OF STATISTICS AND ACTUARIAL SCIENCE

Li, Jie, Spatial multivariate design in the plane and on stream networks

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KANSAS

Kansas State University (7)

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Malla, Ganesh, Order restricted inferences about lifetimes under censoring

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KENTUCKY

University of Kentucky (11)

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Kilty, Joel, L^p boundary value problems on Lipschitz domains

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Zhang, Ping, Iterative methods for computing eigenvalues and exponentials of large matrices

DEPARTMENT OF STATISTICS

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Louisiana State University, Baton Rouge (18)

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Chun, Carolyn, Unavoidable minors in graphs and matroids

Egedy, Charles, The extended picture group, with applications to line arrangement complements

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Fang, Liqun, Stochastic Navier-Stokes equations with fractional Brownian motions

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PROGRAM OF MATHEMATICS AND STATISTICS

Feng, Wu, On calculating residuated approximations and the structure of finite lattices of small width

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Tulane University (3)

DEPARTMENT OF BIOSTATISTICS

Hsueh, Ya-Hui, Extensions of flowgraph models with covariates: An application for kidney retransplantation

DEPARTMENT OF MATHEMATICS

Boettner, Stefan, Mixed transcendental and algebraic extensions for the Risch-Norman algorithm

Boindala, Priya Shilpa, New minimal representations of self-propelled swimmers in low Reynolds number regime using regularized fundamental solutions with applications to collective flow

University of Louisiana at Lafayette (7)

DEPARTMENT OF MATHEMATICS

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Johns Hopkins University (18)

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Nakama, Takehiko, Analysis of execution costs for QuickSelect

Reilly, Elizabeth, Random threshold graphs and related topics

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Department of Biostatistics

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McCall, Matthew, Preprocessing and barcoding of data from a single microarray

Myers, Jessica, Statistical methods for research in healthcare quality and safety from observational data

Reich, Nicholas, Statistical methods for incomplete data from infectious disease outbreaks

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Wu, Hao, Three novel statistical applications in genomics: Redefining CpG island, peak detection from multiple ChIP-chip experiments, and data pre-processing for ABI/SOLiD second generation sequencing technology

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Department of Mathematics

Banerjee, Romie, Real Johnson-Wilson theories and non-immersions of projective spaces

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Department of Mathematics and Statistics

Klein, Martin, Statistical analysis based on physiologically-based pharmacokinetic models

Moldovan, Melania M., A Gershgorin type theorem, spectral inequalities, and simultaneous stability in Euclidean Jordan algebras

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Vancea, Adrian, Infeasible interior point methods for sufficient linear complementarity

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Department of Applied Mathematics and Statistics, and Scientific Computing

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Blakely, Christopher, Meshless methods for elliptic boundary valued problems and the rotational shallow water equations on the sphere

Halper, Russell, On the routing and location of mobile facilities

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Nagem, Mohammed, Diagnostics for nonlinear mixed effects models

Quah, John, A macroscale perspective of near-equilibrium relaxation of stepped crystal surfaces

Wang, Wen-Chyi, Regularized variable selection in proportional hazards model using area under receiver operating characteristic criterion

White, James, Novel methods for metagenomic analysis

Xue, Fei, Numerical solutions of eigenvalue problems with spectral transformations

Zhang, Linbao, Multi-scale modeling and computations

Zhang, Shu, Mining of business data

Department of Mathematics

Adrian, Moshe, A new realization of the tame local Langlands correspondence for $\mathrm{GL}(n, F)$, n a prime

Agathocleous, Eleni, Class numbers of real cyclotomic fields of conductor pq

Chen, I-Kun, Spherical averaged endpoint Strichartz estimates for the two-dimensional Schrödinger equations with inverse square potential

De Simoi, Jacopo, Abundance of escaping orbits in a family of anti-integrable limits of the standard map

Halbert, James, A modified Zwanzig-Mori formalism

Hirn, Matthew, Enumeration of harmonic frames and frame based dimension reduction

Janicki, Ryan, Statistical inference based on estimating functions in exact and misspecified models

King, Emily, Wavelet and frame theory: Frame bound gaps, generalized shearlets, Grassmannian fusion frames, p-adic wavelets

Li, Qiaoluan, Optimal approximation spaces for solving problems with rough coefficients

Moore, Terrence, A theory of Cramer-Rao bounds for constrained parametric models

Ozdemir, Enver, Curves and their applications to factoring polynomials

Wang, Jun, Multivariate variance gamma processes and its applications in multi-asset option pricing

Wilson, Kevin, A Tannakian description for parahoric Bruhat-Tits group schemes

MASSACHUSETTS

Boston University (7)

Department of Mathematics and Statistics

Allen, Benjamin, Studies in the mathematics of evolution and biodiversity

Barendse, Peter, Improved necessary and sufficient conditions for the existence of a subtle cardinal

Farrington, Eleanor, Aspects of Klein's quartic curve

Holzer, Matthew, Renormalization group methods for singularly perturbed systems, normal forms and stability of traveling waves in a reaction-diffusion-mechanics system

Huang, Yifei, A principled statistical analysis of discrete context-dependent neural coding

Kostadinov, Kalin, Constructing an explicit modular symbol

Malerba, Paola, Excitation dominated or inhibition dominated: Different mechanisms behind rythmic interaction in a hippocampal model

Boston University School of Public Health (8)

Department of Biostatistics

Blood, Emily, Performance of mixed effects models in the analysis of mediated longitudinal data generated from a structural equation model

Du, Yangchun, Measuring effects of risk factors on cumulative incidence and remaining lifetime risk in the presence of competing risks

Lyass, Asya, Assessing if randomized treatment group should be included in the imputation model when imputing mission outcome data in randomized superiority clinical trials

Menon, Sandeep, Performance evaluation and operating characteristics of commonly used two stage adaptive designs and extension of the sample size calculation method to a Poisson endpoint

Rong, Jian, On weighted regression of time series for surveillance of influenza mortality

Yang, Mei, A Bayesian approach to bias correction in effect estimates due to disease misclassification: Applications in arthritis research

Young, Robin, Properties of hypothesis tests using generalized additive models with smoothers of geographic location in spatial statistics

Zhu, Yanyan, Stratified proportional odds models for multilevel ordinal data with application to a knee pain severity study

Brandeis University (3)

Department of Mathematics

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Radosevich, Mark, Concave symplectic fillings of spin contact 3-manifolds

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Lutz, Sharon, Modern approaches in association mapping

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Department of Mathematics

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Lee, Ji Oon, Lower bound for ground state energy of dilute Bose gas

Subotic, Aleksandar, A monoidal structure for the Fukaya category

van der Wyck, Frederick, Moduli of singular curves and crimping

Woo, Jeechul, Arithmetic of elliptic curves and surface: Descents and quadratic sections

Zaytman, Yevgeny, $K3$ surfaces of high Picard number and arithmetic applications

Department of Statistics

Baines, Paul, Statistics, science and statistical science: Modeling, inference and computation with applications to the physical sciences

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School of Engineering and Applied Science

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Hua, Xia, Testing regression models with residuals as data

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Osorno, Angelica, An infinite loop space structure for K-theory of bimonoidal categories

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Northeastern University (5)

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Banerjee, Anandam, Tensor structure on smooth motives

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Gonzalez, John, Unbounded solutions of the modified Korteweg-de Vries equations

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Yang, Shih Wei, Cluster algebras of finite type via semisimple groups and generalized minors

Tufts University (2)

Department of Mathematics

Burr, Meredith N., Continuous time random walks, their scaling limits and connections with stochastic integration

Wolf, Jamison Belfint, Random fractals and Levy processes

University of Massachusetts, Amherst (5)

Department of Mathematics

D'Ambroise, Jennie, Generalized FMP and nonlinear Schrödinger type reformulations of some scalar field cosmological models

Law, Kody, Existence, stability and dynamics of solitary waves in nonlinear Schrödinger models with periodic potentials

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Worcester Polytechnic Institute (2)

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Ni, Peng, Anderson acceleration of fixed point iteration with applications to electronic structure computations

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MICHIGAN

Central Michigan University (3)

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Michigan State University (9)

Department of Mathematics

Ay, Ahmet, Deciphering cis-regulatory transcriptional grammar in drosophila melanogaster by mathematical models

Coskun, Emre, The fine moduli space of representations of Clifford algebras

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Karakurt, Cagri, Some applications of the Giroux correspondence in low-dimensional topology

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Michigan Technological University (2)

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Cui, Xiaoqi, Identifying gene-gene interactions and transcription regulators via dimension reduction methods

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Oakland University (2)

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Andridge, Rebecca, Methods for missing data in complex sample surveys

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Liang, Liming, Efficient methods for analysis of genome scale data

Poisson, Laila, Integrative statistical methods for the analysis of transcriptomic and metabolomic data

Xiao, Rui, Statistical methods for genetic association studies

Zheng, Jin, Models and methods for genetic linkage and association analyses

Department of Mathematics

Ananyan, Tigran, Topics in tight closure theory

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Kinser, Ryan, Rank functors and representation of rings of quivers

Kutluhan, Cagatay, Floer homology and symplectic forms on $S^1 \times M^3$

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Magid, Aaron, Deformation spaces of Kleinian surface groups are not locally connected

Maleh, Ray, Fast sparse approximation algorithms for medical imaging

Metcalf-Burton, Jessica, Information rates for secret sharing over various access structures

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Department of Statistics

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Choi, Nam Hee, Investigation of smooth and non-smooth penalties for regularized model selection in regression

Gunter, Lacey, Variable selection for decision making

Katenka, Natallia, Statistical problems in wireless sensor networks

Kleyman, Yevgeniya, Testing for covariate balance in comparative studies

McGowan, Herle, Experimentation methodologies for educational research with an emphasis on the teaching of statistics

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Zhang, Aijun, Statistical methods in credit risk modeling

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Wayne State University (3)

Department of Mathematics

Nguyen, Son, Calculations towards the complex connective K-theory of QS^0

Shkembi, Armira, The cohomology of $A(1)$ and motivic connective K-theories

Zhu, Huiqing, Discontinuous Galerkin methods for singularly perturbed problems

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University of Minnesota-Twin Cities (24)

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Aschenbeck, Michael, A learning approach to detecting lung nodules in CT images

Berget, Andrew, Symmetries of tensors

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Chen, Guangliang, Spectral curvature clustering for hybrid linear modeling

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Hu, Jifeng, Mathematical modeling and analysis of in vitro actin filament dynamics and cell blebbing

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Ohio University, Athens (3)

Department of Mathematics

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University of Cincinnati (7)

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Oklahoma State University (6)

Department of Mathematics

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Portland State University (2)

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Texas Tech University (4)

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University of North Texas (4)

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Bradshaw, Robert, Provable computation of motivic L-functions

Card, Ryan, Brownian motion with boundary diffusion

Cross, Jonathan, Spectral abscissa optimization using polynomial stability conditions

Dundon, Ariana, Families of log canonically polarized varieties

Eaton, Julia, Variational properties of polynomial root functions and spectral functions

Finkel, Daniel, On the number of Fourier-Mukai partners of a K3 surface

Goff, Michael, Bounds on quantities related to simplicial complexes

Gutzwiller, Luke, Affine Schubert-like varieties in type A_n

Holman, Sean, Generic uniqueness in polarization tomography

Kantor, Joshua, Eleven dimensional supergravity on edge manifolds

Kirson, Antonio, Wild automorphisms and abelian varieties

Klee, Steven, Lower bound theorems for simplicial and cubical complexes

Kopp, Travis, Kodaira-Iitaka dimension on subvarieties

Lin, Qiuying, Sparsity and nonconvex nonsmooth optimization

Luoto, Kurt, Quasisymmetric functions and their applications

Rosoff, David, Toward mapping spaces of A-infinity categories

Winfree, Troy, Continuous homotopy fixed point spectra: Finiteness properties and computations

Xu, Liang, Merging trust-region and limited memory technologies for large-scale optimization

Zhang, Jun, Some developments in Artin-Schelter algebras

DEPARTMENT OF STATISTICS

Admiraal, Ryan, Models for heterogeneity in heterosexual partnership networks

Carnegie, Nicole, A comparison of alternative methodologies for estimating HIV incidence

Jiang, Yindeng, Factor model Monte Carlo methods for general fund-of-funds portfolio management

Krivitsky, Pavel, Statistical models for social network data and processes

Lenkoski, Alex, Bayesian model averaging and multivariate conditional independence structures

Ranjan, Roopesh, Combining and evaluating probabilistic forecasts

Seregin, Arseni, Convex analysis methods in shape constrained estimation

Washington State University (5)

DEPARTMENT OF MATHEMATICS

Eubanks, Sherod, Topics in nonnegative matrix theory

Kouznetsov, Andrei, Complex averages of particle quantities and equations of balance

Liu, Pengyu, Maximum likelihood estimation of an unknown change-point in the parameters of a multivariate Gaussian series with applications to environmental monitoring

Moyer, Nathan, Knapsack-type cryptographic system using algebraic number rings

Sun, Yannan, External dependence of multivariate distributions and its applications

WEST VIRGINIA

West Virginia University (3)

DEPARTMENT OF MATHEMATICS

Wang, Xiaofeng, Graph coloring and flows

Yan, Huiya, Hamiltonian line graphs and claw-free graphs

Zeng, Suxing, Numerical solutions of boundary inverse problems for some elliptic partial differential equations

WISCONSIN

Marquette University (1)

DEPARTMENT OF MATHEMATICS, STATISTICS AND COMPUTER SCIENCE

Sheng, Ru, Bayesian approach to hypothesis testing problems with skewed alternatives

University of Wisconsin, Madison (32)

DEPARTMENT OF MATHEMATICS

Bae, Myoungjean, Potential flow and transonic shocks

Berliner, Adam, Determinants, permanents, and the enumeration of forest partitions

Daugherty, Zajj, Degenerate two-boundary centralizer algebras

Davis, Matt, Representations of rank two affine Hecke algebras at roots of unity

Deatt, Louis, The positive semi-definite minimum rank of a triangle-free graph

Ellison, Benjamin, Boolean indexed models and Wheeler's conjecture

Huang, Hongnian, Calabi flow on toric variety

Hubler, Shane, Mathematical analysis of mass spectrometry data

Joseph, Mathew, Some problems in random walks in random environment

Kazalicki, Matija, Some topics in the theory of modular forms and Drinfeld modular forms

Kim, Hanjun, On generations of mirror pairs of Calabi-Yau varieties

Kumar, Rohini, Current fluctuations for independent random walks

Li, Qian, Large scale computing for complementarity and variational inequalities

Remmel, Mark, New models for rotating shallow water Boussinesq equations by subsets of mode interactions

Turetsky, Daniel, Effective algebra and effective dimension

Turkelli, Seyfi, Hurwitz schemes and density of discriminants

Yip, Martha, Combinatorics of Macdonald polynomials

Zhu, Keya, Global regularity of Schrödinger maps into the hyperbolic plane H2 in dimensions d greater than or equal to 3

Department of Statistics

Burgette, Lane, Essays on three Bayesian prior distributions

Choi, Younjeong, Statistical methods for gene set correlation analysis

Hu, Xing (James), False discovery rate control with groups

Jiang, Deyuan, Semiparametric likelihood methods for longitudinal data with nonignorable nonresponse

Kuan, Pei-Fen, Statistical methods for the analysis of genomic data from tiling arrays and next generation sequencing technologies

Ma, Xiwen, Penalized likelihood regression with randomized covariate data

Neely, William, Statistical theory for respondent driven sampling

Shim, Heejung, Bayes CAT: Bayesian co-estimation of alignment and tree

Shinki, Kazuhilo, Topics in asymptotic theory for GARCH-type models

Tang, Rui, Sparse moving maxima models for extreme dependence in multivariate financial time series

Wang, Ping, Statistical methods for microarrays and eQTL mapping

Yu, Tao, Local tests for detecting human brain isotropy-anisotropy areas on DT-MRI

Zhang, Yulin, Joint modeling of longitudinal biomarkers and panel counts data

Zheng, Wei, Quantile regression trees, statistical applications of CUDA programming and identification of active effects without sparsity assumption

University of Wisconsin, Milwaukee (5)

Department of Mathematical Sciences

Bae, Ju Youn, Estimation of the additive genetic covariance function

Dornheim, Harald, Robust-efficient fitting of mixed linear models: Theory, simulations, actuarial extensions, and examples

Janssen, Britta, An efficient exponential time differencing method for nonlinear reaction diffusion problems

Kleefeld, Andreas, Direct and inverse acoustic scattering for three-dimensional surfaces

Zarrouk, Mazen, Analysis of truncated incomplete Hessian Newton minimization method and application in biomolecular simulations

WYOMING

University of Wyoming (2)

Department of Mathematics

May, Daniel, Mutually unbiased bases

Department of Statistics

Chatterjee, Arunendu, Detection of change points using wavelet analysis

FROM THE
AMS SECRETARY

ATTENTION ALL
AMS MEMBERS

Voting Information for 2011 AMS Election

AMS members who have chosen to vote online will receive an email message on or shortly after August 17, 2011, from the AMS Election Coordinator, Survey & Ballot Systems.

The From Line will be "AMS Election Coordinator," the Sender email address will be amsvote@directvote.net, and the Subject Line will be "AMS 2011 Election - login information below."

The body of the message will provide your unique voting login information and the address (URL) of the voting website. If you use a spam filter you may want to use the above address or subject information to configure your spam filter to ensure this email will be delivered to you.

AMS members who have chosen to vote by paper should expect to receive their ballot by the middle of September. Unique voting login information will be printed on the ballot, should you wish to vote online.

At midnight (U.S. Eastern Daylight Time) on November 4, 2011, the website will stop accepting votes. Paper ballots received after this date will not be counted.

Additional information regarding the 2011 AMS Election is available on the AMS website:
www.ams.org/about-us/governance/elections/election-info;
or by contacting the AMS: election@ams.org, 800-321-4267 (US & Canada), 401-455-4000 (worldwide).

Thank you and . . . please remember to vote.

Robert J. Daverman

AMS
American Mathematical Society
ams.org

From the AMS Secretary

Report of the Executive Director, State of the AMS, 2011

When I report to the Council in April, I try to give a broad overview of highlights of the Society's activities in the preceding year. The current report contains such an overview, and it includes, in addition, some retrospective comments about the impact on the AMS and the mathematics community of global economic conditions since the third quarter of 2008.

The year 2010 was a very busy one for the Society in all of its principal areas of activity. I shall highlight a number of specific accomplishments in publishing, professional programs and services, meetings, and advocacy for the mathematics community.

The Economy

There are at least three ways that the unsettled world economy of the last two and a half years has affected the AMS.

1. Our individual members, predominantly from academic positions in mathematical sciences, have been severely affected by reduced public funding for higher education institutions and by the effects of financial markets on the value of college and university endowments.
2. Research libraries, a principal part of the customer base for AMS journals, books, and *Mathematical Reviews*, have suffered from reduced budgets for acquisitions.
3. The Society's long-term investment portfolio fell by about 30 percent in the fall of 2008, and the portion of the portfolio whose spendable income supports programs and services for the mathematics community fell by 50 percent during the same period.

The state of the economy increased the importance of some of the professional services provided by the AMS, especially employment services. At the Joint Mathematics Meetings, special forums were conducted to provide information about rewarding nonacademic career opportunities and the process of applying for all types of jobs. `MathJobs.org` and EIMS worked to make information about open positions known to job seekers.

The American Association of University Professors (AAUP) reports that average faculty salaries rose only 1.4 percent from 2009–10 to 2010–11 and that average pay actually decreased at 30 percent of colleges and universities. The impact on faculty has been much more severe than on employees in other professions, where increases have averaged more than 2.5 percent during the same time period.

Libraries, already suffering from spiraling journal prices over the past twenty years, have had to adjust to reduced budgets as institutions adapt to decreased revenues.

In support of the libraries and our individual members, the Society froze subscription prices in 2010 at 2009 levels and froze individual dues in 2011 at 2010 levels. We have also worked to help individual libraries reduce their subscription expenditures by converting paper subscriptions to electronic ones. At the same time, we took steps to reduce our own expenses so that we could maintain high levels of support for programs and services.

Two years ago when I made my report to the Council, the state of our own long-term investment portfolio was relatively grim. It had fallen from $74M at the end of 2007 to $52M at the end of 2008. The decline had implications for operating revenues. A portion of the long-term portfolio referred to as the Operations Support Fund (OSF) generates spendable income every year that is used for service and outreach programs; the spendable income in any given year is 5 percent of a trailing average of year-end balances in the OSF. The OSF at the end of 2007 was $40.8M and fell to $20.1M at the end of 2008. If that lower balance had persisted, it would have eventually turned into a loss of $1M in annual spendable income.

Fortunately, the long-term portfolio and the OSF have rebounded. At the end of 2010, the long-term portfolio, through additions and strong investment returns in 2009 and 2010, had rebounded to $79M. The following table reports the OSF balances and the spendable income since 2007.

Year	Year-End OSF Balance	OSF Spendable Income
2007	$40.8 million	$0.72 million
2008	$20.1 million	$1.04 million
2009	$35.1 million	$1.40 million
2010	$43.6 million	$1.45 million
2011	TBD	$1.65 million

Highlights of 2010 Activities

2010 was a year of successes and challenges. Here are some highlights of the Society's programs and services.

Journals

In May 2010 the AMS completed its research journal retro-digitization project. The generosity of a private donor supported digitization of the four primary research journals—*Journal of the AMS*, *Transactions of the AMS*, *Proceedings of the AMS* and *Mathematics of Computation*—back to volume 1, issue 1. The oldest of these journals, *Transactions*, dates from 1900. Over 350,000 pages were scanned and then processed by OCR to create a searchable text layer in the final pdf file of each article. In addition, reference lists were keyed and links to MathSciNet were added. The quality of the files is outstanding.

All of these articles were made freely available to the worldwide mathematics community. This is a great service in support of mathematics research and was applauded by librarians. It was also highlighted in announcements made by the International Mathematical Union at ICM2010.

The four primary research journals published a total of 873 articles in 2010.

In October of 2010 the Committee on Publications completed its quadrennial review of the primary research journals. Many aspects of the journals were analyzed. One interesting feature indicates how truly international journal publishing has become. The following table shows where the authors of articles published in AMS journals in the years 2006–2009 live.

	JAMS	TAMS	PAMS	MathComp
U.S.A.	55.9%	36.1%	31.0%	25.5%
Canada	3.9%	4.0%	4.2%	5.3%
Europe	28.3%	39.7%	35.7%	45.1%
Asia & Asia Pacific	10.0%	16.4%	23.7%	21.0%
Other	1.9%	3.8%	5.4%	3.1%

Author[1] domiciles for articles published in 2006–2009.

Mathematical Reviews

Mathematical Reviews (MR) observed its seventieth anniversary in January 2010.

During 2010 MR added 152,103 new items to the MR database. Of these, over 79,000 included reviews.

The literature covered by MR has grown substantially over the last decade. MR follows over 1,900 journals; 774 of these are so-called cover-to-cover journals, in which every article is deemed to have mathematics research content. In publication year 2000, 56,985 journal articles were published in all of the journals MR follows. By publication year 2009, the number of journal articles had grown to 77,969, an increase of 37 percent.

The new release of MathSciNet in October 2010 incorporated a major technical enhancement. MathSciNet now uses MathJax, which renders mathematical expressions set in LaTeX to be viewed through any common browser. The development of MathJax was supported by the AMS, SIAM, and Design Science. The software is open source and is now being widely adopted and supported by scientific publishers and others interested in communicating math on the Web.

Late in 2010 MR completed an agreement with ProQuest to incorporate bibliographic information about Ph.D. theses in the MR database. The entries in the MR database have links to the theses per se in the ProQuest database. Over 59,000 theses were added when the first delivery of data was received from ProQuest.

Books

The AMS now has over 3,000 books in print, including classical works, research monographs, textbooks, and books of general interest.

In 2010 a number of outstanding titles were published, including the second edition of *Partial Differential Equations* by Lawrence C. Evans. Two new titles were added to the AMS Pure and Applied Mathematics Texts series founded by Paul J. Sally Jr. A total of one hundred new books were published in 2010.

Two significant developments are currently in progress. Over 2,000 AMS books have been scanned by Google and have cleared a contractual review to assure that the AMS has the necessary rights and permissions to publish them electronically. They are being released selectively as Google eBooks. Second, preparations are being made to license Contemporary Mathematics as an electronic subscription publication starting in 2012. We will then plan to prepare the entire Contemporary Mathematics backlist, more than 500 volumes, as an electronic bundle.

Meetings

The year started with the Joint Mathematics Meetings in San Francisco. Over 5,300 individuals registered for JMM2010.

In addition, the Society held eight Sectional Meetings, a joint meeting in June with the Sociedad Matemática Mexicana, and a joint meeting in December with the Sociedad de Matemática de Chile. A highlight of the fall sectional meeting at UCLA was the Einstein Lecture presented by Terence Tao. The mathematics department at UCLA did a great job of publicizing Tao's lecture, "The Cosmic Distance Ladder". The lecture attracted over 900 attendees. The Meetings Department also managed arrangements for three weeks of Mathematics Research Communities at Snowbird, Utah.

Programs for Early-Career Mathematicians

The 2010 Mathematics Research Communities (MRC) summer conferences were held at the Snowbird Resort in Utah, June 12–July 2. The three week-long conferences drew 120 early-career mathematicians. The principle aim of MRC

[1] *For multiauthor papers, the domicile of the corresponding author was used.*

MRC 2010 Conference on Birational Geometry and Moduli Spaces.

is to foster the formation of networks of mathematical scientists at the beginning of their careers.

Each MRC is organized by senior researchers around a topic of shared interest. One of the 2010 topics, for example, was "Birational Geometry and Moduli Spaces". Postdocs and advanced graduate students are invited to apply for the program and are selected based on evaluation of their applications by senior organizers.

The main components of the MRC program are a one-week summer conference, a Special Session at the Joint Mathematics Meetings the following January, a mechanism to foster continuing Internet-based communications, and ongoing mentoring from senior colleagues. The initial summer conference is the cornerstone of the program. Within the broad goals of stimulating communication of each participant's interests and forging connections, the format of each summer conference is left up to the organizers.

In 2010 the NSF funding for Mathematics Research Communities was renewed for three more years, 2011 to 2013.

The AMS continued to provide travel grants for graduate students to attend JMM2010 and JMM2011. This special program has continued to grow substantially and is made possible by a private donor. In 2010 approximately eighty students were supported to travel to San Francisco. In January 2011 over one hundred students were supported to attend JMM in New Orleans. In addition, the donor provided additional support in 2010 that has made it possible to expand the program to support travel to the AMS sectional meetings.

New funding was received in November from the Simons Foundation to support research travel grants for early-career mathematicians. The program has been launched to make the first grants in 2011. Each grant recipient will be funded for two years and will have up to \$2,000 per year to reimburse research-related travel. Funding has been granted to support sixty new recipients in each of the three years 2011 to 2013. Both the AMS and the Simons Foundation feel that the travel grant program fills a gap between the AMS travel grants for graduate students and the Simons Foundation Collaboration Grants for mathematicians who are several years past their Ph.Ds.

Public Awareness and Advocacy for Mathematics

JMM2010 in San Francisco was the venue for the first national Who Wants to Be a Mathematician game. The national game was supported largely by private donations. The champion, Evan O'Dorney of Danville, California, went on to distinguish himself in the International Mathematics Olympiad in summer 2010 by placing second in the individual rankings.

The 2010 Arnold Ross Lecture was presented by Thomas C. Hales, Mellon Professor of Mathematics at the University of Pittsburgh. Hales's presentation, titled "Can Computers Do Math?", was about packing problems, giving their history and why they are important in modern mathematics, and their applications. The purpose of this series of lectures for talented high school mathematics students is to stimulate their interest in mathematics beyond the traditional classroom and to show them the tremendous opportunities for careers in mathematics—as mathematics teachers and as researchers in government, industry, and university programs. The lectures are intended to illustrate some recent development in mathematical research.

The 2009–10 AMS-sponsored Congressional Fellow was Katherine Crowley of Washington and Lee University, who served in the office of Senator Al Franken of Minnesota. The American Mathematical Society, in conjunction with the American Association for the Advancement of Science (AAAS), sponsors a Congressional Fellow each year who spends the year working on the staff of a member of Congress or a congressional committee, working as a special legislative assistant in legislative and policy areas requiring scientific and technical input. The program includes an orientation on congressional and executive branch operations and a year-long seminar series on issues involving science, technology, and public policy.

On October 12, 2010, the AMS hosted a briefing on Capitol Hill entitled "The Gulf Oil Spill: How Can We Protect Our Beaches in the Future?" Andrea Bertozzi, professor of mathematics at UCLA, delivered the address to congressional representatives. Bertozzi talked about how scientific modeling and basic research in mathematics are helping us to understand the impact of this major environmental problem. Her research examines the dynamics of oil-sand-water mixtures in an effort to provide more efficient clean-up and protection methods for oil spills like the one that occurred in the Gulf of Mexico in 2010.

—Don McClure
Executive Director

Mathematics Calendar

Please submit conference information for the Mathematics Calendar through the Mathematics Calendar submission form at http://www.ams.org/cgi-bin/mathcal-submit.pl.
The most comprehensive and up-to-date Mathematics Calendar information is available on the AMS website at http://www.ams.org/mathcal/.

August 2011

* 1–12 **Summer Graduate Workshop: Cluster Algebras and Cluster Combinatorics**, Mathematical Sciences Research Institute, Berkeley, California.
Description: Cluster algebras are a class of combinatorially defined rings that provide a unifying structure for phenomena in a variety of algebraic and geometric contexts. A partial list of related areas includes quiver representations, statistical physics, and Teichmuller theory. This summer workshop for graduate students will focus on the combinatorial aspects of cluster algebras, thereby providing a concrete introduction to this rapidly-growing field. Besides providing background on the fundamentals of cluster theory, the summer school will cover complementary topics such as total positivity, the polyhedral geometry of cluster complexes, cluster algebras from surfaces, and connections to statistical physics. No prior knowledge of cluster algebras will be assumed. The workshop will consist of four mini-courses with accompanying tutorials. Students will also have opportunities for further exploration using computer packages in Java and Sage. Attendance in this workshop is by nomination only.
Information: http://www.msri.org/web/msri/scientific/workshops/summer-graduate-workshops/show/-/event/Wm550.

* 2–4 **Workshop on Positivity: Positivity in the classification of operator algebras and dynamical systems, in finite- and infinite-dimensional linear algebra, and its outgrowths**, The Fields Institute for Research in Mathematical Sciences, Toronto, Ontario, Canada.
Description: The notion of positivity, whose study is motivated by deep questions in operator algebras, has important applications in a large number of areas of mathematics. These research directions and their outgrowths have been and remain particularly active in Canada, with David Handelman having been a major contributor over past decades. The workshop is timed to mark David's 60th birthday.
Support: There will be partial financial support available for graduate students and postdocs, with Friday, May 27, 2011 as the deadline for applications and the funding decision made immediately afterwards.
Information: http://www.fields.utoronto.ca/programs/scientific/11-12/positivity/.

* 18–19 **Connections for Women in Quantitative Geometry**, Mathematical Sciences Research Institute, Berkeley, California.
Description: This workshop will provide an introduction to the program on Quantitative Geometry. There will be several short lecture series, given by speakers chosen for the accessibility of their lectures, designed to introduce non-specialists or students to some of the major themes of the program.
Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm572.

* 22–24 **The 36th Sapporo Symposium on Partial Differential Equations**, Department of Mathematics, Hokkaido University, Sapporo, Japan.
Description: The Sapporo Symposium on Partial Differential Equations has been held annually to present the latest developments on PDE with a broad spectrum of interests not limited to the methods of a particular school. This year the invited speakers are: Hua Chen (Wuhan University, Kyoto University); Slim Ibrahim (University of Victoria); Chun Liu (The Pennsylvania State University); Tomoyuki Miyaji (Kyoto University); Yoshinori Morimoto (Kyoto University); Hirokazu Ninomiya (Meiji University); Masahito Ohta (Saitama University); Norbert Pozar (University of California, Los Angeles); Okihiro Sawada (Gifu University); Keisuke Takasao (Hokkaido University); Michio Yamada (Kyoto University); Yusuke Yamauchi (Waseda University).

This section contains announcements of meetings and conferences of interest to some segment of the mathematical public, including ad hoc, local, or regional meetings, and meetings and symposia devoted to specialized topics, as well as announcements of regularly scheduled meetings of national or international mathematical organizations. A complete list of meetings of the Society can be found on the last page of each issue.
An announcement will be published in the *Notices* if it contains a call for papers and specifies the place, date, subject (when applicable), and the speakers; a second announcement will be published only if there are changes or necessary additional information. Once an announcement has appeared, the event will be briefly noted in every third issue until it has been held and a reference will be given in parentheses to the month, year, and page of the issue in which the complete information appeared. Asterisks (*) mark those announcements containing new or revised information.
In general, announcements of meetings and conferences carry only the date, title of meeting, place of meeting, names of speakers (or sometimes a general statement on the program), deadlines for abstracts or contributed papers, and source of further information. If there is any application deadline with respect to participation in the meeting, this fact should be noted. All communications on meetings and conferences in the mathematical sciences should be sent to the Editor of the *Notices* in care of the American Mathematical Society in Providence or electronically to notices@ams.org or mathcal@ams.org.
In order to allow participants to arrange their travel plans, organizers of meetings are urged to submit information for these listings early enough to allow them to appear in more than one issue of the *Notices* prior to the meeting in question. To achieve this, listings should be received in Providence **eight months** prior to the scheduled date of the meeting.
The complete listing of the Mathematics Calendar will be published only in the September issue of the *Notices*. The March, June/July, and December issues will include, along with new announcements, references to any previously announced meetings and conferences occurring within the twelve-month period following the month of those issues. New information about meetings and conferences that will occur later than the twelve-month period will be announced once in full and will not be repeated until the date of the conference or meeting falls within the twelve-month period.
The Mathematics Calendar, as well as Meetings and Conferences of the AMS, is now available electronically through the AMS website on the World Wide Web. To access the AMS website, use the URL: http://www.ams.org/.

Information: http://www.math.sci.hokudai.ac.jp/sympo/sapporo/program_en.html.

* 22–26 **Introductory Workshop on Quantitative Geometry**, Mathematical Sciences Research Institute, Berkeley, California.
Description: Quantitative Geometry deals with geometric questions in which quantitative or asymptotic considerations occur. The workshop will provide a mathematical introduction, a foretaste, of the many themes this exciting topic comprises: geometric group theory, theory of Lipschitz functions, large scale and coarse geometry, embeddings of metric spaces, quantitative aspects of Banach space theory, geometric measure theory and of isoperimetry, and more.
Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm573.

* 30–September 3 **The 7th William Rowan Hamilton Geometry and Topology Conference on "The Geometry and Dynamics of Teichmüller Spaces"**, The Hamilton Mathematics Institute, Trinity College, Dublin, Ireland.
Description: The 7th William Rowan Hamilton Geometry and Topology Workshop is a directed workshop on "The Geometry and Dynamics of Teichmüller Spaces". This year, the workshop will consist of a mini-course August 30–31, followed by a three-day lecture series Thursday, September 1, through Saturday, September 3, 2011.
Information: http://www.hamilton.tcd.ie/events/gt/gt2011.htm.

September 2011

* 1–3 **26th British Topology Meeting**, ICMS, South College Street, Edinburgh, England.
Description: The 26th annual British Topology Meeting will take place at ICMS in Edinburgh September 1-3, 2011.
Invited speakers: Javier Aramayona (Galway), Stefan Friedl (Cologne), Jacob Rasmussen (Cambridge), Saul Schleimer (Warwick), Catharina Stroppel (Bonn), Ulrike Tillmann (Oxford) and Karen Vogtmann (Cornell).
Registration: Participants are required to register by August 1, 2011. See http://www.maths.gla.ac.uk/~ajb/btop/btop-meetings.html| for a list of previous British Topology Meetings.
Organizer: Jim Howie (Heriot-Watt) and Andrew Ranicki (Edinburgh).
Information: http://www.icms.org.uk/workshops/btm.

* 2–6 **Polynomial Identities in Algebras. II.**, Memorial University of Newfoundland, St. John's, NL, Canada.
Description: The workshop is organized by Atlantic Algebra Centre and financially supported by Atlantic Association for Research in the Mathematical Sciences and Memorial University of Newfoundland. The first workshop under the same title was held at Memorial University of Newfoundland in August – September 2002. Since then the theory of polynomial identities in algebra has experienced a strong development. A number of problems have been solved. New methods have been introduced, in particular, the methods developed in the theory of group gradings of associative, Lie and Jordan algebras. In addition to traditional combinatorial methods, people working on polynomial identities make more frequent use of the representation theory, the theory of Hopf algebras, and techniques involving computers. The aim of this workshop is to survey the main achievements in the area for the last 9 years, discuss the current progress and to determine future directions and outstanding problems.
Information: http://www.mun.ca/aac/Workshops/Next-Work/.

* 6–9 **VI International Meeting on Lorentzian Geometry. Granada 2011**, Science Faculty, University of Granada, Granada, Spain.
Description: Lorentzian Geometry was born as a mathematical theory useful for General Relativity. Nowadays, it constitutes a branch of Differential Geometry where many mathematical techniques are involved (Lie groups and algebras, Partial Differential Equations, Geometric Analysis, Functional Analysis,...). This meeting is the sixth edition of a biennial series which started in 2001.
Topics: On pure and applied Lorentzian Geometry such as geodesics, submanifolds, causality, black holes, Einstein equations, geometry of spacetimes or AdS-CFT correspondence, will be covered. The meeting will include two minicourses imparted by professors Vladimir Chernov (Dartmouth College, USA) and Paolo Piccione (University of Sao Paulo, Brazil).
Information: http://gigda.ugr.es/gelogra/.

* 12–16 **ISAM-TopMath Summer School 2011: Variational Methods**, Technische Universitaet, Muenchen, Germany.
Description: This is a joint summer school of ISAM (International School of Applied Mathematics) and TopMath on `Variational Methods' open to graduate students and postdocs. A line-up of speakers who are both outstanding researchers and excellent presenters will give state-of-the-art insight into – variational evolution problems (Mielke/Berlin) – optimal transport (Sturm/Bonn) – optimal control of PDE (Casas/Santander) and – applications in materials science (Ortiz/CalTech). A limited amount of funding is available.
Information: http://www.ma.tum.de/Mathematik/IsamSummerSchoolEn.

* 12–16 **Summer School on Partial Differential Equations**, Märkisches Gildehaus, Caputh, Germany.
Description: The aim of the Summer School is to offer young scholars the possibility to get an introduction to recent developments in partial differential equations and their applications by distinguished international experts. Lecture series are given by G. Huisken (MPI Golm), R. Klein (FU Berlin), H. Kozono (Tohoku), F. Otto (MPI Leipzig). The school addresses students working towards a Master's degree or a Ph.D. Young postdocs are also welcome. Scholarships are available which cover travel expenses and accommodation. For application details, please visit the website.
Information: http://www.math-conf.uni-hannover.de/pde11.

* 18–21 **2011 Federated Conference on Computer Science and Information Systems (FedCSIS)**, Szczecin, Poland.
Call for Papers: Papers should be submitted by June 19th, 2011, using the FedCSIS EasyChair submission system: http://www.easychair.org/account/signin.cgi?conf=fedcsis2011. Accepted and presented papers will be published in the IEEE Xplore Digital Library proceedings entitled: "2011 Federated Conference on Computer Science and Information Systems (FedCSIS)." The IEEE proceedings will be published under nonexclusive copyright. The events' organizers arrange quality journals, edited volumes, etc. and will invite extended and revised papers for post-conference publications (information can be found at the web-sites of individual events).
Information: http://www.fedcsis.org.

* 19–23 **Probabilistic Reasoning in Quantitative Geometry**, Mathematical Sciences Research Institute, Berkeley, California.
Description: "Probabilistic Reasoning in Quantitative Geometry" refers to the use of probabilistic techniques to prove geometric theorems that do not have any a priori probabilistic content. A classical instance of this approach is the probabilistic method to prove existence of geometric objects. Other examples are the use of probabilistic geometric invariants in the local theory of Banach spaces, the more recent use of such invariants in metric geometry, probabilistic tools in group theory, the use of probabilistic methods to prove geometric inequalities, the use of probabilistic reasoning to prove metric embedding results such as Bourgain's embedding theorem, probabilistic interpretations of curvature and their applications, and the use of probabilistic arguments in the context of isoperimetric problems.
Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm574.

* 26–30 **Function Spaces, Weights, and Variable Exponent Analysis**, Centre de Recerca Matemàtica (CRM), Bellaterra, Barcelona, Spain.
Description: The conference is aimed to discuss the current state of the theory of function spaces. In particular, the conference will cover the following topics: Function Spaces of Real Variables (Lebesgue, Lorentz, Orlicz, Sobolev, Nikol'skii-Besov, Lizorkin-Triebel, Morrey, Campanato), Embedding/Duality/Extension theorems, Weights, Weighted inequalities, generalized Lebesgue-Sobolev spaces of variable order. The main topics planned include: 1. Mapping properties of the main operators of harmonic analysis in the classical (Lebesgue, Lorentz, Orlicz, Sobolev, Morrey) spaces and the variable exponent Lebesgue spaces. 2. Spaces with weights, properties of weighted classes, boundedness of operators in the weighted spaces. 3. Approximation theory problems in various function spaces. 4. Spaces of functions with Hölder exponent varying from point to point.
Information: `http://www.crm.cat/cspaces/`.

October 2011

* 1–2 **History and Pedagogy of Mathematics (HPM), Americas Section 2011, West Coast Meeting**, Point Loma Nazarene University, San Diego, California.
First Notice and Call for Papers: HPM seeks a variety of talks on the history of mathematics, the teaching of mathematics, and the history of teaching mathematics. Talks directly relevant to mathematics classrooms are especially welcome. Talks will be 30-40 minutes long.
Information: Prospective speakers should send a title and abstract, as well as their own contact information to Kathy Clark at: `drkclark@gmail.com`. Further details on this meeting should be available by midsummer. For now, please Save the Date. For updated information check, and to read about past meetings, see `http://www.hpm-americas.org`.

* 3–7 **Geometric structures on complex manifolds**, Laboratory of Algebraic Geometry, Higher School of Economics, Moscow, Russia.
Description: Differential-geometric structures play an important role in the study of complex geometry. After Kodaira, Kaehler structures became central in the study of deformation theory and the classification problems. More recently, the non-Kaehler metrics on complex manifolds started to be important in string theory. The manifolds with special holonomy become central in string theory due to advances in supersymmetry. The notion of calibrations, due to Harvey and Lawson, gives a unifying differential-geometric mechanism encompassing the complex geometry and its many generalizations to quaternionic and octonionic domains. We are planning to bring together specialists on complex geometry, potential theory and calibrations, to explore the recent advances in differential geometry of complex manifolds.
Information: `http://bogomolov-lab.ru/GS/`.

* 19–21 **Celebration of Mathematical Sciences in Commemoration of the Centennial of the Birth of Shiing-Shen Chern**, Institute of Mathematics, Academia Sinica, 6F, Astronomy-Mathematics Building, No. 1, Sec. 4, Roosevelt Road, Taipei, Taiwan 10617.
Description: Professor Shiin-Shen Chern was one of the founding fathers of the Institute of Mathematics of the Academia Sinica, and had remained one of its leading supporters his entire life. On the occasion of his 100th birthday, the Institute of Mathematics, Academia Sinica, Taipei, will hold the international conference "Celebration of Mathematical Sciences in Commemoration of the Centennial of the Birth of Shiing-Shen Chern."
Plenary speakers: Luis Caffarelli (Texas), Jih-Hsin Cheng (Academia Sinica), Kenji Fukaya (Kyoto), Gerhard Huisken (Max Planck), Maxim Kontsevich (IHES), Ko-Wei Lih (Academia Sinica), Richard Schoen (Stanford), Yum-Tong Siu (Harvard), Chuu-Liang Terng (UC Irvine), Cedric Villani (Institute H. Poincare). Scientific committee: K. Fukaya (Kyoto), T.-P. Liu (Academia Sinica), R. Schoen (Stanford), Y.-T. Siu (Harvard).
Local organizing committee: J.-H. Cheng (Academia Sinica), J.-N. Wang (NTU), C. Chen (NCTU), M.-K. Chuah (NTHU), R.-L. Sheu (NCKU).
Information: `http://www.math.sinica.edu.tw`.

* 19–21 **Celebration of Mathematical Sciences in Commemoration of the Centennial of the Birth of Shiing-Shen Chern**, Institute of Mathematics, Academia Sinica, 6F, Astronomy-Mathematics Building, No. 1, Sec. 4, Roosevelt Road, Taipei, Taiwan 10617.
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Information: `http://www.math.sinica.edu.tw`.

* 21–22 **National Conference on "Role of Mathematical and Physical Sciences in Engineering and Technology"**, Government Degree College Karanprayag (Chamoli), Uttarakhand, India.
Description: The conference provides a unique opportunity for in-depth technical discussions and exchange of ideas in mathematical and physical sciences, as well as their role in natural and social sciences, engineering and technology, industry and finance. It offers to researchers, industrialists, engineers and students from different parts of the country as well as from the remote part of the Uttarakhand state to present their latest research, to interact with the experts in the field, and to foster interdisciplinary collaborations required to meet the challenges of modern science, technology, and society.
Information: `http://sites.google.com/site/drgauraviitr/homepage/activities`.

* 22–24 **The 5th International Conference on Research and Education in Mathematics (ICREM5)**, Institut Teknologi Bandung, Bandung, Indonesia.
Description: The International Conference on Research and Education in Mathematics (ICREM) is a biennial conference, started in 2001. It covers all aspects of mathematical sciences as well as mathematical education. It is jointly organized by Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Institute for Mathematical Research, Universiti Putra Malaysia INSPEM), and Institute of Mathematics, Vietnam Academy of Science & Technology (IMVAST).
Keynote Speaker: Cedric Villani (Institute Henri Poincare, France), Fields Medalist 2010, supported by International Mathematics Union (IMU); Abdus Salam International Centre for Theoretical Physics (ICTP); United Nations Educational, Scientific and Cultural organization (UNESCO); Indonesian Combinatorial Society (InaCombS); and Indonesian Mathematical Society (IndoMS) (IndoMS).
Information: `http://www.math.itb.ac.id/~icrem5/`.

* 30–November 5 **Chern Centennial Conference**, Mathematical Sciences Research Institute, Berkeley, California.
Description: The Mathematical Sciences Research Institute (MSRI) in conjunction with the Chern Institute of Mathematics (CIM) in Tianjin, China, celebrates the centennial of the birth of Shiing-Shen Chern, one of the greatest geometers of the 20th century and MSRI's co-founder. In commemoration of Chern's work, MSRI and CIM will implement an international mathematics conference. During the first week, October 24 to 28, 2011, the conference will take place at

CIM in Tianjin, China and during the second week, October 30 to November 5, 2011, the conference will be at the MSRI in Berkeley, USA.
Information: Further information about the first week at CIM can be found here: `http://www.nim.nankai.edu.cn/activites/conferences/Chern-Centennial-20111024/index.htm`. For general information visit: `http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm555`.

December 2011

* 12–16 **ICREA Conference on Approximation Theory and Fourier Analysis**, Centre de Recerca Matemàtica (CRM), Bellaterra, Barcelona, Spain.
Description: The key idea of the conference is the interdisciplinary connection between Fourier Analysis and Approximation Theory. The main goal of this conference is to reveal new (and clarify known) relations between problems and methods of Fourier Analysis and Approximation Theory and to promote the integration of these areas.
Information: `http://www.crm.cat/icreaapproximation`.

January 2012

* 16–20 **Introductory Workshop: Lattice Models and Combinatorics**, Mathematical Sciences Research Institute, Berkeley, California.
Description: Research at the interface of lattice statistical mechanics and combinatorial problems of "large sets" has been an exciting and fruitful field in the last decade or so. In this workshop we plan to develop a broad spectrum of methods and applications, spanning the spectrum from theoretical developments to the numerical end. This will cover the behaviour of lattice models at a macroscopic level (scaling limits at criticality and their connection with SLE) and also at a microscopic level (combinatorial and algebraic structures), as well as efficient enumeration techniques and Monte Carlo algorithms to generate these objects.
Information: `http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm578`.

February 2012

* 13–17 **Conference and MAGMA Workshop on "Symmetries of Discrete Objects"**, Rydges Lakeland Resort Hotel, Queenstown, New Zealand.
Description: This event will be a combination of a research conference on symmetries of discrete objects (such as graphs, maps/dessins, polytopes, Riemann surfaces and other complexes), and a MAGMA workshop, including some instructional courses (well suited for graduate students) on the MAGMA package and its capabilities (especially for handling discrete structures and their automorphisms). The aim of the conference is to bring together researchers working in various inter-related fields, introduce their approaches and discoveries to one another, and to promote joint research in and between these fields. To achieve this we will have a small number of keynote talks, several contributed talks, at least one open problem session, and ample time for discussions and problem solving. Anyone with interest in automorphisms of discrete structures is welcome to consider attending.
Information: `http://www.math.auckland.ac.nz/~conder/SODO-2012/`.

* 20–24 **Percolation and Interacting Systems**, Mathematical Sciences Research Institute, Berkeley, California.
Description: Over the last ten years there has been spectacular progress in the understanding of geometrical properties of random processes. Of particular importance in the study of these complex random systems is the aspect of their phase transition (in the wide sense of an abrupt change in macroscopic behavior caused by a small variation in some parameter) and critical phenomena, whose applications range from physics, to the performance of algorithms on networks, to the survival of a biological species. The aim of this workshop is to share and attempt to push forward the state-of-the-art understanding of the geometry and dynamic evolution of these models, with a main focus on percolation, the random cluster model, Ising and other interacting particle systems on lattices.
Information: `http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm579`.

March 2012

* 14–16 **IAENG International Conference on Operations Research 2012**, Royal Garden Hotel, Kowloon, Hong Kong.
Description: The conference ICOR'12 is held under the International MultiConference of Engineers and Computer Scientists 2012. The IMECS 2012 is organized by the International Association of Engineers (IAENG), a non-profit international association for the engineers and the computer scientists. The topics of the ICOR'12 include, but are not limited to, the following: management science, managerial economics, systems thinking and analysis, optimization integer programming, linear programming, nonlinear programming, assignment problem, transportation network design, simulation, statistical, analysis, stochastics, modelling reliability and maintenance, queueing theory, game theory, graph theory, OR algorithms and software developments, OR applications and case studies.
Information: `http://www.iaeng.org/IMECS2012/ICOR2012.html`.

* 26–30 **AIM Workshop: Cohomological methods in abelian varieties**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to the integral motive, Chow groups and etale cohomology of abelian varieties, and applications to arithmetic geometry.
Information: `http://www.aimath.org/ARCC/workshops/cohomabelian.html`.

April 2012

* 1–4 **The 8th International Conference on Scientific Computing and Applications (SCA2012)**, University of Nevada Las Vegas (UNLV), Las Vegas, Nevada.
Description: This will be the 8th in the sequence of conferences on scientific computing and applications (SCA) held in the Pacific Rim region (held previously in China, Canada, Hong Kong, Korean). This is the first time to be held in USA. The purpose of the meeting is to provide a forum for researchers working on various aspects of scientific computing and applications to meet and move this area forward.
Co-Chairs of local organizing committee: Jichun Li and Hongtao Yang (Univ of Nevada Las Vegas, USA).
Important Deadlines: November 1, 2011: Mini-symposium proposal due. December 1, 2011: Abstracts for all talks due.
Information: `http://www.unlv.edu/centers/cams/sca2012/sca2012.html`.

* 2–4 **SIAM Conference on Uncertainty Quantification (UQ12)**, Raleigh Marriott City Center Hotel, Raleigh, North Carolina.
Description: Uncertainty quantification is key for achieving validated predictive computations in a wide range of scientific and engineering applications. The field relies on a broad range of mathematics and statistics groundwork, with associated algorithmic and computational development. This conference strives to bring together an interdisciplinary mix of mathematicians, statisticians, scientists, and engineers with an interest in development and implementation of uncertainty quantification methods. The goal of the meeting is to provide a forum for the sharing of ideas, and to enhance communication among this diverse group of technical experts, thereby contributing to future advances in the field.
Information: `http://www.siam.org/meetings/uq12/`.

* 2–6 **AIM Workshop: Vector equilibrium problems and their applications to random matrix models**, American Institute of Mathematics, Palo Alto, California.

Description: This workshop, sponsored by AIM and the NSF, will be devoted to the study of vector equilibrium problems and their application to the asymptotic analysis of random matrix models.
Information: http://aimath.org/ARCC/workshops/vectorequilib.html.

* 30–May 5 **Random Walks and Random Media**, Mathematical Sciences Research Institute, Berkeley, California.
Description: The field of random media has been the object of intensive mathematical research over the last thirty years. It covers a variety of models, mainly from condensed matter physics, physical chemistry, and geology, where one is interested in materials which have defects or inhomogeneities. These features are taken into account by letting the medium be random. It has been found that this randomness can cause very unexpected effects in the large scale behavior of these models; on occasion these run contrary to the prevailing intuition. A feature of this area, which it has in common with other areas of statistical physics, is that what was initially thought to be just a simple toy model has turned out to be a major mathematical challenge.
Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm581.

May 2012

* 14–18 **AIM Workshop: ACC for minimal log discrepancies and termination of flips**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to two closely connected conjectures in the minimal model program.
Information: http://www.aimath.org/ARCC/workshops/accflips.html.

* 17–19 **International Conference on "Applied Mathematics and Approximation Theory 2012"**, TOBB University of Economics and Technology, Ankara, Turkey.
Description: Celebrating the 60th birthday of Professor George Anastassiou.
Organizer: Oktay Duman, oduman@etu.edu.tr.
Topics: Applied Mathematics and Approximation Theory in the broad sense.
Plenary Speakers: George Anastassiou, Martin Bohner, Dimitru Baleanu, Heiner Gonska, Weimin Han, Cihan Orhan.
International Organizing Committee: Jerry Bona, Sever Dragomir, Sorin Gal, Narenda Govil, Anna Kaminska, Ram Mohapatra, Gaston N'Guerekata, Richard Zalik.
Information: http://amat2012.etu.edu.tr/.

* 21–25 **AIM Workshop: Contact topology in higher dimensions**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to developing high dimensional contact topology.
Information: http://www.aimath.org/ARCC/workshops/contacttop.html.

June 2012

* 12–15 **"The Incomputable" — A workshop of the 6-month Isaac Newton Institute programme — "Semantics and Syntax: A Legacy of Alan Turing" (SAS)**, Kavli Royal Society International Centre, Chicheley Hall, Newport Pagnell MK16 9JJ, United Kingdom.
Description: The Incomputable is one of a series of special events, running throughout the Alan Turing Year, celebrating Turing's unique impact on mathematics, computing, computer science, informatics, morphogenesis, philosophy and the wider scientific world. It is held in association with the Turing Centenary Conference (CiE 2012) in Cambridge the following week, which will run up to the June 23rd centenary of Turing's birth, and will culminate with a birthday celebration at Turing's old college, King's College, Cambridge. The Incomputable is unique in its focus on the mathematical theory of incomputability, and its relevance for the real world. This is a core aspect of Turing's scientific legacy — and this meeting for the first time reunites (in)computability theory and 'big science' in a way not attempted since Turing's premature passing. In 2012, the annual Workshop on Computability Theory is being held in conjunction with The Incomputable.
Contact: S. Barry Cooper; email: pmt6sbc@leeds.ac.uk.
Information: http://www.mathcomp.leeds.ac.uk/turing2012/inc/.

* 18–23 **Turing Centenary Conference (CiE 2012): How the World Computes**, University of Cambridge, Cambridge, United Kingdom.
Description: CiE 2012 is one of a series of special events, running throughout the Alan Turing Year, celebrating Turing's unique impact on mathematics, computing, computer science, informatics, morphogenesis, philosophy and the wider scientific world. Its central theme is the computability-theoretic concerns underlying the broad spectrum of Turing's interests, and the contemporary research areas founded upon and animated by them. In this sense, CiE 2012, held in Cambridge in the week running up to the centenary of Turing's birthday, deals with the essential core of what made Turing's contribution so influential and long-lasting. CiE 2012 promises to be an event worthy of the remarkable scientific career it commemorates.
Invited speakers: Veronica Becher, Lenore Blum, Rodney Downey, Yuri Gurevich, Juris Hartmanis, Andrew Hodges, Richard Jozsa, Stuart Kauffman, Paul Smolensky, James Murray, Leslie Valiant.
Deadline: For submissions: January 27, 2012.
Contact: email: anuj.dawar@cl.cam.ac.uk.
Information: http://www.cie2012.eu.

The following new announcements will not be repeated until the criteria in the next to the last paragraph at the bottom of the first page of this section are met.

August 2012

* 6–11 **XVII International Congress on Mathematical Physics (ICMP12)**, Aalborg Kongress og Kultur Center, Europa Plads 4, 9000 Aalborg, Denmark.
Description: The International Association of Mathematical Physics (IAMP) and the Local Organizing Committee invite you to participate in the XVII International Congress on Mathematical Physics (ICMP12). It will be held in Aalborg, Denmark, August 6-11, 2012. The International Congress on Mathematical Physics is held every three years. It is a major event in the mathematical physics community. The congress will present new results and future challenges, in a series of plenary lectures and topical sessions.
Information: http://www.icmp12.com/.

* 20–24 **AIM Workshop: Invariants in convex geometry and Banach space theory**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to the study of invariants related to a few important problems at the intersection of geometric analysis and Banach space theory.
Information: http://www.aimath.org/ARCC/workshops/convexbanach.html.

* 27–September 7 **Joint Introductory Workshop: Cluster Algebras and Commutative Algebra**, Mathematical Sciences Research Institute, Berkeley, California.
Description: This workshop will take place at the opening of the MSRI special programs on Commutative Algebra and on Cluster Algebras. It will feature lecture series at different levels, to appeal to a wide variety of participants. There will be minicourses on the

basics of cluster algebras, and others developing particular aspects of cluster algebras and commutative algebra.

Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm557.

September 2012

* 3–9 **International Conference on Differential-Difference Equations and Special Functions**, University of Patras, Patras, Greece.

Description: The conference is dedicated to the memory of Professor Panayiotis D. Siafarikas, who left so early in 2010 and its main aim is to bring together experts working in all areas (including numerical investigations and applications) of differential equations, difference equations and special functions and to promote the research in these areas.

Information: http://www.icddesf.upatras.gr.

* 22–23 **AMS Eastern Section Meeting**, Rochester Institute of Technology, Rochester, New York.

Information: http://www.ams.org/meetings/sectional/sectional.html.

October 2012

* 2–4 **SIAM Conference on Mathematics for Industry: Challenges and Frontiers (MI12)**, The Curtis, A Doubletree by Hilton, Denver, Colorado.

Description: The SIAM conferences on Mathematics for Industry focus attention on the many and varied opportunities to promote applications of mathematics to industrial problems. From the start of planning for these conferences, the major objective has been the development and encouragement of industrial, government and academic collaboration. The format of this conference provides a forum for industrial and government engineers and scientists to communicate their needs, objectives and visions, to the broad mathematical community.

Information: http://www.siam.org/meetings/mi12/.

* 13–14 **AMS Southeastern Section Meeting**, Tulane University, New Orleans, Louisiana.

Information: http://www.ams.org/meetings/sectional/sectional.html.

* 20–21 **AMS Central Section Meeting**, University of Akron, Akron, Ohio.

Information: http://www.ams.org/meetings/sectional/sectional.html.

* 27–28 **AMS Western Section Meeting**, University of Arizona, Tucson, Arizona.

Information: http://www.ams.org/meetings/sectional/sectional.html.

January 2013

* 24–25 **Connections for Women: Noncommutative Algebraic Geometry and Representation Theory**, Mathematical Sciences Research Institute, Berkeley, California.

Description: The Connections for Women workshop associated with the MSRI program in noncommutative algebraic geometry and representation theory is intended to bring together women who are working in these areas in all stages of their careers. As the first event in the semester, this workshop will feature a "tapas menu" of current research and open questions: light but intriguing tastes, designed to encourage further exploration and interest. Talks will be aimed at a fairly general audience and will cover diverse topics within the theme of the program. In addition, there will be a poster session for graduate students and recent Ph.D. recipients and a panel discussion on career issues, as well as free time for informal discussion.

Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm9061.

* 28–February 1 **Introductory Workshop: Noncommutative Algebraic Geometry and Representation Theory**, Mathematical Sciences Research Institute, Berkeley, California.

Description: This workshop will provide several short lecture series consisting of two or three lectures each to introduce postdocs, graduate students and non-experts to some of the major themes of the conference. While the precise topics may change to reflect developments in the area, it is likely that we will run mini-series in the following subjects: noncommutative algebraic geometry; D-module theory; derived categories; noncommutative resolutions of singularities; deformation-quantization; symplectic reflection algebras; growth functions of infinite dimensional algebras.

Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm9062.

April 2013

* 8–12 **Interactions between Noncommutative Algebra, Representation Theory, and Algebraic Geometry**, Mathematical Sciences Research Institute, Berkeley, California.

Description: In recent years there have been increasing interactions between noncommutative algebra/representation theory on the one hand and algebraic geometry on the other. This workshop would aim to examine these interactions and, as importantly, to encourage the interactions between the three areas. The precise topics will become more precise nearer the time, but will certainly include: Noncommutative algebraic geometry; noncommutative resolutions of singularities and Calabi-Yau algebras; symplectic reflection and related algebras; D-module theory; deformation-quantization.

Information: http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm9063.

August 2013

* 5–9 **XXII Rolf Nevanlinna Colloquium**, Helsinki, Finland.

Description: For further information, please contact Kirsi Peltonen, Aalto University; email: kirsi.peltonen@tkk.fi.

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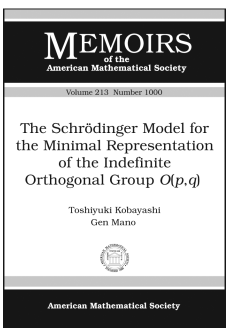
Algebra and Algebraic Geometry



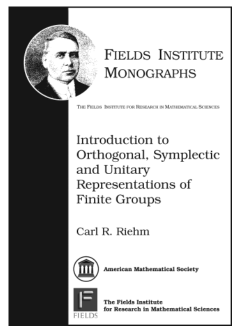
The Schrödinger Model for the Minimal Representation of the Indefinite Orthogonal Group $O(p,q)$

Toshiyuki Kobayashi, *University of Tokyo, Japan*, and **Gen Mano**, *PricewaterhouseCoopers Aarata, Tokyo, Japan*

Contents: Introduction; Two models of the minimal representation of $O(p,q)$; K-finite eigenvectors in the Schrödinger model $L^2(C)$; Radial part of the inversion; Main theorem; Bessel distributions; Appendix: special functions; Bibliography; List of Symbols; Index.

Memoirs of the American Mathematical Society, Volume 213, Number 1000

August 2011, 132 pages, Softcover, ISBN: 978-0-8218-4757-2, 2010 *Mathematics Subject Classification:* 22E30; 22E46, 43A80, **Individual member US$42.60**, List US$71, Institutional member US$56.80, Order code MEMO/213/1000



Introduction to Orthogonal, Symplectic and Unitary Representations of Finite Groups

Carl R. Riehm, *McMaster University, Hamilton, ON, Canada, and The Fields Institute, Toronto, ON, Canada*

Orthogonal, symplectic and unitary representations of finite groups lie at the crossroads of two more traditional subjects of mathematics—linear representations of finite groups, and the theory of quadratic, skew symmetric and Hermitian forms—and thus inherit some of the characteristics of both.

This book is written as an introduction to the subject and not as an encyclopaedic reference text. The principal goal is an exposition of the known results on the equivalence theory, and related matters such as the Witt and Witt-Grothendieck groups, over the "classical" fields—algebraically closed, real closed, finite, local and global. A detailed exposition of the background material needed is given in the first chapter.

It was A. Fröhlich who first gave a systematic organization of this subject, in a series of papers beginning in 1969. His paper *Orthogonal and symplectic representations of groups* represents the culmination of his published work on orthogonal and symplectic representations. The author has included most of the work from that paper, extending it to include unitary representations, and also providing new approaches, such as the use of the equivariant Brauer-Wall group in describing the principal invariants of orthogonal representations and their interplay with each other.

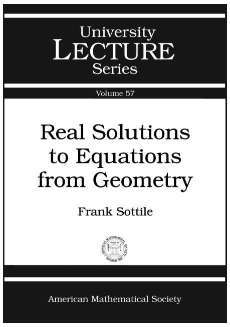
This item will also be of interest to those working in number theory.

Titles in this series are co-published with The Fields Institute for Research in Mathematical Sciences (Toronto, Ontario, Canada).

Contents: Background material; Isometry representations of finite groups; Hermitian forms over semisimple algebras; Equivariant Witt-Grothendieck and Witt groups; Representations over finite, local and global fields; Fröhlich's invariant, Clifford algebras and the equivariant Brauer-Wall group; Bibliography; Glossary; Index.

Fields Institute Monographs, Volume 28

August 2011, 291 pages, Hardcover, ISBN: 978-0-8218-4271-3, LC 2011017501, 2010 *Mathematics Subject Classification:* 20C15, 20C05, 11E81, 11E88, 16W22, **AMS members US$79.20**, List US$99, Order code FIM/28



Real Solutions to Equations from Geometry

Frank Sottile, *Texas A&M University, College Station, TX*

Understanding, finding, or even deciding on the existence of real solutions to a system of equations is a difficult problem with many applications outside of mathematics. While it is hopeless to expect much in general, we know a surprising amount about these questions for systems which possess additional structure often coming from geometry.

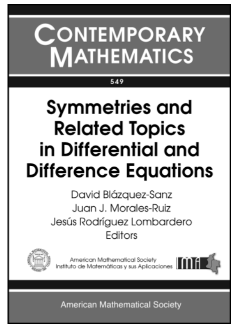
This book focuses on equations from toric varieties and Grassmannians. Not only is much known about these, but such equations are common in applications. There are three main themes: upper bounds on the number of real solutions, lower bounds on the number of real solutions, and geometric problems that can have all solutions be real. The book begins with an overview, giving background on real solutions to univariate polynomials and the geometry of sparse polynomial systems. The first half of the book concludes with fewnomial upper bounds and with lower bounds to sparse polynomial systems. The second half of the book begins by sampling some geometric problems for which all solutions can be real, before devoting the last five chapters to the Shapiro Conjecture, in which the relevant polynomial systems have only real solutions.

Contents: Overview; Real solutions of univariate polynomials; Sparse polynomial systems; Toric degenerations and Kushnirenko's theorem; Fewnomial upper bounds; Fewnomial upper bounds from Gale dual polynomial systems; Lower bounds for sparse polynomial systems; Some lower bounds for systems of polynomials; Enumerative real algebraic geometry; The Shapiro Conjecture for Grassmannians; The Shapiro Conjecture for rational functions; Proof of the Shapiro Conjecture for Grassmannians; Beyond the Shapiro Conjecture for the Grassmannian; The Shapiro Conjecture beyond the Grassmannian; Bibliography; Index of notation; Index.

University Lecture Series, Volume 57

September 2011, approximately 199 pages, Softcover, ISBN: 978-0-8218-5331-3, 2010 *Mathematics Subject Classification:* 14P99; 14M25, 14M15, 14N15, 14P25, 12D10, **AMS members US$37.60**, List US$47, Order code ULECT/57

Analysis



Symmetries and Related Topics in Differential and Difference Equations

David Blázquez-Sanz, *Universidad Sergio Arboleda, Bogatá, Colombia*, **Juan J. Morales-Ruiz**, *Technical University of Madrid, Spain*, and **Jesús Rodríguez Lombardero**, *Universidad de Salamanca, Spain*, Editors

This volume represents the 2009 Jairo Charris Seminar in Symmetries of Differential and Difference Equations, which was held at the Universidad Sergio Arboleda in Bogotá, Colombia.

The papers include topics such as Lie symmetries, equivalence transformations and differential invariants, group theoretical methods in linear equations, namely differential Galois theory and Stokes phenomenon, and the development of some geometrical methods in theoretical physics.

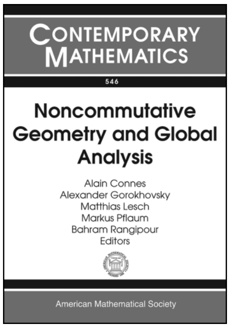
The reader will find new interesting results in symmetries of differential and difference equations, applications in classical and quantum mechanics, two fundamental problems of theoretical mechanics, the mathematical nature of time in Lagrangian mechanics and the preservation of the equations of motion by changes of frame, and discrete Hamiltonian systems arising in geometrical optics and analogous to those of finite quantum mechanics.

This item will also be of interest to those working in mathematical physics.

Contents: **A. A. Monforte** and **J.-A. Weil**, A reduction method for higher order variational equations of Hamiltonian systems; **N. H. Ibragimov**, A survey on integration of parabolic equations by reducing them to the heat equation; **S. Jiménez**, Weil jets, Lie correspondences and applications; **J. Mozo-Fernández**, Some applications of summability: An illustrated survey; **J. M. Díaz**, The structure of time and inertial forces in Lagrangian mechanics; **P J. Olver**, Differential invariant algebras; **J. Sauloy**, The Stokes phenomenon for linear q-difference equations; **K. B. Wolf**, Finite Hamiltonian systems on phase space.

Contemporary Mathematics, Volume 549

September 2011, 165 pages, Softcover, ISBN: 978-0-8218-6872-0, LC 2011012079, 2010 *Mathematics Subject Classification:* 35A30, 34M15, 17B45, 35C05, 70A05, 37J05, 22F05, 53A04, 39A13, **AMS members US$55.20**, List US$69, Order code CONM/549



Noncommutative Geometry and Global Analysis

Alain Connes, *College de France, Paris, France*, **Alexander Gorokhovsky**, *University of Colorado, Boulder, CO*, **Matthias Lesch**, *Universität Bonn, Germany*, **Markus Pflaum**, *University of Colorado, Boulder, CO*, and **Bahram Rangipour**, *University of New Brunswick, Fredericton, NB, Canada*, Editors

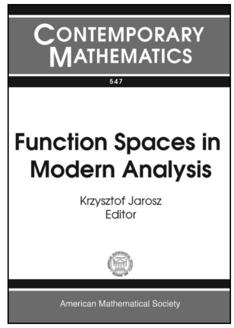
This volume represents the proceedings of the conference on Noncommutative Geometric Methods in Global Analysis, held in honor of Henri Moscovici, from June 29–July 4, 2009, in Bonn, Germany.

Henri Moscovici has made a number of major contributions to noncommutative geometry, global analysis, and representation theory. This volume, which includes articles by some of the leading experts in these fields, provides a panoramic view of the interactions of noncommutative geometry with a variety of areas of mathematics. It focuses on geometry, analysis and topology of manifolds and singular spaces, index theory, group representation theory, connections of noncommutative geometry with number theory and arithmetic geometry, Hopf algebras and their cyclic cohomology.

Contents: **D. Barbasch** and **P. Pandžić**, Dirac cohomology and unipotent representations of complex groups; **P. Bressler**, **A. Gorokhovsky**, **R. Nest**, and **B. Tsygan**, Algebraic index theorem for symplectic deformations of gerbes; **J. Brüning**, **F. W. Kamber**, and **K. Richardson**, Index theory for basic Dirac operators on Riemannian foliations; **A. Connes**, The Witt construction in characteristic one and quantization; **M. Dubois-Violette** and **G. Landi**, Lie prealgebras; **N. Higson**, On the analogy between complex semisimple groups and their Cartan motion groups; **A. Kaygun**, A survey on Hopf-cyclic cohomology and Connes-Moscovici characteristic map; **M. Khalkhali** and **A. Pourkia**, A super version of the Connes-Moscovici Hopf algebra; **V. Mathai** and **S. Wu**, Analytic torsion of $\mathbb{Z}_2$-graded elliptic complexes; **B. Monthubert** and **V. Nistor**, The K-groups and the index theory of certain comparison $C*$-algebras; **H. Moriyoshi** and **P. Piazza**, Relative pairings and the Atiyah-Patodi-Singer index formula for the Godbillon-Vey cocycle; **A. Némethi**, Two exact sequences for lattice cohomology; **B. Rangipour**, Cup products in Hopf cyclic cohomology with coefficients in contramodules; **M. Wodzicki**, Algebras of p-symbols, noncommutative p-residue, and the Brauer group; **G. Yu**, Large scale geometry and its applications.

Contemporary Mathematics, Volume 546

July 2011, 315 pages, Softcover, ISBN: 978-0-8218-4944-6, LC 2011008749, 2010 *Mathematics Subject Classification:* 13F35, 14B05, 16E40, 16T05, 19K56, 19D55, 22E46, 58B34, 53C24, 58J42, **AMS members US$84**, List US$105, Order code CONM/546



Function Spaces in Modern Analysis

Krzysztof Jarosz, *Southern Illinois University at Edwardsville, IL*, Editor

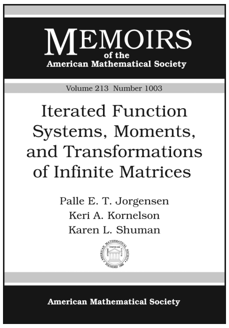
This volume contains the proceedings of the Sixth Conference on Function Spaces, which was held from May 18–22, 2010, at Southern Illinois University at Edwardsville.

The papers cover a broad range of topics, including spaces and algebras of analytic functions of one and of many variables (and operators on such spaces), spaces of integrable functions, spaces of Banach-valued functions, isometries of function spaces, geometry of Banach spaces, and other related subjects.

Contents: **A. V. Abanin**, **R. Ishimura**, and **L. H. Khoi**, Exponential-polynomial bases for null spaces of convolution operators in $A^{-\infty}$; **M. Abel**, Locally m-pseudoconvex algebras; **N. Arcozzi**, **R. Rochberg**, **E. Sawyer**, and **B. D. Wick**, Distance functions for reproducing kernel Hilbert spaces; **H. A. Peimbert** and **A. G. García**, Some properties of families of functions in $C_b(X, \mathbb{C}), \beta)$; **R. M. Aron** and **P. Rueda**, p-compact homogeneous polynomials from an ideal point of view; **F. Botelho** and **J. Jamison**, Homomorphisms of non-commutative Banach *-algebras of Lipschitz functions; **A. E. Cardwell**, An extension of a lemma by Phelps to Hilbert spaces; **P. H. Enflo** and **T. M. Smith**, Algebraic complements and ranges of linear operators; **M. Haralampidou**, Wedderburn decomposition of pseudo-H-algebras; **O. Hatori**, **S. Lambert**, **A. Luttman**, **T. Miura**, **T. Tonev**, and **R. Yates**, Spectral preservers in commutative Banach algebras; **G. Hirasawa**, **T. Miura**, and **H. Takagi**, Spectral radii conditions for isomorphisms between unital semisimple commutative Banach algebras; **A. J. Izzo**, The peak point conjecture and uniform algebras invariant under group actions; **K. Jarosz**, Function spaces—Selected open problems; **R. Kantrowitz**, **M. M. Neumann**, and **T. J. Ransford**, Regularity, scrambling, and the steady state for stochastic matrices; **J. W. D. Mason**, A survey of non-complex analogs of uniform algebras; **M. Mouattamid**, Properties of solution-space of the Lagrange multivariate interpolation problem using translation-invariant Fourier-transformable kernels; **S. Mukherjee**, **F. Jafari**, and **J. E. McInroy**, On the range of composition operators on spaces of entire functions; **T. Oikhberg**, Reverse monotone approximation property; **H. Rahimi**, **M. Ghahramani**, and **S. Moayeri**, Biprojectivity and weak amenability of some Banach algebras; **K. Shamseddine**, Nontrivial order preserving automorphisms of non-Archimedean fields; **T. Tonev** and **E. Toneva**, Composition operators between subsets of function algebras; **J. Wermer**, Function theory on certain three-manifolds.

Contemporary Mathematics, Volume 547

August 2011, 244 pages, Softcover, ISBN: 978-0-8218-5251-4, LC 2011009108, 2010 *Mathematics Subject Classification:* 46B04, 46E10, 46E15, 46E25, 46E30, 46H05, 46J10, 46J15; 30Hxx, 32Cxx, 47Lxx, **AMS members US$71.20**, List US$89, Order code CONM/547



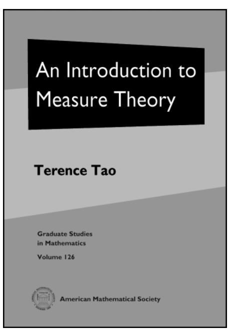
Iterated Function Systems, Moments, and Transformations of Infinite Matrices

Palle E. T. Jorgensen, *University of Iowa, Iowa City, IA*, **Keri A. Kornelson**, *University of Oklahoma, Norman, OK*, and **Karen L. Shuman**, *Grinnell College, IA*

Contents: Notation; The moment problem; A transformation of moment matrices: the affine case; Moment matrix transformation: measurable maps; The Kato-Friedrichs operator; The integral operator of a moment matrix; Boundedness and spectral properties; The moment problem revisited; Acknowledgements; Bibliography.

Memoirs of the American Mathematical Society, Volume 213, Number 1003

August 2011, 105 pages, Softcover, ISBN: 978-0-8218-5248-4, 2010 *Mathematics Subject Classification:* 28A12, 34B45, 42C05, 42A82, 46E22, 47L30, 47L60, 47C10, 47S50, 54E70, 60J10, 60J20, 78M05, 81S30, 81Q15, 81T75, 82B44, 90B15, **Individual member US$42**, List US$70, Institutional member US$56, Order code MEMO/213/1003



An Introduction to Measure Theory

Terence Tao, *University of California, Los Angeles, CA*

This is a graduate text introducing the fundamentals of measure theory and integration theory, which is the foundation of modern real analysis. The text focuses first on the concrete setting of Lebesgue measure and the Lebesgue integral (which in turn is motivated by the more classical concepts of Jordan measure and the Riemann integral), before moving on to abstract measure and integration theory, including the standard convergence theorems, Fubini's theorem, and the Carathéodory extension theorem. Classical differentiation theorems, such as the Lebesgue and Radamacher differentiation theorems, are also covered, as are connections with probability theory. The material is intended to cover a quarter or semester's worth of material for a first graduate course in real analysis.

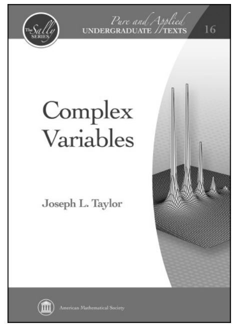
There is an emphasis in the text on tying together the abstract and the concrete sides of the subject, using the latter to illustrate and motivate the former. The central role of key principles (such as Littlewood's three principles) as providing guiding intuition to the subject is also emphasized. There are a large number of exercises throughout that develop key aspects of the theory, and are thus an integral component of the text.

As a supplementary section, a discussion of general problem-solving strategies in analysis is also given. The last three sections discuss optional topics related to the main matter of the book.

Contents: Measure theory; Related articles; Bibliography; Index.

Graduate Studies in Mathematics, Volume 126

October 2011, approximately 219 pages, Hardcover, ISBN: 978-0-8218-6919-2, LC 2011018926, 2010 *Mathematics Subject Classification:* 28A20, 28A25, 28A35, **AMS members US$42.40**, List US$53, Order code GSM/126



Complex Variables

Joseph L. Taylor, *University of Utah, Salt Lake City, UT*

The text covers a broad spectrum between basic and advanced complex variables on the one hand and between theoretical and applied or computational material on the other hand. With careful selection of the emphasis put on the various sections, examples, and exercises, the book can be used in a one- or two-semester course for undergraduate mathematics majors, a one-semester course for engineering or physics majors, or a one-semester course for first-year mathematics graduate students. It has been tested in all three settings at the University of Utah.

The exposition is clear, concise, and lively. There is a clean and modern approach to Cauchy's theorems and Taylor series expansions, with rigorous proofs but no long and tedious arguments. This is followed by the rich harvest of easy consequences of the existence of power series expansions.

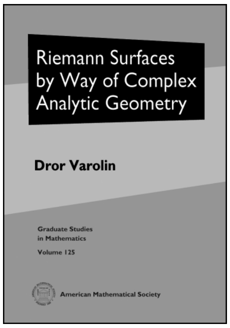
Through the central portion of the text, there is a careful and extensive treatment of residue theory and its application to computation of integrals, conformal mapping and its applications to applied problems, analytic continuation, and the proofs of the Picard theorems.

Chapter 8 covers material on infinite products and zeroes of entire functions. This leads to the final chapter, which is devoted to the Riemann zeta function, the Riemann Hypothesis, and a proof of the Prime Number Theorem.

Contents: The complex numbers; Analytic functions; Power series expansions; The general Cauchy theorems; Residue theory; Conformal mappings; Analytic continuation and the Picard theorems; Infinite products; The gamma and zeta functions; Bibliography; Index.

Pure and Applied Undergraduate Texts, Volume 16

October 2011, approximately 308 pages, Hardcover, ISBN: 978-0-8218-6901-7, 2010 *Mathematics Subject Classification:* 30-01, 30Axx, 30Bxx, 30Dxx, 30Exx, **AMS members US$50.40**, List US$63, Order code AMSTEXT/16



Riemann Surfaces by Way of Complex Analytic Geometry

Dror Varolin, *Stony Brook University, NY*

This book establishes the basic function theory and complex geometry of Riemann surfaces, both open and compact. Many of the methods used in the book are adaptations and simplifications of methods from the theories of several complex variables and complex analytic geometry and would serve as excellent training for mathematicians wanting to work in complex analytic geometry.

After three introductory chapters, the book embarks on its central, and certainly most novel, goal of studying Hermitian holomorphic line bundles and their sections. Among other things, finite-dimensionality of spaces of sections of holomorphic line bundles of compact Riemann surfaces and the triviality of holomorphic line bundles over Riemann surfaces are proved, with various applications. Perhaps the main result of the book is Hörmander's Theorem on the square-integrable solution of the Cauchy-Riemann equations. The crowning application is the proof of the Kodaira and Narasimhan Embedding Theorems for compact and open Riemann surfaces.

The intended reader has had first courses in real and complex analysis, as well as advanced calculus and basic differential topology (though the latter subject is not crucial). As such, the book should appeal to a broad portion of the mathematical and scientific community.

This book is the first to give a textbook exposition of Riemann surface theory from the viewpoint of positive Hermitian line bundles and Hörmander $\bar\partial$ estimates. It is more analytical and PDE oriented than prior texts in the field, and is an excellent introduction to the methods used currently in complex geometry, as exemplified in J. P. Demailly's online but otherwise unpublished book "Complex analytic and differential geometry." I used it for a one quarter course on Riemann surfaces and found it to be clearly written and self-contained. It not only fills a significant gap in the large textbook literature on Riemann surfaces but is also rather indispensible for those who would like to teach the subject from a differential geometric and PDE viewpoint.

—***Steven Zelditch***

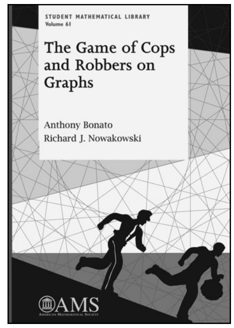
This item will also be of interest to those working in algebra and algebraic geometry.

Contents: Complex analysis; Riemann surfaces; Functions on Riemann surfaces; Complex line bundles; Complex differential forms; Calculus on line bundles; Potential theory; Solving $\bar\partial$ with smooth data; Harmonic forms; Uniformization; Hörmander's Theorem; Embedding Riemann surfaces; The Riemann-Roch Theorem; Abel's Theorem; Bibliography; Index.

Graduate Studies in Mathematics, Volume 125

September 2011, 236 pages, Hardcover, ISBN: 978-0-8218-5369-6, LC 2011014621, 2010 *Mathematics Subject Classification:* 30F10, 30F15, 30F30, 30F45, 30F99, 30G99, 31A05, 31A99, 32W05, **AMS members US$50.40**, List US$63, Order code GSM/125

Discrete Mathematics and Combinatorics



The Game of Cops and Robbers on Graphs

Anthony Bonato, *Ryerson University, Toronto, ON, Canada*, and **Richard J. Nowakowski**, *Dalhousie University, Halifax, NS, Canada*

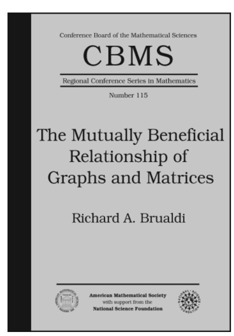
This book is the first and only one of its kind on the topic of Cops and Robbers games, and more generally, on the field of vertex pursuit games on graphs. The book is written in a lively and highly readable fashion, which should appeal to both senior undergraduates and experts in the field (and everyone in between). One of the main goals of the book is to bring together the key results in the field; as such, it presents structural, probabilistic, and algorithmic results on Cops and Robbers games. Several recent and new results are discussed, along with a comprehensive set of references. The book is suitable for self-study or as a textbook, owing in part to the over 200 exercises. The reader will gain insight into all the main directions of research in the field and will be exposed to a number of open problems.

This item will also be of interest to those working in applications.

Contents: Introduction; Characterizations; Meyniel's conjecture; Graph products and classes; Algorithms; Random graphs; Infinite graphs; Variants of Cops and Robbers; Good guys versus bad guys; Bibliography; Index.

Student Mathematical Library, Volume 61

September 2011, approximately 267 pages, Softcover, ISBN: 978-0-8218-5347-4, 2010 *Mathematics Subject Classification:* 05C57, 91A43, 05C75, 05C80, 05C63, 05C85, **AMS members US$36**, List US$45, Order code STML/61



The Mutually Beneficial Relationship of Graphs and Matrices

Richard A. Brualdi, *University of Wisconsin, Madison, WI*

Graphs and matrices enjoy a fascinating and mutually beneficial relationship. This interplay has benefited both graph theory and linear algebra. In one direction, knowledge about one of the graphs that can be associated with a matrix can be used to illuminate matrix properties and to get better information about the matrix. Examples include the use of digraphs to obtain strong results on diagonal dominance and eigenvalue inclusion regions and the use of the Rado-Hall theorem to deduce properties of special classes of matrices. Going the other way, linear algebraic properties of one of the matrices associated with a graph can be used to obtain useful combinatorial information about the graph.

The adjacency matrix and the Laplacian matrix are two well-known matrices associated to a graph, and their eigenvalues encode important information about the graph. Another important linear algebraic invariant associated with a graph is the Colin de Verdière number, which, for instance, characterizes certain topological properties of the graph.

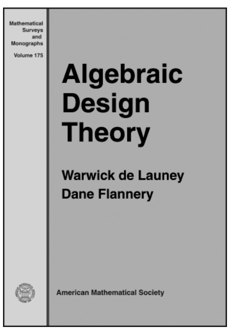
This book is not a comprehensive study of graphs and matrices. The particular content of the lectures was chosen for its accessibility, beauty, and current relevance, and for the possibility of enticing the audience to want to learn more.

A co-publication of the AMS and CBMS.

Contents: Some fundamentals; Eigenvalues of graphs; Rado-Hall theorem and applications; Colin de Verdière number; Classes of matrices of zeros and ones; Matrix sign patterns; Eigenvalue inclusion and diagonal products; Tournaments; Two matrix polytopes; Digraphs and eigenvalues of (0,1)-matrices; Index.

CBMS Regional Conference Series in Mathematics, Number 115

July 2011, 96 pages, Softcover, ISBN: 978-0-8218-5315-3, LC 2011014290, 2010 *Mathematics Subject Classification:* 05C50; 05B35, 05C20, 15A15, 15A18, 15B35, **AMS members US$27.20, All Individuals US$27.20**, List US$34, Order code CBMS/115



Algebraic Design Theory

Warwick de Launey, and **Dane Flannery**, *National University of Ireland, Galway, Ireland*

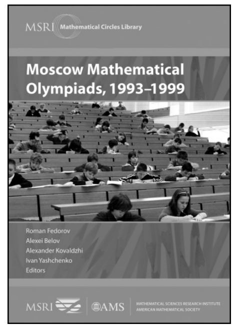
Combinatorial design theory is a source of simply stated, concrete, yet difficult discrete problems, with the Hadamard conjecture being a prime example. It has become clear that many of these problems are essentially algebraic in nature. This book provides a unified vision of the algebraic themes which have developed so far in design theory. These include the applications in design theory of matrix algebra, the automorphism group and its regular subgroups, the composition of smaller designs to make larger designs, and the connection between designs with regular group actions and solutions to group ring equations. Everything is explained at an elementary level in terms of orthogonality sets and pairwise combinatorial designs—new and simple combinatorial notions which cover many of the commonly studied designs. Particular attention is paid to how the main themes apply in the important new context of cocyclic development. Indeed, this book contains a comprehensive account of cocyclic Hadamard matrices. The book was written to inspire researchers, ranging from the expert to the beginning student, in algebra or design theory, to investigate the fundamental algebraic problems posed by combinatorial design theory.

Contents: Overview; Many kinds of pairwise combinatorial designs; A primer for algebraic design theory; Orthogonality; Modeling Λ-equivalence; The Grammian; Transposability; New designs from old; Automorphism groups; Group development and regular actions on arrays; Origins of cocyclic development; Group extensions and cocycles; Cocyclic pairwise combinatorial designs; Centrally regular actions; Cocyclic associates; Special classes of cocyclic designs; The Paley matrices; A large family of cocyclic Hadamard matrices; Substitution schemes for cocyclic Hadamard matrices; Calculating cocyclic development rules; Cocyclic Hadamard matrices indexed by elementary abelian groups; Cocyclic concordant systems of orthogonal designs; Asymptotic existence of cocyclic Hadamard matrices; Bibliography; Index.

Mathematical Surveys and Monographs, Volume 175

August 2011, 298 pages, Hardcover, ISBN: 978-0-8218-4496-0, LC 2011014837, 2010 *Mathematics Subject Classification:* 05-02, 05Bxx, 05E18, 16B99, 20Dxx; 05-04, 15A24, 16S99, 20B20, 20J06, **AMS members US$75.20**, List US$94, Order code SURV/175

General Interest



Moscow Mathematical Olympiads, 1993–1999

Roman Fedorov, *Max Planck Institute for Mathematics, Bonn, Germany*, **Alexei Belov**, *Moscow Institute of Open Education, Russia, and Shanghai University, People's Republic of China*, **Alexander Kovaldzhi**, *"Second School" Lyceum, Moscow, Russia*, and **Ivan Yashchenko**, *Moscow Center for Continuous Mathematical Education, Russia*, Editors

The Moscow Mathematical Olympiad has been challenging high-school students with stimulating, original problems of different degrees of difficulty for over 75 years. The problems are nonstandard; solving them takes wit, thinking outside the box, and, sometimes, hours of contemplation. Some are within the reach of most mathematically competent high-school students, while others are difficult even for a mathematics professor. Many mathematically inclined students have found that tackling these problems, or even just reading their solutions, is a great way to develop mathematical insight.

In 2006 the Moscow Center for Continuous Mathematical Education began publishing a collection of problems from the Moscow Mathematical Olympiads, providing for each an answer (and sometimes a hint) as well as one or more detailed solutions. This volume represents the years 1993–1999.

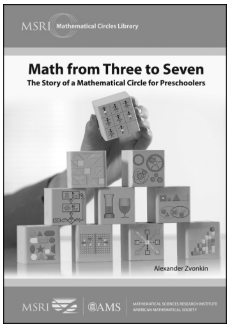
The problems and the accompanying material are well suited for math circles. They are also appropriate for problem-solving classes and practice for regional and national mathematics competitions.

Titles in this series are co-published with the Mathematical Sciences Research Institute (MSRI).

Contents: Problems; Answers; Hints; Solutions; Reference facts; Postscript by V. M. Tikhomirov: Reflections on the Moscow Mathematical Olympiads; Bibliography; Problem authorship.

MSRI Mathematical Circles Library, Volume 4

August 2011, 220 pages, Softcover, ISBN: 978-0-8218-5363-4, LC 2011013244, 2010 *Mathematics Subject Classification:* 00A07, 97-01, 97D50, 00A08, **AMS members US$31.20**, List US$39, Order code MCL/4



Math from Three to Seven

The Story of a Mathematical Circle for Preschoolers

Alexander Zvonkin, *Université Bordeaux I, Talence, France*

This book is a captivating account of a professional mathematician's experiences conducting a math circle for preschoolers in his apartment in Moscow in the 1980s. As anyone who has taught or raised young children knows, mathematical education for little kids is a real mystery. What are they capable of? What should they learn first? How hard should they work? Should they even "work" at all? Should we push them, or just let them be? There are no correct answers to these questions, and the author deals with them in classic math-circle style: he doesn't ask and then answer a question, but shows us a problem—be it mathematical or pedagogical—and describes to us what happened. His book is a narrative about what he did, what he tried, what worked, what failed, but most important, what the kids experienced.

This book does not purport to show you how to create precocious high achievers. It is just one person's story about things he tried with a half-dozen young children. Mathematicians, psychologists, educators, parents, and everybody interested in the intellectual development in young children will find this book to be an invaluable, inspiring resource.

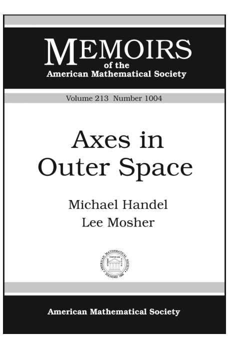
Titles in this series are co-published with the Mathematical Sciences Research Institute (MSRI).

Contents: Introduction; The first session: Narrative and reflections; The boys' math circle, year one; Children and $\binom{5}{2}$: The story of one problem; The boys' math circle, year two; Notation, abstraction, mathematics, and language; The boys' math circle, year three; The boys' math circle, final six months; At home and in school; The girls' math circle, year one; The girls' math circle, year two; This is not an epilogue; Index of math, pedagogy, and psychology.

MSRI Mathematical Circles Library, Volume 5

August 2011, 300 pages, Softcover, ISBN: 978-0-8218-6873-7, LC 2011016999, 2010 *Mathematics Subject Classification:* 00A08, 00A09, 00A35, 97A20, 97A80, 97C30, 97U60, **AMS members US$39.20**, List US$49, Order code MCL/5

Geometry and Topology



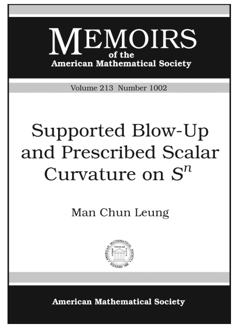
Axes in Outer Space

Michael Handel, *CUNY, Herbert H. Lehman College, Bronx, NY*, and **Lee Mosher**, *Rutgers University, Newark, NJ*

Contents: Introduction; Preliminaries; The ideal Whitehead graph; Cutting and pasting local stable Whitehead graphs; Weak train tracks; Topology of the axis bundle; Fold lines; Bibliography.

Memoirs of the American Mathematical Society, Volume 213, Number 1004

August 2011, 104 pages, Softcover, ISBN: 978-0-8218-6927-7, 2010 *Mathematics Subject Classification:* 20-XX; 57-XX, **Individual member US$42**, List US$70, Institutional member US$56, Order code MEMO/213/1004



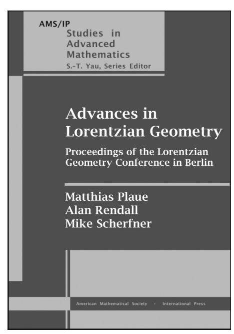
Supported Blow-Up and Prescribed Scalar Curvature on S^n

Man Chun Leung, *National University of Singapore, Republic of Singapore*

Contents: Introduction; The subcritical approach; Simple, towering, aggregated and clustered blow-ups; Supported and collapsed blow-ups; Toward isolated blow-ups; Toward supported blow-up for $\Delta\tilde{K}(0) > 0$—excluding simple blow-up; Excluding collapsed isolated blow-up ($\text{Hess}_o\tilde{K}(0)$ positive definite); Close up; Single simple blow-up and the proof of the Main Theorem; Bibliography.

Memoirs of the American Mathematical Society, Volume 213, Number 1002

August 2011, 99 pages, Softcover, ISBN: 978-0-8218-5337-5, 2010 *Mathematics Subject Classification:* 35J60; 53C21, **Individual member US$41.40**, List US$69, Institutional member US$55.20, Order code MEMO/213/1002



Advances in Lorentzian Geometry

Proceedings of the Lorentzian Geometry Conference in Berlin

Matthias Plaue, *Technische Universität Berlin, Germany*, **Alan Rendall**, *Max-Planck-Institut für Gravitationsphysik, Potsdam, Germany*, and **Mike Scherfner**, *Technische Universität Berlin, Germany*, Editors

This volume offers deep insight into the methods and concepts of a very active field of mathematics that has many connections with physics. Researchers and students will find it to be a useful source for their own investigations, as well as a general report on the latest topics of interest.

Presented are contributions from several specialists in differential geometry and mathematical physics, collectively demonstrating the wide range of applications of Lorentzian geometry, and ranging in character from research papers to surveys to the development of new ideas.

This volume consists mainly of papers drawn from the conference "New Developments in Lorentzian Geometry" (held in November 2009 in Berlin, Germany), which was organized with the help of the

DFG Collaborative Research Center's "SFB 647 Space-Time-Matter" group, the Berlin Mathematical School, and Technische Universität Berlin.

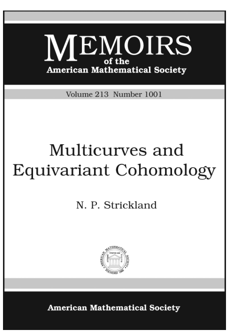
This item will also be of interest to those working in mathematical physics.

Titles in this series are co-published with International Press, Cambridge, MA.

Contents: **R. Bartolo**, **A. M. Candela**, and **E. Caponio**, An Avez-Seifert type theorem for orthogonal geodesics on a stationary spacetime; **M. Caballero** and **R. M. Rubio**, Calabi-Bernstein problems for spacelike slices in certain generalized Robertson-Walker spacetimes; **Y. Choquet-Bruhat** and **J. M. Martín-García**, A geometric energy estimate for data on a characteristic cone; **R. Deszcz**, **M. Głogowska**, **M. Hotloś**, and **K. Sawicz**, A survey on generalized Einstein metric conditions; **F. Dobarro** and **B. Ünal**, Non-rotating killing vector fields on standard static space-times; **R. Geroch**, Faster than light?; **G. Hall**, Projective structure in space-times; **P. G. LeFloch**, Einstein spacetimes with weak regularity; **E. Minguzzi**, Time functions as utility functions; **M. Sánchez**, Recent progress on the notion of global hyperbolicity; **S. Suhr**, Homologically maximizing geodesics in conformally flat tori.

AMS/IP Studies in Advanced Mathematics, Volume 49

June 2011, 143 pages, Softcover, ISBN: 978-0-8218-5352-8, LC 2011010875, 2010 *Mathematics Subject Classification:* 53-02, 53B30, 83C05, **AMS members US$47.20**, List US$59, Order code AMSIP/49



Multicurves and Equivariant Cohomology

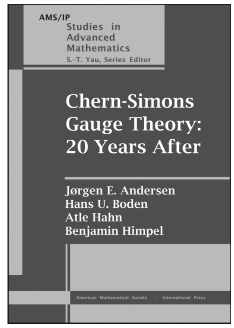
N. P. Strickland, *University of Sheffield, England*

Contents: Introduction; Multicurves; Differential forms; Equivariant projective spaces; Equivariant orientability; Simple examples; Formal groups from algebraic groups; Equivariant formal groups of product type; Equivariant formal groups over rational rings; Equivariant formal groups of pushout type; Equivariant Morava *E*-theory; A completion theorem; Equivariant formal group laws and complex cobordism; A counterexample; Divisors; Embeddings; Symmetric powers of multicurves; Classification of divisors; Local structure of the scheme of divisors; Generalised homology of Grassmannians; Thom isomorphisms and the projective bundle theorem; Duality; Further theory of infinite Grassmannians; Transfers and the Burnside ring; Generalisations; Bibliography; Index.

Memoirs of the American Mathematical Society, Volume 213, Number 1001

August 2011, 117 pages, Softcover, ISBN: 978-0-8218-4901-9, 2010 *Mathematics Subject Classification:* 55N20, 55N22, 55N91, 14L05, **Individual member US$42**, List US$70, Institutional member US$56, Order code MEMO/213/1001

Mathematical Physics



Chern-Simons Gauge Theory: 20 Years After

Jørgen E. Andersen, *Aarhus University, Denmark*, **Hans U. Boden**, *McMaster University, Hamilton, ON, Canada*, **Atle Hahn**, *Universidade de Lisboa, Portugal*, and **Benjamin Himpel**, *Universität Bonn, Germany*, Editors

In 1989, Edward Witten discovered a deep relationship between quantum field theory and knot theory, and this beautiful discovery created a new field of research called Chern-Simons theory. This field has the remarkable feature of intertwining a large number of diverse branches of research in mathematics and physics, among them low-dimensional topology, differential geometry, quantum algebra, functional and stochastic analysis, quantum gravity, and string theory.

The 20-year anniversary of Witten's discovery provided an opportunity to bring together researchers working in Chern-Simons theory for a meeting, and the resulting conference, which took place during the summer of 2009 at the Max Planck Institute for Mathematics in Bonn, included many of the leading experts in the field. This volume documents the activities of the conference and presents several original research articles, including another monumental paper by Witten that is sure to stimulate further activity in this and related fields. This collection will provide an excellent overview of the current research directions and recent progress in Chern-Simons gauge theory.

This item will also be of interest to those working in geometry and topology.

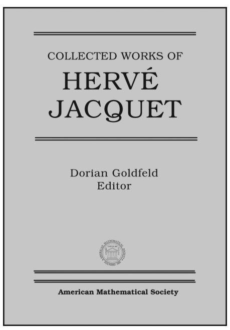
Titles in this series are co-published with International Press, Cambridge, MA.

Contents: **C. Beasley**, Remarks on Wilson loops and Seifert loops in Chern-Simons theory; **T. Dimofte** and **S. Gukov**, Quantum field theory and the volume conjecture; **J. Dubois**, Computational aspects in Reidemeister torsion and Chern-Simons theories; **E. Guadagnini**, Functional integration and abelian link invariants; **M. Hedden** and **P. Kirk**, Chern-Simons invariants, SO(3) instantons, and $\mathbb{Z}/2$ homology cobordism; **C. M. Herald**, Extending the $SU(3)$ Casson invariant to rational homology 3-spheres; **K. Hikami**, Decomposition of Witten-Reshetikhin-Turaev invariant: Linking pairing and modular forms; **K. Hikami** and **H. Murakami**, Representations and the colored Jones polynomial of a torus knot; **L. Jeffrey** and **B. McLellan**, Eta-invariants and anomalies in $U/1$ Chern-Simons theory; **R. M. Kashaev**, Delta-groupoids and ideal triangulations; **C. Lescop**, Invariants of knots and 3-manifolds derived from the equivariant linking pairing; **M. Mariño**, Chern-Simons theory, the $1/N$ expansion, and string theory; **C. Meusburger**, Global Lorentzian geometry from lightlike geodesics: What does an observer in (2+1)-gravity see?; **A. Miković** and **J. F. Martins**, Spin foam state sums and Chern-Simons theory; **R. C. Penner**, Representations of the Ptolemy groupoid, Johnson homomorphisms, and finite type invariants; **A. N. Sengupta**, Yang-Mills in two dimensions and Chern-Simons in three; **G. Thompson**, Intersection pairings on spaces of connections and Chern-Simons theory on Seifert manifolds; **J. Weitsman**, Fermionization and convergent perturbation expansions in Chern-Simons gauge theory; **E. Witten**, Analytic continuation of Chern-Simons theory.

AMS/IP Studies in Advanced Mathematics, Volume 50

July 2011, 446 pages, Softcover, ISBN: 978-0-8218-5353-5, LC 2011012166, 2010 *Mathematics Subject Classification:* 11F23, 14E20, 16S10, 19L10, 20C20, 20F99, 20L05, 30F60, 32G15, 46E25, 53C50, 53D20, 53D99, 54C40, 55R80, 57M25, 57M27, 57M50, 57M60, 57N05, 57N10, 57R56, 58D27, 58D30, 58E09, 58J28, 58J30, 58J52, 58Z05, 70S15, 81T08, 81T13, 81T25, 81T30, 81T45, 83C80, **AMS members US$104**, List US$130, Order code AMSIP/50

Number Theory



Collected Works of Hervé Jacquet

Dorian Goldfeld, *Columbia University, New York, NY*, Editor

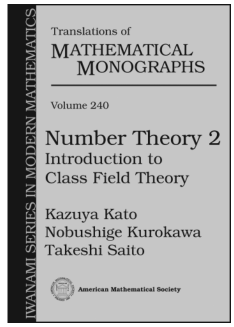
Hervé Jacquet is one of the founders of the modern theory of automorphic representations and their associated L-functions. This volume represents a selection of his most influential papers not already available in book form. The volume contains papers on the L-function attached to a pair of representations of the general linear group. Thus, it completes Jacquet's papers on the subject (joint with Shalika and Piatetski-Shapiro) that can be found in the volume of selected works of Piatetski-Shapiro. In particular, two often quoted papers of Jacquet and Shalika on the classification of automorphic representations and a historically important paper of Gelbart and Jacquet on the functorial transfer from $GL(2)$ to $GL(3)$ are included. Another series of papers pertains to the relative trace formula introduced by Jacquet. This is a variant of the standard trace formula which is used to study the period integrals of automorphic forms. Nearly complete results are obtained for the period of an automorphic form over a unitary group.

This item will also be of interest to those working in algebra and algebraic geometry.

Contents: with **J. A. Shalika**, A non-vanishing theorem for zeta functions ofGL_n; with **S. Gelbart**, A relation between automorphic representations of $GL(2)$ and $GL(3)$; with **I. I. Piatetski-Shapiro and J. Shalika**, Conducteur des représentations du groupe linéaire; with **J. A. Shalika**, On Euler products and the classification of automorphic representations. I; with **J. A. Shalika**, On Euler products and the classification of automorphic forms. II; with **K. F. Lai**, A relative trace formula; with **J. A. Shalika**, A lemma on highly ramified ε-factors; Sur un résultat de Waldspurger; Représentations distinguées pour le groupe orthogonal; with **K. F. Lai and S. Rallis**, A trace formula for symmetric spaces; Factorization of period integrals; with **N. Chen**, Positivity of quadratic base change L-functions; Facteurs de transfert pour les intégrales de Kloosterman; Smooth transfer of Kloosterman integrals; Kloosterman identities over a quadratic extension. II.

Collected Works, Volume 23

September 2011, 597 pages, Hardcover, ISBN: 978-0-8218-5356-6, 2010 *Mathematics Subject Classification:* 11F67, 11F70, 11F72, 11R39, 22E55, **AMS members US$109.60**, List US$137, Order code CWORKS/23



Number Theory 2

Introduction to Class Field Theory

Kazuya Kato, *University of Chicago, IL*, **Nobushige Kurokawa**, *Tokyo Institute of Technology, Japan*, and **Takeshi Saito**, *University of Tokyo, Japan*

This book, the second of three related volumes on number theory, is the English translation of the original Japanese book. Here, the idea of class field theory, a highlight in algebraic number theory, is first described with many concrete examples. A detailed account of proofs is thoroughly exposited in the final chapter. The authors also explain the local-global method in number theory, including the use of ideles and adeles. Basic properties of zeta and L-functions are established and used to prove the prime number theorem and the Dirichlet theorem on prime numbers in arithmetic progressions. With this book, the reader can enjoy the beauty of numbers and obtain fundamental knowledge of modern number theory.

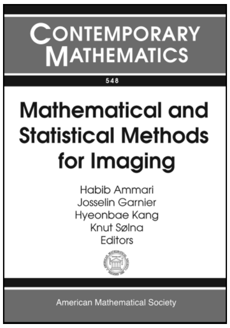
The translation of the first volume was published as *Number Theory 1: Fermat's Dream*, Translations of Mathematical Monographs (*Iwanami Series in Modern Mathematics*), vol. 186, American Mathematical Society, 2000.

Contents: What is class field theory?; Local and global fields; ζ (II); Class field theory (II); Appendix B. Galois theory; Appendix C. Lights of places; Appendix. Answers to questions; Appendix. Answers to exercises; Index.

Translations of Mathematical Monographs (*Iwanami Series in Modern Mathematics*), Volume 240

September 2011, approximately 231 pages, Softcover, ISBN: 978-0-8218-1355-3, LC 99033556, 2010 *Mathematics Subject Classification:* 11-01; 11Mxx, 11Rxx, 11Sxx, **AMS members US$39.20**, List US$49, Order code MMONO/240

Probability and Statistics



Mathematical and Statistical Methods for Imaging

Habib Ammari, *Ecole Normale Supérieure, Paris, France*, **Josselin Garnier**, *Université Paris VII, France*, **Hyeonbae Kang**, *Inha University, Incheon, Korea*, and **Knut Sølna**, *University of California, Irvine, CA*, Editors

This volume contains the proceedings of the NIMS Thematic Workshop on Mathematical and Statistical Methods for Imaging, which was held from August 10–13, 2010, at Inha University, Incheon, Korea.

The goal of this volume is to give the reader a deep and unified understanding of the field of imaging and of the analytical and statistical tools used in imaging. It offers a good overview of the current status of the field and of directions for further research. Challenging problems are addressed from analytical, numerical, and statistical perspectives. The articles are devoted to four main areas: analytical investigation of robustness; hypothesis testing and resolution analysis, particularly for anomaly detection; new efficient imaging techniques; and the effects of anisotropy, dissipation, or attenuation in imaging.

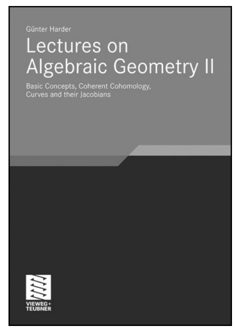
Contents: J. Garnier, Use of random matrix theory for target detection, localization, and reconstruction; **P. Garapon**, Resolution limits in source localization and small inclusion imaging; **S. Gdoura** and **L. G. Bustos**, Transient wave imaging of anomalies: A numerical study; **G. Bao**, **J. Lin**, and **F. Triki**, Numerical solution of the inverse source problem for the Helmholtz equation with multiple frequency data; **M. Lim** and **S. Yu**, Reconstruction of the shape of an inclusion from elastic moment tensors; **J. C. Schotland**, Path integrals and optical tomography; **K. Jeon** and **C.-O. Lee**, Denoising of B_z data for conductivity reconstruction in magnetic resonance electrical impedance tomography (MREIT); **D. G. Alfaro Vigo** and **K. Sølna**, Time reversal for inclusion detection in one-dimensional randomly layered media; **E. Bretin** and **A. Wahab**, Some anisotropic viscoelastic Green functions; **H. Ammari**, **E. Bretin**, **J. Garnier**, and **A. Wahab**, Time reversal in attenuating acoustic media.

Contemporary Mathematics, Volume 548

August 2011, 163 pages, Softcover, ISBN: 978-0-8218-5289-7, LC 2011011086, 2010 *Mathematics Subject Classification:* 35R30, 35A20, 35B40, 44A12, 78M05, 78M25, 78A45, **AMS members US$55.20**, List US$69, Order code CONM/548

New AMS-Distributed Publications

Algebra and Algebraic Geometry



Lectures on Algebraic Geometry II

Basic Concepts, Coherent Cohomology, Curves and Their Jacobians

Günter Harder, *Max Planck Institute for Mathematics, Bonn, Germany*

This second volume introduces the concept of schemes, reviews some commutative algebra, and introduces projective schemes. The finiteness theorem for coherent sheaves is proved; here again the techniques of homological algebra and sheaf cohomology are needed. In the last two chapters, projective curves over an arbitrary ground field are discussed, the theory of Jacobians is developed, and the existence of the Picard scheme is proved.

Finally, the author explores further developments—for instance, étale cohomology—and states some fundamental theorems.

A publication of Vieweg+Teubner. The AMS is exclusive distributor in North America. Vieweg+Teubner Publications are available worldwide from the AMS outside of Germany, Switzerland, Austria, and Japan.

Contents: Basic concepts of the theory of schemes; Some commutative algebra; Projective schemes; Curves and the theorem of Riemann–Roch; The Picard functor for curves and Jacobians.

Vieweg Aspects of Mathematics, Volume 41

April 2011, 365 pages, Hardcover, ISBN: 978-3-8348-0432-7, 2010 *Mathematics Subject Classification:* 14-XX, **AMS members US$80.95**, List US$89.95, Order code VWAM/41

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MSRI invites applications for 40 Research Professors, 200 Research Members, and 30 semester-long Post-Doctoral Fellows in the following programs: Cluster Algebras (August 20 to December 21, 2012), Commutative Algebra (August 20, 2012 to May 24, 2013) , and Noncommutative Algebraic Geometry and Representation Theory (January 14, 2013 to May 24, 2013). Research Professorships are intended for senior researchers who will be making key contributions to a program, including the mentoring of postdoctoral fellows, and who will be in residence for three or more months. Research Memberships are intended for researchers who will be making contributions to a program and who will be in residence for one or more months. Post-Doctoral Fellowships are intended for recent Ph.D.s. Interested individuals should carefully describe the purpose of their proposed visit, and indicate why a residency at MSRI will advance their research program. To receive full consideration, application must be complete, including all letters of support by the following deadlines: Research Professorships, October 01, 2011; Research Memberships, December 01, 2011; Post-doctoral Fellowships, December 01, 2011. It is the policy of MSRI actively to seek to achieve diversity in its programs and workshops. Thus, a strong effort is made to remove barriers that hinder equal opportunity, particularly for those groups that have been historically underrepresented in the mathematical sciences. Application information: `http://www.msri.org/propapps/applications/application_material`.

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Suggested uses for classified advertising are positions available, books or lecture notes for sale, books being sought, exchange or rental of houses, and typing services.

The 2011 rate is \$3.25 per word. No discounts for multiple ads or the same ad in consecutive issues. For an additional \$10 charge, announcements can be placed anonymously. Correspondence will be forwarded.

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Upcoming deadlines for classified advertising are as follows:September 2011 issue–June 28, 2011; October 2011 issue–July 28, 2011; November 2011 issue–August 30, 2011; December 2011 issue–December 28, 2011; January 2012 issue–October 31, 2011.

U.S. laws prohibit discrimination in employment on the basis of color, age, sex, race, religion, or national origin. "Positions Available" advertisements from institutions outside the U.S. cannot be published unless they are accompanied by a statement that the institution does not discriminate on these grounds whether or not it is subject to U.S. laws. Details and specific wording may be found on page 667 (vol. 56).

Situations wanted advertisements from involuntarily unemployed mathematicians are accepted under certain conditions for free publication. Call toll-free 800-321-4AMS (321-4267) in the U.S. and Canada or 401-455-4084 worldwide for further information.

Submission: Promotions Department, AMS, P.O. Box 6248, Providence,Rhode Island 02940; or via fax: 401-331-3842; or send email to`classads@ams.org`. AMS location for express delivery packages is 201 Charles Street, Providence, Rhode Island 20904. Advertisers will bebilled upon publication.

Meetings & Conferences of the AMS

IMPORTANT INFORMATION REGARDING MEETINGS PROGRAMS: AMS Sectional Meeting programs do not appear in the print version of the *Notices*. However, comprehensive and continually updated meeting and program information with links to the abstract for each talk can be found on the AMS website. See `http://www.ams.org/meetings/`. Final programs for Sectional Meetings will be archived on the AMS website accessible from the stated URL and in an electronic issue of the *Notices* as noted below for each meeting.

Ithaca, New York

Cornell University

September 10–11, 2011
Saturday – Sunday

Meeting #1072
Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: July 2011
Program first available on AMS website: July 28, 2011
Program issue of electronic *Notices*: September 2011
Issue of *Abstracts*: Volume 32, Issue 4

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: Expired
For abstracts: Expired

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Mladen Bestvina, University of Utah, *Topology and geometry of out(F_n)*.

Nigel Higson, Pennsylvania State University, *C*-algebras and group representations*.

Gang Tian, Princeton University, *Title to be announced*.

Katrin Wehrheim, Massachusetts Institute of Technology, *How to construct topological invariants via decompositions and the symplectic category*.

Special Sessions

Analysis, Probability, and Mathematical Physics on Fractals, **Luke Rogers**, University of Connecticut, **Robert Strichartz**, Cornell University, and **Alexander Teplyaev**, University of Connecticut.

Difference Equations and Applications, **Michael Radin**, Rochester Institute of Technology.

Gauge Theory and Low-dimensional Topology, **Weimin Chen**, University of Massachusetts-Amherst, and **Daniel Ruberman**, Brandeis University.

Geometric Aspects of Analysis and Measure Theory, **Leonid Kovalev** and **Jani Onninen**, Syracuse University, and **Raanan Schul**, State University of New York at Stony Brook.

Geometric Structures on Manifolds with Special Holonomy, and Applications in Physics, **Tamar Friedmann**, University of Rochester, **Colleen Robles**, Texas A&M University, and **Sema Salur**, University of Rochester.

Geometric and Algebraic Topology, **Boris Goldfarb** and **Marco Varisco**, University at Albany, SUNY.

Geometry of Arithmetic Groups, **Mladen Bestvina**, University of Utah, and **Ken Brown**, **Martin Kassabov**, and **Tim Riley**, Cornell University.

Kac-Moody Lie Algebras, Vertex Algebras, and Related Topics, **Alex Feingold**, Binghamton University, and **Antun Milas**, State University of New York at Albany.

Mathematical Aspects of Cryptography and Cyber Security, **Benjamin Fine**, Fairfield University, **Delaram Kahrobaei**, City University of New York, and **Gerhard Rosenberger**, Passau University and Hamburg University, Germany.

Multivariable Operator Theory, **Ronald G. Douglas**, Texas A&M University, and **Rongwei Yang**, State University of New York at Albany.

Parabolic Evolution Equations of Geometric Type, **Xiaodong Cao**, Cornell University, and **Bennett Chow**, University of California San Diego.

Partial Differential Equations of Mixed Elliptic-Hyperbolic Type and Applications, **Marcus Khuri**, Stony Brook University, and **Dehua Wang**, University of Pittsburgh.

Representations of Local and Global Groups, **Mahdi Asgari**, Oklahoma State University, and **Birgit Speh**, Cornell University.

Set Theory, **Paul Larson**, Miami University, Ohio, **Justin Moore**, Cornell University, and **Ernest Schimmerling**, Carnegie Mellon University.

Species and Hopf Algebraic Combinatorics, **Marcelo Aguiar**, Texas A&M University, and **Samuel Hsiao**, Bard College.

Symplectic Geometry and Topology, **Tara Holm**, Cornell University, and **Katrin Wehrheim**, Massachusetts Institute of Technology.

Winston-Salem, North Carolina

Wake Forest University

September 24–25, 2011

Saturday – Sunday

Meeting #1073

Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: June 2011
Program first available on AMS website: August 11, 2011
Program issue of electronic *Notices*: September 2011
Issue of *Abstracts*: Volume 32, Issue 4

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: Expired
For abstracts: August 2, 2011

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Benjamin B. Brubaker, Massachusetts Institute of Technology, *Square ice, symmetric functions, and their connections to automorphic forms*.

Shelly Harvey, Rice University, *4-dimensional equivalence relations on knots*.

Allen Knutson, Cornell University, *Modern developments in Schubert calculus*.

Seth M. Sullivant, North Carolina State University, *Algebraic statistics*.

Special Sessions

Algebraic and Geometric Aspects of Matroids (Code: SS 1A), **Hoda Bidkhori**, **Alex Fink**, and **Seth Sullivant**, North Carolina State University.

Applications of Difference and Differential Equations to Biology (Code: SS 2A), **Anna Mummert**, Marshall University, and **Richard C. Schugart**, Western Kentucky University.

Combinatorial Algebraic Geometry (Code: SS 6A), **W. Frank Moore**, Wake Forest University and Cornell University, and **Allen Knutson**, Cornell University.

Extremal Combinatorics (Code: SS 7A), **Tao Jiang**, Miami University, and **Linyuan Lu**, University of South Carolina.

Geometric Knot Theory and its Applications (Code: SS 12A), **Yuanan Diao**, University of North Carolina at Charlotte, **Jason Parsley**, Wake Forest University, and **Eric Rawdon**, University of St. Thomas.

Low-Dimensional Topology and Geometry (Code: SS 13A), **Shelly Harvey**, Rice University, and **John Etnyre**, Georgia Institute of Technology.

Modular Forms, Elliptic Curves, and Related Topics (Code: SS 11A), **Matthew Boylan**, University of South Carolina, and **Jeremy Rouse**, Wake Forest University.

New Developments in Graph Theory (Code: SS 10A), **Joshua Cooper** and **Kevin Milans**, University of South Carolina, and **Carlos Nicolas** and **Clifford Smyth**, University of North Carolina at Greensboro.

Noncommutative Algebra (Code: SS 5A), **Ellen E. Kirkman** and **James J. Kuzmanovich**, Wake Forest University.

Nonlinear Boundary Value Problems (Code: SS 9A), **Maya Chhetri**, University of North Carolina at Greensboro, and **Stephen B. Robinson**, Wake Forest University.

Nonlinear Dispersive Equations (Code: SS 4A), **Sarah Raynor**, Wake Forest University, **Jeremy Marzuola**, University of North Carolina at Chapel Hill, and **Gideon Simpson**, University of Toronto.

Recent Advances in Infectious Disease Modeling (Code: SS 8A), **Fred Chen** and **Miaohua Jiang**, Wake Forest University.

Set Theoretic Topology (Code: SS 14A), **Peter Nyikos**, University of South Carolina.

Symmetric Functions, Symmetric Group Characters, and Their Generalizations (Code: SS 3A), **Sarah Mason**, Wake Forest University, **Aaron Lauve**, Loyola University-Chicago, and **Ed Allen**, Wake Forest University.

Lincoln, Nebraska

University of Nebraska-Lincoln

October 14–16, 2011

Friday – Sunday

Meeting #1074

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: August 2011
Program first available on AMS website: September 1, 2011
Program issue of electronic *Notices*: October 2011
Issue of *Abstracts*: Volume 32, Issue 4

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: Expired
For abstracts: August 23, 2011

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Lewis P. Bowen, Texas A&M University, *Entropy theory for actions of sofic groups*.

Emmanuel Candes, Stanford University, *Recovering the unseen: Some recent advances in low-rank matrix reconstruction* (Erdős Memorial Lecture).

Alina Cojocaru, University of Illinois at Chicago and Mathematics Institute of the Romanian Academy, *Questions about the reductions modulo primes of an elliptic curve*.

Michael Zieve, University of Michigan, *The happy marriage between arithmetic geometry and dynamical systems*.

Special Sessions

Algebraic Geometry and Graded Commutative Algebra (Code: SS 8A), **Susan Cooper** and **Brian Harbourne**, University of Nebraska-Lincoln.

Algorithmic and Geometric Properties of Groups and Semigroups (Code: SS 10A), **Susan Hermiller** and **John Meakin**, University of Nebraska-Lincoln.

Association Schemes and Related Topics (Code: SS 1A), **Sung Y. Song**, Iowa State University, and **Paul Terwilliger**, University of Wisconsin Madison.

Asymptotic Behavior and Regularity for Nonlinear Evolution Equations (Code: SS 4A), **Petronela Radu** and **Lorena Bociu**, University of Nebraska-Lincoln.

Coding Theory (Code: SS 7A), **Christine Kelley** and **Judy Walker**, University of Nebraska-Lincoln.

Commutative Algebra (Code: SS 16A), **Christina Eubanks-Turner**, University of Louisiana at Lafayette, and **Aihua Li**, Montclair State University.

Computational and Applied Mathematics (Code: SS 13A), **Ludwig Kohaupt**, Beuth University of Technology Berlin, Germany, and **Yan Wu**, Georgia Southern University.

Continuous and Numerical Analysis in the Control of PDE's (Code: SS 9A), **George Avalos**, **Mohammad Rammaha**, and **Daniel Toundykov**, University of Nebraska-Lincoln.

Discrete Methods and Models in Biomathematics (Code: SS 18A), **Dora Matache** and **Jim Rogers**, University of Nebraska at Omaha, and **Alan Veliz-Cuba**, University of Nebraska-Lincoln.

Dynamic Systems on Time Scales with Applications (Code: SS 3A), **Lynn Erbe** and **Allan Peterson**, University of Nebraska-Lincoln.

Dynamical Systems and Operator Algebras (Code: SS 15A), **Lewis Bowen**, Texas A&M University, and **David Kerr**, Texas A&M University at Galveston.

Extremal and Probabilistic Combinatorics (Code: SS 5A), **Stephen Hartke** and **Jamie Radcliffe**, University of Nebraska-Lincoln.

Invariants in Knot Theory and Low-dimensional Topology (Code: SS 14A), **Mark Brittenham**, University of Nebraska-Lincoln, and **Robert Todd**, University of Nebraska at Omaha.

Local Commutative Algebra (Code: SS 11A), **H. Ananthnarayan**, University of Nebraska-Lincoln, **Inês B. Henriques**, University of California Riverside, and **Hamid Rahmati**, Syracuse University.

Matrices and Graphs (Code: SS 12A), **In-Jae Kim**, Minnesota State University, **Adam Berliner**, St. Olaf College, **Leslie Hogben**, Iowa State University, and **Bryan Shader**, University of Wyoming.

Quantum Groups and Representation Theory (Code: SS 2A), **Jonathan Kujawa**, University of Oklahoma, and **Natasha Rozhkovskaya**, Kansas State University.

Recent Directions in Number Theory (Code: SS 17A), **Alina Cojocaru**, University of Illinois at Chicago, and **Michael Zieve**, University of Michigan.

Recent Progress in Operator Algebras (Code: SS 6A), **Allan P. Donsig** and **David R. Pitts**, University of Nebraska-Lincoln.

Graduate Student Poster Session

Graduate students are encouraged to participate in the AMS Poster session to be held 8-9 p.m., Friday, October 14, at the Downtown Holiday Inn. We expect a large crowd (there will be a cash bar), so this is a great chance to publicize your work and get to know people! In order to present a poster, you need to register for the poster session and submit an abstract. You can do this online at the Math Department's poster site: `http://www.math.unl.edu/~math-gsab/2011FallAMSSectionMeeting/AMSGRADPOST.html`. The deadline to submit an abstract is September 30.

Accommodations

Participants should make their own arrangements directly with a hotel of their choice as early as possible. Special rates have been negotiated with the hotels listed below. Rates quoted do not include taxes. The AMS is not responsible for rate changes or for the quality of the accommodations. When making a reservation with a conference hotel, participants should state that they are with the **American Mathematical Society (AMS) Sectional Meeting**. Cancellation and early checkout policies vary; be sure to check when you make your reservation. When making reservations please call the hotel directly and ask for "in house" reservations. You will not receive the conference discount if you book online.

Holiday Inn Downtown, 141 North 9th St., Lincoln, NE, 68508; Phone: 402–475–4011, fax: 402–475–4366; `http://www.holidayinn.com/hotels/us/en/lincoln/lnkdt/hoteldetail`. Rates are US$94 single, US$99 double, and include free WiFI, and complimentary breakfast. The hotel is only about four blocks away from the meeting site on campus. A shuttle to the airport is available on request. Cancellation and early checkout policies vary; be sure to check when you make your reservation. The deadline for reservations is **September 15, 2011**.

Embassy Suites, 1040 P Street, Lincoln, NE, 68508; Phone: 402-474-1111, `http://www.embassysuiteslincoln.com`. The rate is US$124 for up to 4 people and includes a complimentary breakfast. The hotel is only about three blocks away from the meeting site on campus. A shuttle to the airport is available on request. Cancellation and early checkout policies vary; be sure to check when you make your reservation. The deadline for reservations is **September 15, 2011**.

Cornhusker Marriott, 333 S. 13th Street, Lincoln, NE; Phone: 402–474–7474; `http://www.thecornhusker.com`. Rates are US$89 single/double. The hotel is about seven blocks away from the meeting site on campus. A shuttle to the airport is available on request. Cancellation and early checkout policies vary; be sure to check when you make your reservation. The deadline for reservations is **September 15, 2011**.

Additional Housing Options can be found by visiting the University of Nebraska-Lincoln Mathematics Department website: `http://www.math.unl.edu/events/special/ams/2011/`.

Food Service

A list of on-campus and off-campus restaurants will be available at the registration desk.

Other Activities

Book Sales: Stop by the on-site AMS bookstore and review the newest titles from the AMS, enjoy up to 25% percent off all AMS publications, or take home an AMS t-shirt! Complimentary coffee will be served courtesy of AMS Membership Services.

AMS Editorial Activity: An acquisitions editor from the AMS book program will be present to speak with prospective authors. If you have a book project that you would like to discuss with the AMS, please stop by the book exhibit.

Parking

The closest public parking to the meeting site is found at the Stadium Drive parking garage.

From the Lincoln airport take I-80 to the Downtown exit I-180 (401A) going south. When you enter downtown Lincoln, you will be on 9th street, you will need to be in the far left lane. Turn left onto P Street; turn left onto 10th Street. You want to be in the far right lane once on 10th Street. After Q Street, you will want to take the second right which is T Street. Entry to parking garage will be to your left. Cost is about US$1 per hour up to a maximum of US$5 per day.

There are also a number of parking garages within a short walk (5–10 minute) from campus. Haymarket, Market Place, and Que Place are the three closest. For more information please see `http://www.ParkItDowntown.org`. Handicapped parking permits are available upon prior request; contact Marilyn Johnson at `mjohnson11@math.unl.edu`.

Registration and Meeting Information

Registration and the AMS Book Exhibit will be held in the lower level lobby of Avery Hall. Invited Addresses and all other sessions will be held in Avery Hall and nearby buildings. Please refer to the campus map at `http://maps.unl.edu/` for specific locations. The registration desk will be open on Friday, October 14, 2:00 p.m.–5:30 p.m. and Saturday, October 15, 7:30 a.m.–4:00 p.m. Fees are US$52 for AMS members, US$72 for nonmembers; and US$5 for students, unemployed mathematicians, and emeritus members. Fees are payable on-site via cash, check or credit card.

Special Social Event

The University of Nebraska Mathematics Department is hosting a reception on Saturday evening, October 15, between 5:30 p.m. and 6:30 p.m. following the **Erdős Lecture.** Join us for refreshments, hors d'oeuvres, and a cash bar.

Travel

By Plane: The University of Nebraska-Lincoln campus is four miles from the Lincoln Municipal Airport (LNK), which is served by Delta and United.

It is also possible to fly into Omaha (OMA), rent a car, and drive the 60-mile distance to Lincoln. Or take one of the two shuttles listed below from Omaha to Lincoln.

By Car: From I-80 take the Downtown exit I-180 (401A) going south, you will see Memorial Stadium on your left (difficult to miss). As I-180 South ends, it becomes 9th Street in downtown Lincoln. The first intersection you will approach will be 9th and Q Street. (The Downtown Holiday Inn is one block directly ahead on the right.)

To get to Avery Hall, you should get into the far left lane and turn left on P Street (one way), then turn left again on 10th street and work your way over to the farthest right lane on 10th street, so that you can turn right on T street—it comes just after a bend in the road. Then you can go left into a big parking garage. Avery Hall is the three-story building about 100 yards directly east of south entrance of the parking garage.

By bus or train: Amtrak train and Greyhound bus services are available into the Lincoln, Nebraska, area. Please check transportation availability from your area by visiting `www.Amtrak.com` or `www.greyhound.com`. Taxi service is available to the university from all mass transit locations.

Car Rental

Hertz Rent A Car is the official car rental company for the meeting. Depending on variables such as location, length of rental, and size of vehicle, Hertz will offer participants the best available rate which can range from 5-25 percent discount off regular rates. Participants must use the assigned Meeting Hertz Discount Number (**CV#04N30001**) and meet Hertz rate requirements to receive the discount. (Rate discounts are available at all corporate and participating licensee locations.) Reservations can be made by calling 800-654-2240 or online at `www.hertz.com`.

Weather

Climate summary for the month of October for Lincoln, NE:

Average High Temperature - 64° F or 18° C
Average Low Temperature - 41° F or 5° C
Average Monthly Precipitation - 2.3 inches or 5.8 cm

Information for International Participants

Visa regulations are continually changing for travel to the United States. Visa applications may take from three to four months to process and require a personal interview, as well as specific personal information. International participants should view the important information about traveling to the U.S. found at `http://sites.nationalacademies.org/pga/biso/visas/` and http://travel.state.gov/visa/visa_1750.html. If you need a preliminary conference invitation in order to secure a visa, please send your request to pfs@ams.org.

If you discover you do need a visa, the National Academies website (see above) provides these tips for successful visa applications:

* Visa applicants are expected to provide evidence that they are intending to return to their country of residence. Therefore, applicants should provide proof of "binding" or sufficient ties to their home country or permanent residence abroad. This may include documentation of the following:

- family ties in home country or country of legal permanent residence
- property ownership
- bank accounts
- employment contract or statement from employer stating that the position will continue when the employee returns;

* Visa applications are more likely to be successful if done in a visitor's home country than in a third country;

* Applicants should present their entire trip itinerary, including travel to any countries other than the United States, at the time of their visa application;

* Include a letter of invitation from the meeting organizer or the U.S. host, specifying the subject, location and dates of the activity, and how travel and local expenses will be covered;

* If travel plans will depend on early approval of the visa application, specify this at the time of the application;

* Provide proof of professional scientific and/or educational status (students should provide a university transcript).

This list is not to be considered complete. Please visit the websites above for the most up-to-date information.

For additional local information please visit the University of Nebraska's Sectional Meeting website: http://www.math.unl.edu/events/special/ams/2011/.

Salt Lake City, Utah

University of Utah

October 22–23, 2011

Saturday – Sunday

Meeting #1075

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: August 2011
Program first available on AMS website: September 8, 2011
Program issue of electronic *Notices*: October 2011
Issue of *Abstracts*: Volume 32, Issue 4

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: Expired
For abstracts: August 30, 2011

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Graeme Milton, University of Utah, *Metamaterials: High contrast composites with unusual properties.*

Lei Ni, University of California San Diego, *Gap theorems on Kähler manifolds.*

Igor Pak, University of California Los Angeles, *The future of combinatorial bijections.*

Monica Visan, University of California Los Angeles, *Dispersive partial differential equations at critical regularity.*

Special Sessions

Algebraic Geometry (Code: SS 8A), **Tommaso de Fernex** and **Christopher Hacon**, University of Utah.

Applied Analysis (Code: SS 15A), **Marian Bocea**, North Dakota State University, and **Mihai Mihailescu**, University of Craiova Romania.

Category Theory in Graphs, Geometry and Inverse Problems (Code: SS 12A), **Robert Owczarek**, Enfitec. Inc., and **Hanna Makaruk**, Los Alamos National Laboratory NM.

Celestial and Geometric Mechanics (Code: SS 5A), **Lennard Bakker** and **Tiancheng Ouyang**, Brigham Young University.

Commutative Algebra (Code: SS 3A), **Chin-Yi Jean Chan**, Central Michigan University, and **Lance E. Miller** and **Anurag K. Singh**, University of Utah.

Computational and Algorithmic Algebraic Geometry (Code: SS 17A), **Zach Teitler**, Boise State University, and **Jim Wolper**, Idaho State University.

Electromagnetic Wave Propagation in Complex and Random Environments (Code: SS 4A), **David Dobson**, University of Utah, and **Peijun Li**, Purdue University.

Geometric Evolution Equations and Related Topics. (Code: SS 2A), **Andrejs Treibergs**, University of Utah Salt Lake City, **Lei Ni**, University of California San Diego, and **Brett Kotschwar**, Arizona State University.

Geometric, Combinatorial, and Computational Group Theory (Code: SS 1A), **Eric Freden**, Southern Utah University, and **Eric Swenson**, Brigham Young University.

Harmonic Analysis and Dispersive Partial Differential Equations (Code: SS 6A), **Xiaoyi Zhang**, University of Iowa, and **Monica Visan** and **Betsy Stovall**, University of California Los Angeles.

Hypergeometric Functions and Differential Equations (Code: SS 13A), **Laura F. Matusevich**, Texas A&M University, and **Christine Berkesch**, Stockholm University.

Inverse Problems and Homogenization (Code: SS 10A), **Elena Cherkaev** and **Fernando Guevara Vasquez**, University of Utah.

Noncommutative Geometry and Algebra (Code: SS 11A), **Kenneth R. Goodearl**, University of California Santa Barbara, and **Milen Yakimov**, Louisiana State University.

Nonlinear Waves (Code: SS 7A), **Zhi-Qiang Wang** and **Nghiem Nguyen**, Utah State University.

Recent Progress in Numerical Partial Differential Equations (Code: SS 9A), **Jichun Li**, University of Nevada-Las Vegas, and **Shue-Sum Chow**, Brigham Young University.

Reductive Groups and Hecke Algebras (Code: SS 14A), **Dan Ciubotaru**, University of Utah, **Cathy Kriloff**, Idaho State University, and **Peter Trapa**, University of Utah.

Understanding Bio-fluids via Modeling, Simulation and Analysis (Code: SS 16A), **Christel Hohenegger**, University of Utah.

Accommodations

Participants should make their own arrangements directly with a hotel of their choice as early as possible. Special rates have been negotiated with the hotels listed below. Rates quoted do not include taxes. The AMS is not responsible for rate changes or for the quality of the accommodations. When making a reservation with a conference hotel, participants should state that they are with the **American Mathematical Society (AMS) Sectional Meeting**. Cancellation and early checkout policies vary; be sure to check when you make your reservation. When making reservations please call the hotel directly and ask for "in house" reservations.

Salt Lake City Marriott–University Park, 480 Wakara Way, Salt Lake City, UT; reservations: 800-228-9290, group name is under AMS Fall Meeting; hotel direct: 801-581-1000; fax: 801-584-3321; `www.saltlakecitymarriott.com`. Rates are US$89 single/double; includes parking and wireless Internet, complimentary shuttle service within two miles of the hotel, and complimentary parking. The hotel is full-service with an on-site restaurant/bar and is less than one mile from the meeting site on campus. Cancellation and early checkout policies vary; be sure to check when making your reservation. **Deadline for reservations is September 21, 2011**.

University Guest House, 110 South Fort Douglas Blvd., Salt Lake City, UT; 801-587-1000 or 888-416-4075; visit: `www.universityguesthouse.com`; US$89 single/double. **Deadline for reservations is September 21, 2011**. Be sure to mention you are with the **AMS Math Conference** and check cancellation and early checkout policies.

Red Lion Hotel, 161 West 600 South, Salt Lake City, UT; Call 800-RED-LION (800-733-5466). US$84 single, US$89 double; includes "Roaring Start full buffet breakfast". Visit: `www.saltlakecityredlion.com`. **Deadline for reservations is September 23, 2011**. Be sure to mention you are with the **AMS Math Conference** and check cancellation and early checkout policies.

Additional Salt Lake City housing is available at:

Hyatt Place, Salt Lake City/Downtown/The Gateway, 55 North 400 West, Salt Lake City, UT 84101; Phone: 801-456-6300.

Hilton, 255 South West Temple, Salt Lake City, UT 84101; Phone: 801-328-2000 or 877-776-4936.

Food Service

There are a number of restaurants adjacent to the campus. A list of restaurants will be available at the registration desk.

Local Information

Please visit the website maintained by the Department of Mathematics at `www.math.utah.edu`, the University of Utah website `www.utah.edu`., or Salt Lake Convention and Visitors Bureau site at `www.visitsaltlake.com`.

Other Activities

Book Sales: Stop by the on-site AMS bookstore and review the newest titles from the AMS, enjoy up to 25 percent off all AMS publications, or take home an AMS t-shirt! Complimentary coffee will be served courtesy of AMS Membership Services.

AMS Editorial Activity: An acquisitions editor from the AMS book program will be present to speak with prospective authors. If you have a book project that you would like to discuss with the AMS, please stop by the book exhibit.

Parking

Parking is not enforced on weekends (except in the obvious do not park zones and special reserved spots) and participants can park in any of the posted lots free of charge. (See map at `http://www.map.utah.edu/`).

Registration and Meeting Information

Registration and AMS Book Exhibit will be held in the John Widtsoe Building (JWB). Invited Addresses and the book sale will also be in this room. All other sessions will be held in nearby buildings. Please refer to the campus map at `http://www.map.utah.edu/index.html` for specific locations. The registration desk will be open on Saturday, October 22, 7:30 a.m.–4:00 p.m. and Sunday, October 23, 7:30 a.m.–12:00 p.m. Fees are US$52 for AMS members, US$72 for nonmembers; and US$5 for students, unemployed mathematicians, and emeritus members. Fees are payable on-site via cash, check or credit card.

Travel

By Air: The Salt Lake City International Airport is served by most major airlines and is located ten minutes from downtown Salt Lake City. Taxi fare is approximately US$25–US$30.

Driving: From the Salt Lake International Airport: Take I-80 East approximately 1.5 miles to the North Temple exit. Follow North Temple approximately 3 miles to State Street (one block beyond the Mormon Temple). Turn right on State Street and go south three blocks to 200 South. Turn left proceeding east on 200 South for approximately 2 miles until you reach University Street (1400 East).

From I-15 Northbound: Take the eastbound 600 South exit. At State Street turn left, proceeding 4 blocks north until you reach 200 South. Turn right proceeding east on 200 South for approximately 2 miles until you reach University Street (1400 East).

From I-15 South Bound: Take the eastbound 600 South exit. At 300 West turn right proceeding approximately 1.5 miles south until you reach 200 South. Turn left proceeding east on 200 South for approximately 2 miles until you reach University Street (1400 East).

Once you get to University Street you will be facing “President’s Circle”. This is a one-way street that you enter on the south. Drive ¾ of the way around the circle to the Mathematics Complex.

By bus or train: Amtrak train and Greyhound bus services are available into the Salt Lake City, Utah, area. Both services are very convenient to recommended hotels as the terminal is based downtown. Please check transportation availability from your area by visiting `www.Amtrak.com` or `www.greyhound.com`. Taxi and bus service is available from hotels to the university.

Car Rental

Hertz Rent A Car is the official car rental company for the meeting. Depending on variables such as location, length of rental, and size of vehicle, Hertz will offer participants the best available rate which can range from 5–25 percent discount off regular rates. Participants must use the assigned Meeting Hertz Discount Number (**CV#04N30001**) and meet Hertz rate requirements to receive the discount. (Rate discounts are available at all corporate and participating licensee locations.) Reservations can be made by calling 800-654-2240 or online at `www.hertz.com`.

Weather

Temperatures vary from 70 F to 50 F in October. Fall is the favorite season of many who visit and live in Utah. Vibrant colors splash across the mountains and canyons as the cooler temperatures turn the leaves all shades of gold, purple, red, green, and brown. For up-to-date forecasts visit: `www.visitsaltlake.com`.

Information for International Participants

Visa regulations are continually changing for travel to the United States. Visa applications may take from three to four months to process and require a personal interview, as well as specific personal information. International participants should view the important information about traveling to the U.S. found at `http://sites.nationalacademies.org/pga/biso/visas/` and `http://travel.state.gov/visa/visa_1750.html`. If you need a preliminary conference invitation in order to secure a visa, please send your request to `pfs@ams.org`.

If you discover you do need a visa, the National Academies website (see above) provides these tips for successful visa applications:

* Visa applicants are expected to provide evidence that they are intending to return to their country of residence. Therefore, applicants should provide proof of “binding” or sufficient ties to their home country or permanent residence abroad. This may include documentation of the following:

- family ties in home country or country of legal permanent residence

- property ownership

- bank accounts

- employment contract or statement from employer stating that the position will continue when the employee returns;

* Visa applications are more likely to be successful if done in a visitor’s home country than in a third country;

* Applicants should present their entire trip itinerary, including travel to any countries other than the United States, at the time of their visa application;

* Include a letter of invitation from the meeting organizer or the U.S. host, specifying the subject, location and dates of the activity, and how travel and local expenses will be covered;

* If travel plans will depend on early approval of the visa application, specify this at the time of the application;

* Provide proof of professional scientific and/or educational status (students should provide a university transcript).

This list is not to be considered complete. Please visit the websites above for the most up-to-date information.

Port Elizabeth, Republic of South Africa

Nelson Mandela Metropolitan University

November 29 – December 3, 2011

Tuesday – Saturday

Meeting #1076

First Joint International Meeting between the AMS and the South African Mathematical Society.
Associate secretary: Matthew Miller
Announcement issue of *Notices*: July 2011
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Not applicable

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/internmtgs.html`.

Invited Addresses

Mark J. Ablowitz, University of Colorado, *Nonlinear systems—from oceans to number theory*.

Mikhail Petrov, University of Swaziland, *Title to be announced*.

James Raftery, University of Kwazulu Natal, *Title to be announced*.

Daya Reddy, University of Cape Town, *Title to be announced*.

Peter Sarnak, Princeton University, *Title to be announced*.

Amanda Weltman, University of Cape Town, *Title to be announced.*

Special Sessions

Combinatorial and Computational Group Theory with Applications, **Gilbert Baumslag**, City College of New York, **Mark Berman**, University of Cape Town, and **Vladimir Shpilrain**, City College of New York.

Combinatorics and Graph Theory, **Michael Henning**, University of Johannesburg, **Robin Thomas**, Georgia Institute of Technology, and **Jacques Verstraete**, University of California, San Diego.

Finite Groups and Combinatorial Structures, **Jashmid Moori**, North-West University, Mafikeng, and **B. Rodrigues**, University of Kwazulu-Natal, Westville.

Geometry and Differential Equations, **Jesse Ratzkin**, University of Cape Town.

High Performance Computing and Imaging, **Steven B. Damelin**, Georgia Southern University and University of the Witswatersrand, and **Hari Kumar**, University of the Witswatersrand.

Nonlinear Waves and Integrable Systems, **Mark Ablowitz**, University of Colorado at Boulder, and **Barbara Prinari**, University of Colorado at Colorado Springs.

Operator and Banach Algebras, and Noncommutative Analysis, **David Blecher**, University of Houston, **Garth Dales**, University of Leeds, **Louis Labuschagne**, North-West University, Potchefstroom Campus, and **Anton Stroh**, University of Pretoria.

Recent Advances in Computational Methods for Partial Differential Equations, **Kailash C. Patidar**, University of the Western Cape.

Topology and Categories, **Hans-Peter Kuenzi**, University of Cape Town.

Boston, Massachusetts

John B. Hynes Veterans Memorial Convention Center, Boston Marriott Hotel, and Boston Sheraton Hotel

January 4–7, 2012

Wednesday – Saturday

Meeting #1077

Joint Mathematics Meetings, including the 118th Annual Meeting of the AMS, 95th Annual Meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: October 2011
Program first available on AMS website: November 1, 2011
Program issue of electronic *Notices*: January 2012
Issue of *Abstracts*: Volume 33, Issue 1

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: July 28, 2011
For abstracts: September 22, 2011

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/national.html`.

Joint Invited Addresses

Erik Demaine, Massachusetts Institute of Technology, *Title to be announced* (AMS-MAA-SIAM Gerald and Judith Porter Public Lecture).

AMS Invited Addresses

George E. Andrews, Penn State University, *Title to be announced* (AMS Retiring Presidential Address).

Bradley Efron, Stanford University, *Title to be announced* (AMS Josiah Willard Gibbs Lecture).

Edward Frenkel, University of California Berkeley, *Langlands program, trace formulas, and their geometrization, I* (AMS Colloquium Lectures: Lecture I).

Edward Frenkel, University of California Berkeley, *Langlands program, trace formulas, and their geometrization, II* (AMS Colloquium Lectures: Lecture II).

Edward Frenkel, University of California Berkeley, *Langlands program, trace formulas, and their geometrization, III* (AMS Colloquium Lectures: Lecture III).

Larry Guth, University of Toronto, *The polynomial method in combinatorial geometry*.

Assaf Naor, Courant Institute of Mathematical Sciences, *The Ribe program*.

Eric Rains, California Institute of Technology, *Beyond q: Special functions on elliptic curves*.

Wilhelm Schlag, University of Chicago, *Invariant manifolds and dispersive Hamiltonian evolution equations*.

AMS Special Sessions

Some sessions are cosponsored with other organizations. These are noted within the parenthesis at the end of each listing, where applicable.

Advanced Investigations on Applied Optimization and Multiple Fractional Programming (Code: SS 6A), **Ram U. Verma**, Texas A&M University, and **Alexander J. Zaslavski**, Technion, Israel.

Advances in Coding Theory (Code: SS 10A), **Sarah Spence Adams**, Olin College of Engineering, **Gretchen L. Matthews**, Clemson University, and **Judy L. Walker**, University of Nebraska-Lincoln.

Advances in Mathematical Biology (Code: SS 56A), **David Chan** and **Rebecca Segal**, Virginia Commonwealth University.

Algebraic and Geometric Aspects of Integrable Systems and Random Matrices (Code: SS 58A), **Anton Dzhamay**, University of Northern Colorado, and **Kenichi Maruno** and **Virgil Pierce**, University of Texas, Pan American.

Arithmetic Geometry (Code: SS 51A), **Bo-Hae Im**, Chung-Ang University, South Korea, **Jennifer Johnson-Leung**, University of Idaho, and **Jennifer Paulhus**, Villanova University.

Calculus of Functors and Its Applications (Code: SS 11A), **Brian Munson** and **Ismar Volic**, Wellesley College.

Classical Fourier Analysis and Partial Differential Equations (Code: SS 27A), **William O. Bray**, University of Maine, and **Mark A. Pinsky**, Northwestern University.

Climate Modeling and Geophysical Fluid Dynamics (Code: SS 39A), **Qingshan Chen**, Florida State University, and **Nathan Glatt-Holtz**, Indiana University.

Combinatorial Geometry of Polytopes (Code: SS 42A), **Egon Schulte**, Northeastern University, and **Asia Ivic Weiss**, York University.

Control Theory and Inverse Problems for Partial Differential Equations (Code: SS 18A), **Shitao Liu**, University of Virginia, and **Ting Zhou**, University of California, Irvine.

Control of Biological and Physical Systems (Code: SS 36A), **Wandi Ding**, Middle Tennessee State University, **Volodymyr Hrynkiv**, University of Houston-Downtown, and **Suzanne Lenhart**, University of Tennessee, Knoxville, and NIMBioS.

Difference Equations and Applications (Code: SS 3A), **Michael Radin**, Rochester Institute of Technology.

Differential Algebraic Geometry and Galois Theory (in memory of Jerald Kovacic) (Code: SS 7A), **Phyllis Joan Cassidy**, Smith College and the City University of New York, **Richard Churchill**, Hunter College and Graduate Center at CUNY, **Claude Mitschi**, Université de Strasbourg, France, and **Michael Singer**, North Carolina State University.

Dynamical Systems in Algebraic and Arithmetic Geometry (Code: SS 19A), **Patrick Ingram**, University of Waterloo, Canada, **Michelle Manes**, University of Hawaii, Honolulu, and **Clayton Petsche**, Hunter College (CUNY).

Enumerative and Algebraic Combinatorics (Code: SS 40A), **Ira Gessel**, Brandeis University, and **Alexander Posnikov** and **Richard Stanley**, Massachusetts Institute of Technology.

Fractal Geometry in Pure and Applied Mathematics (in memory of Benoit Mandelbrot) (Code: SS 4A), **Michael L. Lapidus**, University of California, Riverside, **Erin Pearse**, University of Oklahoma, and **Machiel van Frankenhuijsen**, Utah Valley University.

Fractional, Hybrid, and Stochastic Dynamical Systems with Applications (Code: SS 12A), **John Graef**, University of Tennessee at Chattanooga, **Gangaram S. Ladde**, University of South Florida, Tampa, and **Aghala S. Vatsala**, University of Louisiana at Lafayette.

Frontiers in Geomathematics (Code: SS 55A), **Willi Freeden**, University of Kaiserslautern, **Volker Michel**, University of Siegen, and **M. Zuhair Nashed**, University of Central Florida.

Generalized Cohomology Theories in Engineering Practice (Code: SS 37A), **Robert Kotiuga**, Boston University.

Geometric Invariants of Groups and Related Topics (Code: SS 14A), **Nic Koban**, University of Maine, Farmington, and **Peter N. Wong**, Bates College.

Global Dynamics of Rational Difference Equations with Applications (Code: SS 33A), **Mustafa R. S. Kulenovic**, **Gerasimos Ladas**, and **Orlando Merino**, University of Rhode Island.

Groups, Algorithms, Complexity, and Theory of Security (Code: SS 28A), **Maggie Habeeb** and **Delaram Kahrobaei**, City University of New York.

History of Mathematics (Code: SS 65A), **Sloan Despeaux**, Western Carolina University, **Craig Fraser**, University of Toronto, and **Deborah Kent**, Hillsdale College (AMS-MAA).

Homotopy Theory (Code: SS 5A), **Mark Behrens**, Massachusetts Institute of Technology, **Mark W. Johnson**, Pennsylvania State University, Altoona, **Haynes R. Miller**, Massachusetts Institute of Technology, **James Turner**, Calvin College, and **Donald Yau**, Ohio State University.

Hyperbolicity in Manifolds and Groups (Code: SS 25A), **David Futer**, Temple University, and **Genevieve Walsh**, Tufts University.

Knot Theory (Code: SS 0A), **Tim Cochran** and **Shelly Harvey**, Rice University.

Linear Algebraic Groups: Their Arithmetic, Geometry, and Representations (Code: SS 49A), **R. Skip Garibaldi**, Emory University, and **George McNinch**, Tufts University.

Local Field Properties, Microstructure, and Multiscale Modeling of Heterogeneous Media (Code: SS 23A), **Silvia Jiménez** and **Bogdan Vernescu**, Worcester Polytechnic Institute.

Mathematical Principles and Theories of Integrable Systems (Code: SS 35A), **Wen-Ziu Ma**, University of South Florida, **Syed Tauseef Mohyud-Din**, HITEC University, and **Zhijun Qiao**, University of Texas, Pan American.

Mathematical Theory of Control of Quantum Systems (Code: SS 38A), **Francesca Albertini**, University of Padua, **Domenico D'Alessandro**, Iowa State University, **Raffaele Romano**, University of Trieste, and **Francesco Ticozzi**, University of Padua.

Mathematics and Education Reform (Code: SS 41A), **William Barker**, Bowdoin College, **William McCallum**, University of Arizona, and **Bonnie Saunders**, University of Illinois at Chicago (AMS-MAA-MER).

Mathematics and Statistics in Computational Biology. (Code: SS 52A), **Mark A. Kon**, Boston University.

Mathematics in Industry (Code: SS 34A), **Kirk E. Jordan**, IBM T. J. Watson Research, **Donald Schwendeman**, Rensselaer Polytechnic Institute, and **Burt S. Tilley** and **Suzanne L. Weekes**, Worcester Polytechnic Institute.

Mathematics in Natural Resource Modeling (Code: SS 9A), **Catherine Roberts**, College of the Holy Cross.

Mathematics of Computation: Algebra and Number Theory (Code: SS 16A), **Jean-Marc Couveignes**, Université de Toulouse, **Michael J. Mossinghoff**, Davidson College, and **Igor E. Shparlinski**, Macquarie University, Australia (AMS-SIAM).

Mathematics of Computation: Differential Equations, Linear Algebra, and Applications (Code: SS 26A), **Chi-Wang Shu**, Brown University (AMS-SIAM).

Mathematics of Decisions, Elections, and Games (Code: SS 57A), **Karl-Dieter Crisman**, Gordon College, **Michael Jones**, *Mathematical Reviews*, and **Michael Orrison**, Harvey Mudd College.

Matrices and Graphs (Code: SS 50A), **Leslie Hogben**, Iowa State University and American Institute of Mathematics, and **Bryan L. Shader**, University of Wyoming.

My Favorite Graph Theory Conjectures (Code: SS 29A), **Ralucca Gera**, Naval Postgraduate School, and **Craig Larson**, Virginia Commonwealth University.

Noncommutative Birational Geometry and Cluster Algebras (Code: SS 44A), **Arkady Berenstein**, University of Oregon, and **Vladimir Retakh**, Rutgers University.

Nonlinear Analysis of Partial Differential Equation Models in Biology and Chemical Physics (Code: SS 48A), **Zhonghai Ding**, University of Nevada, Las Vegas, and **Zhaosheng Feng**, University of Texas-Pan American.

Nonlinear Hyperbolic Partial Differential Equations (Code: SS 32A), **Barbara Lee Keyfitz** and **Charis Tsikkou**, Ohio State University (AMS-AWM).

Operator Theory on Analytic Function Spaces (Code: SS 43A), **Robert F. Allen**, University of Wisconsin, La Crosse, and **Katherine C. Heller** and **Matthew A. Pons**, North Central College.

Optimal Control in Applied Mathematical Modeling (Code: SS 45A), **Natali Hritonenko**, Prairie View A&M University, and **Yuri Yatsenko**, Houston Baptist University.

Progress in Free Analysis (Code: SS 46A), **J. William Helton**, University of California, San Diego, and **Paul S. Muhly**, University of Iowa.

Radon Transforms and Geometric Analysis (in honor of Sigurdur Helgason's 85th birthday) (Code: SS 17A), **Jens Christensen**, University of Maryland, and **Fulton Gonzalez** and **Todd Quinto**, Tufts University.

Rational Points on Varieties (Code: SS 30A), **Jennifer Balakrishnan** and **Bjorn Poonen**, Massachusetts Institute of Technology, **Bianca Viray**, Brown University, and **Kirsten Wickelgren**, Harvard University.

Reaction Diffusion Equations and Applications (Code: SS 31A), **Jerome Goddard II** and **Shivaji Ratnasingham**, Mississippi State University, and **Junping Shi**, College of William and Mary.

Recent Advances in Mathematical Biology, Ecology, and Epidemiology (Code: SS 21A), **Sophia R. Jang**, Texas Tech University, **Andrew L. Nevai**, University of Central Florida, and **Lih-Ing W. Roeger**, Texas Tech University.

Recent Trends in Graph Theory (Code: SS 24A), **Ralucca Gera**, Naval Postgraduate School.

Research in Mathematics by Undergraduates and Students in Post-Baccalaureate Programs (Code: SS 66A), **Bernard Brooks** and **Jobby Jacob**, Rochester Institute of Technology, **Jacqueline Jensen**, Sam Houston State University, and **Darren A Narayan**, Rochester Institute of Technology (AMS-MAA).

Science for Policy and Policy for Science: Career Opportunities at the Intersection of Science and Policy (Code: SS 59A), **Cynthia Robinson** and **Shar Steed**, AAAS Science & Technology Fellowships (AMS-AAAS).

Set-Valued Optimization and Variational Problems (Code: SS 47A), **Andreas H. Hamel**, Yeshiva University, **Akhtar A. Khan**, Rochester Institute of Technology, and **Miguel Sama**, E.T.S.I. Industriales.

Several Complex Variables and Multivariable Operator Theory (Code: SS 8A), **Ronald Douglas**, Texas A&M University, and **John McCarthy**, Washington University.

Some Nonlinear Partial Differential Equations — Theory and Application (Code: SS 54A), **Jerry L. Bona**, University of Illinois, Chicago, and **Laihan Luo**, New York Institute of Technology.

Stability Analysis for Infinite Dimensional Hamiltonian Systems (Code: SS 63A), **Wilhelm Schlag**, University of Chicago, and **Gene Wayne**, Boston University.

Stochastic Analysis (in honor of Hui-Hsiung Kuo) (Code: SS 1A), **Julius Esunge**, University of Mary Washington, and **Aurel Stan**, Ohio State University.

Tensor Categories and Representation Theory (Code: SS 22A), **Deepak Naidu**, Texas A&M University, and **Dmitri Nikshych**, University of New Hampshire.

The Life and Legacy of Alan Turing (Code: SS 13A), **Damir Dzhafarov**, University of Chicago and University of Notre Dame, **Jeff Hirst**, Appalachian State University, and **Carl Mummert**, Marshall University (AMS-ASL).

Theory and Applications of Stochastic Differential and Partial Differential Equations (Code: SS 15A), **Edward Allen**, Texas Tech University, **Mahmoud Anabtawi**, American University of Sharjah, **Armando Arciniega**, University of Texas at San Antonio, **Gangaram S. Ladde**, University of South Florida, and **Sivapragasam Sathananthan**, Tennessee State University.

Topological Graph Theory: Structure and Symmetry (Code: SS 20A), **Jonathan L. Gross**, Columbia University, and **Thomas W. Tucker**, Colgate University.

Trends in Representation Theory (Code: SS 2A), **Donald King**, Northeastern University, and **Alfred Noel**, University of Massachusetts, Boston.

Uniformly and Partially Hyperbolic Dynamical Systems (Code: SS 53A), **Todd Fisher**, Brigham Young University, and **Boris Hasselblatt**, Tufts University.

Call for MAA Contributed Papers

The MAA Committee on Contributed Paper Sessions solicits contributed papers pertinent to the sessions listed below. Contributed Paper Session presentations are limited to fifteen minutes, except in the general session where they are limited to ten minutes. Each session room is equipped with a computer projector, an overhead projector, and a screen. Please note that the dates and times scheduled for these sessions remain tentative.

Arts and Mathematics, Together Again, organized by **Douglas E. Norton**, Villanova University; Thursday morning and afternoon. SIGMAA-Arts again sponsors its series of sessions on the connections between Mathematics and the Arts. Mathematical interpretations, analysis, constructions, or motivations for art; aesthetic interpretations, analysis, constructions, or motivations for mathematics; visual or verbal or vocal, dance or drama, geometry or algebra or number theory or topology, theoretical discoveries or teaching experiences: all are welcome! Come! Contribute! Share! Learn! Presentations should reflect ongoing research or pedagogical innovation at the intersection of Mathematics and the Arts.

The Capstone Course: Innovations and Implementations, organized by **Kathryn Weld**, Manhattan College, and **Agnes Rash**, St. Joseph's College; Wednesday morning. There are a variety of models for capping the major, and often these take the form of a special capstone course or senior seminar. We invite papers describing innovative implementations of the capstone course, and evidence of success in the classroom.

What content is covered? If the course involves problem solving or undergraduate presentations, how are topics chosen? What are the goals and outcomes for the course and how is success measured? Does the course play a role in departmental assessment of the major? Does the course make connections for students to regional undergraduate mathematics conferences, and if so, how? What are the special problems (if any) posed by student collaboration and the use of the Internet, and how does the course address them? Sponsored by PRIMUS: Problems, Resources, and Issues in Undergraduate Mathematics Studies. Papers from the session may be considered for a special issue of PRIMUS on the capstone course.

Developmental Mathematics Education: Helping Underprepared Students Transition to College-Level Mathematics, organized by **Kimberly Presser** and **J. Winston Crawley**, Shippensburg University; Friday afternoon. The struggle to assist underprepared students to be successful in college-level mathematics is not new. However, in recent years, the number of underprepared or math anxious students coming to our colleges and universities has been growing. In order to help these students to be successful, we need to undertake new strategies for support services; courses offered; and perhaps even in our programs themselves. This session invites papers on all aspects of developmental mathematics education. In particular, what classroom practices are effective with such students and how does research in student learning inform these practices? For students interested in math-intensive majors such as the sciences, how can we best prepare these students for several subsequent mathematics courses? How can we best coordinate support services with the courses offered in our mathematics departments? We are interested in hearing presentations from across the spectrum of community colleges through four-year universities at this session.

Early Assessment: Find Out What Your Students Understand (and Don't Understand) Before They Take the Test, organized by **Miriam Harris-Botzum**, Lehigh Carbon Community College, and **Bonnie Gold**, Monmouth University; Saturday afternoon. Assessment has two aspects, formative and summative. Both can be used to improve student learning. But where summative assessment looks at long-term comprehension and retention of material, and is generally used to assign grades, formative assessment is more short-term—what did the students get out of this lecture, or this concept, and what don't they quite get yet? And formative assessment need not be counted towards a student's grade; the goal of formative assessment is to inform your teaching and your students' studying. Angelo and Cross's Classroom Assessment Techniques is full of good ideas for finding out where students' understanding is, and there are quite a few chapters in the *MAA Notes* volume 49, "Assessment Practices in Undergraduate Mathematics" devoted to formative assessment methods. This session invites talks sharing methods, and evidence for their effectiveness, you have used in your classes to find out what your students have learned so far and, with that information, help them learn the rest better. Sponsored by the MAA Committee on Assessment.

Effective Use of Dynamic Mathematical Software in the Classroom, organized by **M. E. Waggoner**, Simpson College, and **Therese Shelton**, Southwestern University; Wednesday morning. Although using dynamic mathematical software programs, such as GeoGebra or Fathom, can be very effective as a teaching tool, it is often difficult to find the time to develop the files needed for a classroom experience. The purpose of this session is to provide a jump start to using software in the classroom. We are looking for talks that present one specific mathematics lesson using some dynamic software. The presentation will describe how the software was used in the classroom, and the files used in the lesson will be made available online. As a result, the audience will have a ready-made lesson to use. The lesson could be for any mathematical course and use any third-party software including GeoGebra, Fathom, Geometer's Sketchpad, calculator simulators, spreadsheets or a computer algebra system. It is preferred that the lesson include hands-on use of the software by students and not simply a classroom demonstration. Preference will be given to uses of widely used software such as those listed above or freeware.

The History of Mathematics and its Uses in the Classroom, organized by **Amy Shell-Gellasch**, Beloit College; Saturday morning. This session features talks about original research in the history of mathematics, ideas for the inclusion of the history of mathematics in mathematics courses, or ideas for courses dedicated to the history of mathematics.

Interest in the history of mathematics has grown rapidly in the last decades. Specialists and non-specialists alike contribute to the field. Many mathematicians use history to enhance the teaching of college mathematics. Sponsored by the SIGMAA on the History of Mathematics.

Innovations in Teaching Statistics in the New Decade, organized by **Andrew Zieffler**, University of Minnesota; **Brian Gill**, Seattle Pacific University; and **Nancy Boynton**, SUNY Fredonia; Friday afternoon. What have you found that is working particularly well in your statistics class? What did you try that really didn't work? What went wrong? Are there new technologies, websites, textbook ancillary materials activities or other teaching methods that are working well for you? What shouldnÆt we let go of from the traditional courses? And what should we let go of? Tell us about your course—especially what makes it successful. We encourage contributions concerning either an introductory or a more advanced undergraduate course. Sponsored by the SIGMAA on Statistics Education. Presenters will be considered for the Dex Whittinghill Award for Best Contributed Paper.

Innovative and Effective Ways to Teach Linear Algebra, organized by **David Strong**, Pepperdine University; **Gil Strang**, MIT; and **David Lay**, University of Maryland;

Wednesday afternoon. Linear algebra is one of the most interesting and useful areas of mathematics, because of its beautiful and multifaceted theory, as well as the enormous importance it plays in understanding and solving many real world problems. Consequently, many valuable and creative ways to teach its rich theory and its many applications are continually being developed and refined. This session will serve as a forum in which to share and discuss new or improved teaching ideas and approaches. These innovative and effective ways to teach linear algebra include, but are not necessarily limited to: (1) hands-on, in-class demos; (2) effective use of technology, such as Matlab, Maple, Mathematica, Java Applets, or Flash; (3) interesting and enlightening connections between ideas that arise in linear algebra and ideas in other mathematical branches; (4) interesting and compelling examples and problems involving particular ideas being taught; (5) comparing and contrasting visual (geometric) and more abstract (algebraic) explanations of specific ideas; and (6) other novel and useful approaches or pedagogical tools.

The Mathematical Preparation of Teachers: The Impact of the Common Core State Standards Initiative, organized by **Kenneth C. Millett**, University of California Santa Barbara; **Elizabeth Burroughs**, Montana State University; **Holly Peters Hirst**, Appalachian State University; and **William McCallum**, The University of Arizona; Saturday morning. How has the mathematical preparation of teachers been influenced by the widespread state adoption of the Common Core State Standards? Papers describing the changes in mathematics curricula and teacher preparation programs at a range of institutions will provide the context for exploring the implications of the CCSS on the content and emphasis of mathematics courses and the consideration of options available to faculty members and their departments in addressing the CCSS mathematics objectives. Sponsored by the Committee on the Mathematical Education of Teachers (COMET).

Mathematics and Sports, organized by **R. Drew Pasteur**, College of Wooster; Wednesday morning. Applications of mathematics are plentiful in sports, relating to probability, statistics, linear algebra, calculus, and numerical analysis, among other areas. This contributed paper session will feature various uses of mathematics to study phenomena arising from multiple sports. The success of the 2010 Mathematics Awareness Month, with this theme, and the increasing prominence of a peer-reviewed academic journal in this area are both evidence of its growth. The expanding availability of play-by-play data for professional and some collegiate sports is leading to innovative kinds of analysis. This session will include both expository talks and presentations of original research; undergraduate students and their mentors are particularly encouraged to submit abstracts for consideration.

Mathematics Experiences in Business, Industry and Government, organized by **Carla D. Martin**, James Madison University; **Phil Gustafson**, Mesa State College; and **Michael Monticino**, University of North Texas; Thursday morning. The MAA Business, Industry and Government Special Interest Group (BIG SIGMAA) provides resources and a forum for mathematicians working in Business, Industry and Government (BIG) to help advance the mathematics profession by making connections, building partnerships, and sharing ideas. BIG SIGMAA consists of mathematicians in BIG as well as faculty and students in academia who are working on BIG problems.

Mathematicians, including those in academia, with BIG experience are invited to present papers or discuss projects involving the application of mathematics to BIG problems. The goal of this contributed paper session sponsored by BIG SIGMAA is to provide a venue for mathematicians with experience in business, industry, and government to share projects and mathematical ideas in this regard. Anyone interested in learning more about BIG practitioners, projects, and issues, will find this session of interest.

The Mathematics of Sudoku and Other Pencil Puzzles, organized by **Laura Taalman** and **Jason Rosenhouse**, James Madison University; Wednesday and Thursday afternoons. This session is for talks about mathematical research, classroom use, and possible undergraduate research projects that relate to Sudoku or other pencil puzzles such as Ken Ken, Slitherlink, Masyu, Kakuro, and so on. We invite papers for any type of pencil puzzle, from any mathematical perspective, including graph theory, game theory, Gröbner bases, Latin squares, integer programming, probability, rook problems, exact cover problems, and NP- completeness. Speakers whose talks are accepted to the session will be encouraged to submit puzzles to the organizers for inclusion in a handout that will be made available at the session.

The Mathematics of Sustainability, organized by **Elton Graves**, Rose-Hulman Institute of Technology, and **Peter Otto**, Willamette University; Friday afternoon. This session is intended to encourage papers from colleagues who have used sustainability models or discussion in their undergraduate mathematics classroom.

Topics such as sustainable harvesting of food and natural resources, development of sustainable energy sources, conservation and recycling, greenhouse gas emissions, global warming, new types of "green" buildings, etc. are ideas which have now become global issues.

Papers for this session should describe how mathematical sustainability models/discussions have been used in the undergraduate mathematics classroom. Models/discussion may include but are not limited to: global warming; green house gas models; sustainable use of resources including food, water, minerals; power generation; alternative fuel generation; conservation; recycling; and sustainable structures including retrofitting older buildings.

Faculty members who have participated in interdisciplinary programs, classes, projects, or assignments are encouraged to present. Papers from all undergraduate mathematical courses or interdisciplinary courses with a mathematics component are welcome and encouraged.

Modeling Across the Mathematics Curriculum, organized by **Benjamin Galluzzo**, Shippensburg University; **Mariah Birgen**, Wartburg College; and **Joyati Debnath**, Winona State University; Friday morning. By answering the question: How can I apply my education to the "real world"? Mathematical modeling offers a great opportunity to attract and retain outstanding students. While some departments offer mathematical modeling in a single course setting, inclusion of application-based activities across the full range of the curriculum presents a greater challenge. The 2004 MAA CUPM Curriculum Guide recommends that "every course in the undergraduate mathematics program—from the most basic to the most advanced—should strive to include meaningful application that genuinely advance students' ability to analyze real-life situations and construct and analyze appropriate mathematical models". Inside or outside of the classroom, as an individual project or a semester long theme, as an introduction to mathematical applications for entry level students or as a gateway to undergraduate research, mathematical modeling serves as an excellent platform for satisfying CUPM expectations and reaching a broad student audience. This session invites scholarly papers that discuss how modeling is used to engage and excite students—at all levels—about mathematics.

Motivating Statistical and Quantitative Learning through Social Engagement, organized by **Brian Gill**, Seattle Pacific University; **Eric Gaze**, Bowdoin College; **Andrew Zieffler**, University of Minnesota; and **Stuart Boersma**, Central Washington University; Saturday morning and afternoon. It is important for our students to learn to apply statistics and quantitative methods to real problems. Our students are interested in service learning and civic engagement and they provide important ways for students to both do useful work and also better understand the techniques that they learn in their courses. Social justice is not often discussed in mathematics or statistics courses; however, we can use quantitative techniques to better understand the differences in the lives of people in various segments of society. We invite submissions that describe successful statistics or quantitative literacy courses that include a service learning, social justice or civic engagement component. Sponsored by the SIGMAA on Statistics Education and the SIGMAA on Quantitative Literacy. Presenters identifying their presentation as being about a statistics course will be considered for the Dex Whittinghill Award for Best Contributed Paper.

My Most Successful Math Club Activity, organized by **Jacqueline Jensen**, Slippery Rock University, and **Deanna Haunsberger**, Carleton College; Thursday morning. Math clubs enhance the culture of a mathematics department and inspire students to study and major in mathematics. How does one develop a new group? How about refreshing an existing one? What successful math club activities have your students engaged in recently that is replicable at other schools?

This session features presentations from math club advisors and others who will share their favorite non-standard activity for math clubs. Our goal is to provide ideas and support for mentors of math clubs, especially those trying to begin or reactivate a group. Speakers should focus on a single activity that motivates and engages students, and, when applicable, include suggestions for acquiring funding for such activities. It is our hope that these talks will spur immediate discussion between speakers and audience members, and lead to re-energizing math clubs and engaging students. Sponsored by the MAA Committee on Undergraduate Student Activities and Chapters.

Philosophy of Mathematics and Mathematical Practice, organized by **Dan Sloughter**, Furman University, and **Bonnie Gold**, Monmouth University; Friday afternoon. Philosophers search for insights into the most general epistemological and ontological questions: How do we know, and what is it that we know? Since mathematical knowledge is a significant piece of what we know, an explanation of the nature of mathematics plays an important role in philosophy. To this end, a philosopher of mathematics must pay careful attention to mathematical practice, what it is that mathematicians claim to know and how they claim to know it.

A philosopher's explanation of mathematics cannot be a local explanation: it must fit within the larger picture of knowledge as a whole. A mathematician may have an account of mathematics which suffices for her work, but unless this account fits coherently into a larger epistemological and ontological picture, it will not suffice as a philosophy of mathematics.

This session will address questions concerning the relationship between the philosophy and the practice of mathematics. We encourage papers to address questions such as: Should the philosophy of mathematics influence, or be influenced by, the practice of mathematics? Is it necessary for the philosophy of mathematics to influence the practice of mathematics for it to be relevant to mathematicians? Sponsored by the SIGMAA on the Philosophy of Mathematics.

Preparing College Students for Calculus, organized by **Andrew Bennett**, Kansas State University; Thursday morning. What do students need to know and be able to do in order to succeed in calculus? More mathematics? More mathematical ways of thinking? More about how to learn and study? (Or, perhaps, all of the above?) This session is intended to solicit a wide range of perspectives on the issues related to and successful approaches in preparing college students to succeed in calculus. This work is part of the MAA CRAFTY committee's information gathering process to inform our upcoming examination of the topic.

We encourage talks on illustrative examples of the mathematics or mathematical thinking necessary for calculus; new and innovative approaches to pre-calculus or calculus with review courses; research on the factors involved in student readiness or success in calculus; and successful extra-course support programs (such as supplemental instruction). In all cases, speakers should present evidence of success in these approaches or offer reflective insight on the core challenges. (While we gratefully acknowledge the critical role that high school curricula play in this conversation, we are interested in talks about courses or programs housed in colleges and universities). Sponsored by the CUPM Subcommittee on Curriculum Renewal Across the first Two Years (CRAFTY).

Projects, Demonstrations, and Activities that Engage Liberal Arts Mathematics Students, organized by **Sarah Mabrouk**, Framingham State University; Thursday afternoon. Many colleges and universities offer liberal arts mathematics courses (lower-level courses other than statistics, college algebra, precalculus, and calculus) designed for students whose majors are in disciplines other than mathematics, science, social science, or business. Students taking such courses have a variety of backgrounds and strengths and differing levels of interest and comfort with mathematics.

This session invites papers regarding projects, demonstrations, and activities that can be used to enhance the learning experience for students taking liberal arts mathematics courses. Papers should include information about the topic(s) related to the project/demonstration/activity, preliminary information that must be presented, and the goal(s)/outcome(s) for the project/demonstration/activity. Presenters discussing demonstrations and activities are encouraged to give the demonstration or perform the activity, if time and equipment allow, and to discuss the appropriateness of the demonstration/activity for the learning environment and the class size. Presenters discussing projects are encouraged to address how the project was conducted (individual or group), how the project was presented for evaluation (in-class or online presentation, written paper, poster session, or online discussion), grading issues, if any, and the rubric used to appraise the students' work. Each presenter is encouraged to discuss how the project/demonstration/activity fits into the course, the use of technology, if any, the students' reactions, and the effect of the project/demonstration/activity on the students' attitudes towards and understanding of mathematics.

Quantitative Literacy and Decision Making, organized by **Eric Gaze**, Bowdoin College; **Cinnamon Hillyard**, University of Washington Bothell; and **Semra Kilic-Bahi**, Colby Sawyer College; Friday morning. Our students are being asked to make decisions in an increasingly complex world that require fundamental quantitative literacy in diverse fields such as personal health, finance, and public policy. The ability to reason from evidence by questioning assumptions and premises, and assessing the veracity of claims is especially critical when arguments are based on data and mathematical models. Students' abilities to obtain, process, and understand information related to such issues is crucial for them in making well-informed decisions and participating in a democratic society.

This session seeks papers that discuss courses, classroom materials, curricular and/or extracurricular activities that focus on exploring the use and misuse of mathematical concepts related to making important decisions that affect the personal, professional, and academic lives of our students. All presentations are expected to be scholarly in nature, including some evidence (qualitative or quantitative) of the effectiveness of the activity. Sponsored by the SIGMAA on Quantitative Literacy.

Research on the Teaching and Learning of Undergraduate Mathematics, organized by **Sean Larsen**, Portland State University; **Stacy Brown**, Pitzer College; and **Karen Marrongelle**, Portland State University; Thursday morning and afternoon. This session sponsored by the SIGMAA on RUME (Special Interest Group of the MAA on Research in Undergraduate Mathematics Education) presents papers that address issues concerning the teaching and learning of undergraduate mathematics, including theoretical and empirical investigations that employ quantitative and qualitative methodologies.

Proposals for reports of Research on Undergraduate Mathematics Education are invited. The research should build on the existing research literature and use established methodologies to investigate important issues in undergraduate mathematics teaching and learning. The goals of the session are to share high quality research on undergraduate mathematics education with the broader mathematics community. The session will feature research in a number of mathematical areas including linear algebra, advanced calculus, abstract algebra, and mathematical proof.

The Scholarship of Teaching and Learning in Collegiate Mathematics, organized by **Jackie Dewar**, Loyola Marymount University; **Thomas Banchoff**, Brown University; **Pam Crawford**, Jacksonville University; and **Edwin Herman**, and **Nathan Wodarz**, University of Wisconsin-Stevens Point; Wednesday morning and afternoon. The Scholarship of Teaching and Learning is a growing field in which faculty bring disciplinary knowledge to bear on questions of teaching and learning and use student-based evidence to support their conclusions. Work in this area emphasizes pedagogical techniques and questions. The scope of the research can range from small, relatively informal investigations about teaching innovations in the classroom to larger or more formal investigations of student learning.

Reports that address issues concerning the teaching and learning of postsecondary mathematics are invited. Appropriate for this session are reports of classroom-based investigations of teaching methods, student learning difficulties, or curricular assessment. Papers must discuss more than anecdotal evidence. For example, papers might reference the following types of evidence: student work, pre/post tests, interviews, surveys, think-alouds, etc.

The goals of this session are to: feature scholarly work focused on teaching of postsecondary mathematics; provide a venue for mathematicians to make public their scholarly work on teaching; and highlight evidence-based arguments for the value of teaching innovations.

Topics and Techniques for Teaching Real Analysis, organized by **Paul Musial**, Chicago State University; **James Peterson**, Benedictine College; **Erik Talvila**, University of the Fraser Valley; and **Robert Vallin**, Slippery Rock University of Pennsylvania; Friday morning. Analysis of the real numbers and of functions of a real variable is an integral part of the mathematics curriculum. An instructor of a real analysis class must have deep content knowledge, but also must have ways of motivating the learning of this important but technically difficult subject. The organizers propose a contributed paper session at which mathematicians can share their ideas for teaching an undergraduate real analysis course. This session was given at the 2007 New Orleans and 2008 San Diego Joint Mathematics Meetings where each time the sessions had to be spread out over two days due to the large volume of speakers. Every session was well-attended (between 50 and 100 people at each talk) and generated good and important discussions within the audience in the time between speakers.

The intended audience for the session is instructors teaching undergraduate real analysis courses at a college or university. Participants will find new ways of understanding the material taught in a real analysis course and new ways of presenting this material. It is assumed that the participants have taken at least one real analysis course and have a graduate degree in mathematics.

Touch It, Feel It, Learn It: Tactile Learning Activities in the Undergraduate Mathematics Classroom, organized by **Jessica Mikhaylov**, U.S. Military Academy at West Point, and **Julie Barnes**, Western Carolina University; Wednesday afternoon. This session invites presentations describing activities that use tactile teaching methods in any undergraduate mathematics classes. Some examples of tactile methods could include props that students can touch to understand concepts better, projects where students create physical models that represent a concept, or in-class activities where students work together to create a hands-on demonstration of their understanding of a particular concept. This session seeks presentations that focus on engaging students through interaction with props, use of manipulative materials, or even inviting students to physically become a part of a function or concept; this does not include technology demonstrations such as computer visualizations. We seek innovative and creative ways for physically involving students in mathematics. Presentations that include how to integrate a particular activity into class, student reactions, educational benefits, difficulties to avoid, and/or possible modifications of the activity are desired.

Trends in Teaching Mathematics Online, organized by **Michael B. Scott**, California State University, Monterey Bay; Saturday afternoon. This session will highlight the challenges, triumphs and emerging trends in teaching mathematics online. It will also provide a forum for instructors to share and discuss new or improved teaching ideas, approaches and technologies for teaching mathematics courses online. Presentations will be geared to both instructors teaching mathematics online for the first time and veteran practitioners. The demand for effective online courses continues to grow. Although teaching online has been around for some time, technologies and techniques continue to evolve. This evolution can present new and more effective learning experiences for students. The focus of the reports include, but are not necessarily limited to descriptions of and solutions to challenges and pitfalls when teaching mathematics online, effective practices of online instruction, experiences using new and emerging technologies in online instruction, innovative pedagogical and assessment models, strategies for teaching upper-division courses, and analysis of the effectiveness of teaching mathematics online. Sponsored by the Committee on Technologies in Mathematics Education (CTiME) and SIGMAA on Mathematics Instruction Using the Web.

Trends in Undergraduate Mathematical Biology Education, organized by **Timothy D. Comar**, Benedictine University; Thursday morning and afternoon. This session highlights successful implementations of biomathematics courses and content in undergraduate curriculum, entire biomathematics curricula, efforts to recruit students into biomathematics courses, involvement of undergraduate students in biomathematics research, preparation for graduate work in biomathematics and computational biology or for medical careers, and assessment of how these courses and activities impact the students. Several reports emphasize that aspects of biological research are becoming more quantitative and that life science students should be introduced to a greater array of mathematical and computational techniques and to the integration of mathematics and biological content at the undergraduate level. These reports include "Bio 2010" (National Research Council, 2003) and "A New Biology for the 21st Century" (National Research Council, 2009). Additionally, the 2009 document, "Scientific Foundations for Future Physicians", co-published by the Association of American Medical Colleges and the Howard Hughes Medical Institute, recommends that future physicians need increased quantitative training.

Moreover, presenting quantitative approaches to biological problems to all biology majors, not just those who intend to pursue research or medical careers, in their introductory college mathematics courses provides these students with a wider range of tools and can better motivate the mathematics. It is also important for mathematics majors to be made aware of current issues at the intersection of mathematics and biology because mathematical and computational biology provides interesting, approachable problems for research even at the undergraduate level and mathematics students need to be trained to collaborate with scientists in other disciplines particularly including biology.

Topics may include scholarly work addressing the issues related to the design of effective biomathematics courses and curricula, how best to gear content toward pre-med students, integration of biology into existing mathematics courses, collaborations between mathematicians and biologists that have led to new courses, course modules, or undergraduate research projects, effective use of appropriate technology in biomathematics courses, and assessment issues. Sponsored by the SIGMAA on Mathematical and computational Biology.

Wavelets in Undergraduate Education, organized by **Caroline Haddad**, SUNY Geneseo; **Catherine Beneteau**, University of South Florida; **David Ruch**, Metropolitan State College of Denver; and **Patrick Van Fleet**, University of St. Thomas; Friday afternoon. Wavelets are functions that satisfy certain mathematical properties and are used to represent data or other functions. They work extremely well in analyzing data with finite domains having different scales or resolutions. Interesting applications include digital image processing, FBI fingerprint compression, signal processing of audio files, de-noising noisy data, earthquake prediction, and solving partial differential equations. Wavelets have typically been studied at the graduate level, but are making their way into the undergraduate curriculum. We are interested in presentations that effectively incorporate wavelets in an innovative way at the undergraduate level. This may include an undergraduate course in wavelets; a topic on wavelets in some other course using, but not limited to, hands-on demonstrations, projects, labs that utilize technology such as Matlab, Mathematica, Maple, Java applets, etc.; or research opportunities for undergraduates.

Writing the History of the MAA, organized by **Victor J. Katz**, University of the District of Columbia; **Janet Beery**, University of Redlands; and **Amy Shell-Gellasch**, Beloit College; Friday morning. In preparation for the MAA centennial celebration in 2015, it is important to fill in gaps in the history of the organization and its sections. Many sections do not have written histories, and there are many facets of the MAA's history that have not been fully explored. We invite section historians or other officers or individuals to begin research on the histories of their sections and to present their preliminary findings at this session. We also invite members to begin research and to present their findings on other topics related to the history of the MAA, particularly in the last 50 years. Examples of topics include the history of any MAA sponsored projects, the history of electronic services in the MAA, the changes in membership over the years, the development of the publication program, or the history and accomplishments of a particular committee. This session is sponsored by the History Subcommittee of the Centennial Committee and is a follow-up to the Panel Discussion of the same name at the 2011 JMM. Sponsored by the History Subcommittee of the MAA Centennial Committee.

General Contributed Paper Session, organized by **Jennifer Beineke**, Western New England College; **Lynnette Boos**, Providence College; and **Aliza Steurer**, Dominican University; Wednesday, Thursday, Friday, and Saturday mornings and afternoons. Papers may be presented on any mathematical topic. Papers that fit into one of the other sessions should be sent to that session, not to the general session.

Submission Procedures for MAA Contributed Paper Abstracts

Abstracts may be submitted electronically at `http://jointmathematicsmeetings.org/meetings/abstracts/abstract.pl?type=jmm`. Simply fill in the number of authors, and then follow the step-by-step instructions. **The deadline for abstracts is Thursday, September 22, 2011**.

Participants may submit at most one abstract for MAA contributed paper sessions at this meeting. If your paper cannot be accommodated in the session in which it is submitted, it will automatically be considered for the general session.

The organizer(s) of your session will automatically receive a copy of the abstract, so it is not necessary for you to send it directly to the organizer. All accepted abstracts are published in a book that is available to registered participants at the meeting. Questions concerning the submission of abstracts should be addressed to `abs-coord@ams.org`.

Honolulu, Hawaii

University of Hawaii

March 3–4, 2012

Saturday – Sunday

Meeting #1078

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: October 2012
Program first available on AMS website: January 26, 2012
Program issue of electronic *Notices*: March 2012
Issue of *Abstracts*: Volume 33, Issue 2

Deadlines

For organizers: August 3, 2011
For consideration of contributed papers in Special Sessions: November 22, 2011
For abstracts: December 13, 2011

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Zhiqin Lu, University of California Irvine, *To be announced*.

Peter Schroder, California Institute of Technology, *To be announced*.

Pham Tiep, University of Arizona, Tucson, *To be announced*

Lauren Williams, University of California Berkeley, *To be announced*.

Special Sessions

Automorphic and Modular Forms (Code: SS 4A), **Pavel Guerzhoy**, University of Hawaii, and **Zachary A. Kent**, Emory University.

Geometry and Analysis on Fractal Spaces (Code: SS 3A), **Michel Lapidus**, University of California, Riverside, **Hung Lu**, Hawaii Pacific University, **John A. Rock**, California State Polytechnic University, Pomona, and **Machiel van Frankenhuijsen**, Utah Valley University.

Kaehler Geometry and Its Applications (Code: SS 1A), **Zhiqin Lu**, University of California Irvine, **Jeff Streets**, Princeton University, **Li-Sheng Tseng**, Harvard University, and **Ben Weinkove**, University of California San Diego.

Linear and Permutation Representations (Code: SS 2A), **Robert Guralnick**, University of Southern California, and **Pham Huu Tiep**, University of Arizona.

Tampa, Florida

University of South Florida

March 10–11, 2012

Saturday – Sunday

Meeting #1079

Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: January
Program first available on AMS website: February 2, 2012
Program issue of electronic *Notices*: March 2012
Issue of *Abstracts*: Volume 33, Issue 2

Deadlines

For organizers: August 10, 2011
For consideration of contributed papers in Special Sessions: November 29, 2011
For abstracts: January 18, 2012

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Anne Condon, University of British Columbia, *Title to be announced.*

Mark Ellingham, Vanderbilt University, *Title to be announced.*

Mauro Maggioni, Duke University, *Digital data sets: Geometry, random walks, multiscale analysis, and applications.*

Weiqiang Wang, University of Virginia, *Title to be announced.*

Special Sessions

Algebraic and Combinatorial Structures in Knot Theory (Code: SS 2A), **J. Scott Carter**, University of South Alabama, and **Mohamed Elhamdadi** and **Masahico Saito**, University of South Florida.

Analysis in Metric Spaces (Code: SS 3A), **Thomas Bieske**, University of South Florida, and **Jason Gong**, University of Pittsburgh.

Applications of Complex Analysis in Mathematical Physics (Code: SS 9A), **Razvan Teodorescu**, University of South Florida, **Mihai Putinar**, University of California, Santa Barbara, and **Pavel Bleher**, Indiana University-Purdue University Indianapolis.

Complex Analysis and Operator Theory (Code: SS 8A), **Sherman Kouchekian**, University of South Florida, and **William Ross**, University of Richmond.

Discrete Models in Molecular Biology (Code: SS 1A), **Alessandra Carbone**, Université Pierre et Marie Curie and Laboratory of Microorganisms Genomics, **Natasha Jonoska**, University of South Florida, and **Reidun Twarock**, University of York.

Hopf Algebras and Galois Module Theory (Code: SS 7A), **James Carter**, College of Charleston, and **Robert Underwood**, Auburn University Montgomery.

Interaction between Algebraic Combinatorics and Representation Theory (Code: SS 4A), **Mahir Can**, Tulane University, and **Weiqiang Wang**, University of Virginia.

Modeling Crystalline and Quasi-Crystalline Materials (Code: SS 5A), **Mile Krajcevski** and **Gregory McColm**, University of South Florida.

Solvability and Integrability of Nonlinear Evolution Equations (Code: SS 6A), **Wen-Xiu Ma**, University of South Florida, and **Ahmet Yildirim**, Ege University and University of South Florida.

Washington, District of Columbia

George Washington University

March 17–18, 2012

Saturday – Sunday

Meeting #1080

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: January 2012
Program first available on AMS website: February 9, 2012
Program issue of electronic *Notices*: March 2012
Issue of *Abstracts*: Volume 33, Issue 2

Deadlines

For organizers: August 17, 2011
For consideration of contributed papers in Special Sessions: December 6, 2011
For abstracts: January 31, 2012

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Jim Geelen, University of Waterloo, *Title to be announced.*

Boris Solomyak, University of Washington, *Title to be announced.*

Gunther Uhlmann, University of Washington, *Title to be announced* (Einstein Public Lecture in Mathematics).

Anna Wienhard, Princeton University, *Title to be announced.*

Special Sessions

Homology Theories Motivated by Knot Theory (Code: SS 3A), **Jozef H. Przytycki**, George Washington University, **Radmila Sazdanovic**, University of Pennsylvania, and **Alexander N. Shumakovitch** and **Hao Wu**, George Washington University.

Matroid Theory (Code: SS 1A), **Joseph E. Bonin**, George Washington University, and **Sandra Kingan**, Brooklyn College.

Optimization: Theory and Applications (Code: SS 2A), **Roman Sznajder**, Bowie State University.

Self-organization Phenomena in Reaction Diffusion Equations (Code: SS 5A), **Xiaofeng Ren**, George Washington University, and **Junping Shi**, College of William and Mary.

Structural and Extremal Problems in Graph Theory (Code: SS 4A), **Daniel Cranston**, Virginia Commonwealth University, and **Gexin Yu**, College of William & Mary.

Tilings, Substitutions, and Bratteli-Vershik Transformations (Code: SS 6A), **E. Arthur Robinson**, George Washington University, and **Boris Solomyak**, University of Washington.

Lawrence, Kansas

University of Kansas

March 30 – April 1, 2012

Friday – Sunday

Meeting #1081

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: February 2012
Program first available on AMS website: March 8, 2012
Program issue of electronic *Notices*: March 2012
Issue of *Abstracts*: Volume 33, Issue 2

Deadlines

For organizers: August 31, 2011
For consideration of contributed papers in Special Sessions: December 20, 2011
For abstracts: February 14, 2012

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Frank Calegari, Northwestern University, *Title to be announced*.

Christopher Leininger, University of Illinois at Urbana-Champaign, *Title to be announced*.

Alina Marian, University of Illinois at Chicago, *Title to be announced*.

Catherine Yan, Texas A&M University, *Title to be announced*.

Special Sessions

Combinatorial Commutative Algebra (Code: SS 1A), **Christopher Francisco** and **Jeffrey Mermin**, Oklahoma State University, and **Jay Schweig**, University of Kansas.

Partial Differential Equations (Code: SS 2A), **Milena Stanislavova** and **Atanas Stefanov**, University of Kansas.

Rochester, New York

Rochester Institute of Technology

September 22–23, 2012

Saturday – Sunday

Meeting #1082

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: May 2012
Program first available on AMS website: July 19, 2012
Program issue of electronic *Notices*: September 2012
Issue of *Abstracts*: Volume 33, Issue 3

Deadlines

For organizers: February 22, 2012
For consideration of contributed papers in Special Sessions: May 15, 2012
For abstracts: July 10, 2012

New Orleans, Louisiana

Tulane University

October 13–14, 2012

Saturday – Sunday

Meeting #1083

Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: June 2012
Program first available on AMS website: September 6, 2012
Program issue of electronic *Notices*: October 2012
Issue of *Abstracts*: Volume 33, Issue 3

Deadlines

For organizers: March 13, 2012
For consideration of contributed papers in Special Sessions: July 3, 2012
For abstracts: August 28, 2012

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Anita Layton, Duke University, *Title to be announced*.

Lenhard Ng, Duke University, *Title to be announced*.

Henry K. Schenck, University of Illinois at Urbana-Champaign, *From approximation theory to algebraic geometry: The ubiquity of splines*.

Milen Yakimov, Louisiana State University, *Title to be announced*.

Akron, Ohio

University of Akron

October 20–21, 2012

Saturday – Sunday

Meeting #1084

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: August 2012
Program first available on AMS website: September 27, 2012
Program issue of electronic *Notices*: October 2012
Issue of *Abstracts*: Volume 33, Issue 4

Deadlines

For organizers: March 22, 2012
For consideration of contributed papers in Special Sessions: July 10, 2012
For abstracts: September 4, 2012

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Tanya Christiansen, University of Missouri, *Title to be announced.*

Tim Cochran, Rice University, *Title to be announced.*

Ronald Solomon, Ohio State University, *Title to be announced.*

Ben Weinkove, University of California San Diego, *Title to be announced.*

Tucson, Arizona

University of Arizona, Tucson

October 27–28, 2012

Saturday – Sunday

Meeting #1085

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: August 2012
Program first available on AMS website: October 4, 2012
Program issue of electronic *Notices*: October 2012
Issue of *Abstracts*: Volume 33, Issue 4

Deadlines

For organizers: March 27, 2012
For consideration of contributed papers in Special Sessions: July 17, 2012
For abstracts: September 11, 2012

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Michael Hutchings, University of California Berkeley, *Title to be announced.*

Kenneth McLaughlin, University of Arizona, Tucson, *Title to be announced.*

Ken Ono, Emory University, *Title to be announced* (Erdős Memorial Lecture).

Jacob Sterbenz, University of California San Diego, *Title to be announced.*

Goufang Wei, University of California, Santa Barbara, *Title to be announced.*

Special Sessions

Harmonic Maass Forms and q-series (Code: SS 1A), **Ken Ono**, Emory University, **Amanda Folsom**, Yale University, and **Zachary Kent**, Emory University.

San Diego, California

San Diego Convention Center and San Diego Marriott Hotel and Marina

January 9–12, 2013

Wednesday – Saturday

Meeting #1086

Joint Mathematics Meetings, including the 119th Annual Meeting of the AMS, 96th Annual Meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: October 2012
Program first available on AMS website: November 1, 2012
Program issue of electronic *Notices*: January 2012
Issue of *Abstracts*: Volume 34, Issue 1

Deadlines

For organizers: April 1, 2012
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Chestnut Hill, Massachusetts

Boston College

April 6–7, 2013

Saturday – Sunday
Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: September 6, 2012
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Ames, Iowa

Iowa State University

April 27–28, 2013

Saturday – Sunday
Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: April 2013
Issue of *Abstracts*: To be announced

Deadlines

For organizers: September 27, 2012
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Special Sessions

Operator Algebras and Topological Dynamics (Code: SS 1A), **Ken Ono**, Emory University, **Amanda Folsom**, Yale University, and **Zachary Kent**, Emory University.

Alba Iulia, Romania

June 27–30, 2013

Thursday – Sunday
First Joint International Meeting of the AMS and the Romanian Mathematical Society, in partnership with the "Simion Stoilow" Institute of Mathematics of the Romanian Academy.
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: To be announced
Program first available on AMS website: Not applicable
Program issue of electronic *Notices*: Not applicable
Issue of *Abstracts*: Not applicable

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

St. Louis, Missouri

Washington University

October 18–20, 2013

Friday – Sunday
Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: March 20, 2013
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Riverside, California

University of California Riverside

November 2–3, 2013

Saturday – Sunday
Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 2, 2013
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Baltimore, Maryland

Baltimore Convention Center, Baltimore Hilton, and Marriott Inner Harbor

January 15–18, 2014

Wednesday – Saturday
Joint Mathematics Meetings, including the 120th Annual Meeting of the AMS, 97th Annual Meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic, with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).
Associate secretary: Matthew Miller
Announcement issue of *Notices*: October 2013
Program first available on AMS website: November 1, 2013
Program issue of electronic *Notices*: January 2013
Issue of *Abstracts*: Volume 35, Issue 1

Deadlines

For organizers: April 1, 2013
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Tel Aviv, Israel

Bar-Ilan University, Ramat-Gan and Tel-Aviv University, Ramat-Aviv

June 16–19, 2014

Monday – Thursday
The 2nd Joint International Meeting between the AMS and the Israel Mathematical Union.
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

San Antonio, Texas

Henry B. Gonzalez Convention Center and Grand Hyatt San Antonio

January 10–13, 2015

Saturday – Tuesday
Joint Mathematics Meetings, including the 121st Annual Meeting of the AMS, 98th Annual Meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association of Symbolic Logic, with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: October 2014
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: January 2015
Issue of *Abstracts*: Volume 36, Issue 1

Deadlines

For organizers: April 1, 2014
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Porto, Portugal

University of Porto

June 11–14, 2015

Thursday – Sunday
Associate secretary: Robert J. Daverman
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Not applicable

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Meetings and Conferences of the AMS

Associate Secretaries of the AMS

Western Section: Michel L. Lapidus, Department of Mathematics, University of California, Surge Bldg., Riverside, CA 92521-0135; e-mail: lapidus@math.ucr.edu; telephone: 951-827-5910.

Central Section: **Georgia Benkart**, University of Wisconsin-Madison, Department of Mathematics, 480 Lincoln Drive, Madison, WI 53706-1388; e-mail: benkart@math.wisc.edu; telephone: 608-263-4283.

Eastern Section: **Steven H. Weintraub**, Department of Mathematics, Lehigh University, Bethlehem, PA 18105-3174; e-mail: steve.weintraub@lehigh.edu; telephone: 610-758-3717.

Southeastern Section: **Matthew Miller,** Department of Mathematics, University of South Carolina, Columbia, SC 29208-0001, e-mail: miller@math.sc.edu; telephone: 803-777-3690.

The Meetings and Conferences section of the *Notices* gives information on all AMS meetings and conferences approved by press time for this issue. Please refer to the page numbers cited in the table of contents on this page for more detailed information on each event. Invited Speakers and Special Sessions are listed as soon as they are approved by the cognizant program committee; the codes listed are needed for electronic abstract submission. For some meetings the list may be incomplete. **Information in this issue may be dated. Up-to-date meeting and conference information can be found at** www.ams.org/meetings/.

Meetings:

Important Information Regarding AMS Meetings

Potential organizers, speakers, and hosts should refer to page 100 in the January 2011 issue of the *Notices* for general information regarding participation in AMS meetings and conferences.

Abstracts

Speakers should submit abstracts on the easy-to-use interactive Web form. No knowledge of LaTeX is necessary to submit an electronic form, although those who use LaTeX may submit abstracts with such coding, and all math displays and similarily coded material (such as accent marks in text) must be typeset in LaTeX. Visit http://www.ams.org/cgi-bin/abstracts/abstract.pl. Questions about abstracts may be sent to abs-info@ams.org. Close attention should be paid to specified deadlines in this issue. Unfortunately, late abstracts cannot be accommodated.

Conferences: (see http://www.ams.org/meetings/ for the most up-to-date information on these conferences.)

July 24–29, 2011: Conference on Applied Mathematics, Modeling, and Computational Science, Waterloo, Canada (held in cooperation with the AMS).

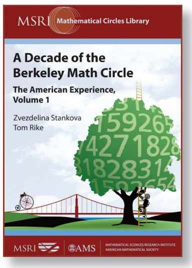
AMERICAN MATHEMATICAL SOCIETY

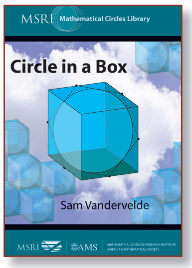
MSRI Mathematical Circles Library

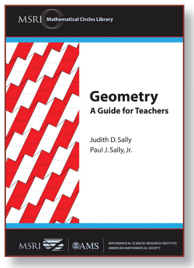
Mathematical Circles are gatherings of motivated students and teachers looking for new challenges in mathematics as well as a deeper understanding of the subject. While solving problems is emphasized, the circles also pay considerable attention to mathematical ideas and techniques.

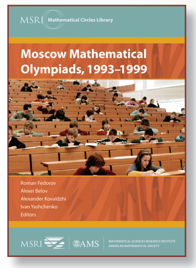
This book series is designed as a resource for leaders and participants in mathematical clubs and circles. Books may also be of interest to parents and teachers.

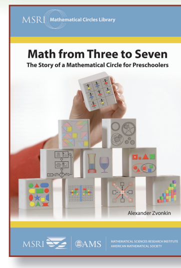
Titles in this series are co-published with the Mathematical Sciences Research Institute (MSRI).











A Decade of the Berkeley Math Circle

The American Experience, Volume I

Zvezdelina Stankova, *Mills College, Oakland, CA, and University of California, Berkeley, CA*, and Tom Rike, *Oakland High School, CA*, Editors

This book uses a dozen sessions presented at the pioneering Berkeley Math Circle to illustrate the variety of topics these extracurricular programs cover in inspiring young people to a lifelong love of mathematics. The book offers a thorough introduction to the structure and content of mathematical circles. It is designed to motivate advanced students, their parents, and teachers of mathematics who are interested in establishing these programs.

Volume 1; 2008; 326 pages; Softcover; ISBN: 978-0-8218-4683-4; List US$49; AMS members US$39.20; Order code MCL/1

Circle in a Box

Sam Vandervelde, *St. Lawrence University, Canton, NY*

For those interested in starting and running a math circle, I think it is an invaluable resource.

—MAA Reviews

The first part of this book offers helpful advice on all aspects of math circle operations, culled from conversations with over a dozen directors of successful math circles. The second part of the book outlines ten independent math circle sessions, covering a variety of topics and difficulty levels. Each chapter contains detailed presentation notes along with a useful collection of problems and solutions.

Volume 2; 2009; 217 pages; Softcover; ISBN: 978-0-8218-4752-7; List US$39; AMS members US$31.20; Order code MCL/2

Geometry

A Guide for Teachers

Judith D. Sally, *Northwestern University, Evanston, IL*, and Paul J. Sally, Jr., *University of Chicago, IL*

This geometry book is written for future and current middle school teachers, but is also designed for elementary and high school teachers. The book consists of ten seminars covering the fundamental topics in school geometry. The seminars are crafted to clarify and enhance understanding of the subject. The book is also intended to be a source for problems in geometry for enrichment programs such as Math Circles and Young Scholars.

Volume 3; 2011; 202 pages; Softcover; ISBN: 978-0-8218-5362-7; List US$39; AMS members US$31.20; Order code MCL/3

Moscow Mathematical Olympiads, 1993–1999

Roman Fedorov, Alexei Belov, Alexander Kovaldzhi, and Ivan Yashchenko, Editors

The Moscow Mathematical Olympiad has been challenging high-school students with stimulating, original problems of different degrees of difficulty for over 75 years.

In 2006 the Moscow Center for Continuous Mathematical Education began publishing a collection of problems from the Moscow Mathematical Olympiads, providing for each an answer (and sometimes a hint) as well as one or more detailed solutions. This volume represents the years 1993–1999.

Volume 4; 2011; 220 pages; Softcover; ISBN: 978-0-8218-5363-4; List US$39; AMS members US$31.20; Order code MCL/4

Math from Three to Seven

The Story of a Mathematical Circle for Preschoolers

Alexander Zvonkin, *Université Bordeaux I, Talence, France*

This book is a captivating account of a professional mathematician's experiences conducting a math circle for preschoolers in his apartment in Moscow in the 1980s. As anyone who has taught or raised young children knows, mathematical education for little kids is a real mystery. This book does not purport to show you how to create precocious high achievers. It is just one person's story about things he tried with a half-dozen young children. Anyone interested in the intellectual development of young children will find this book to be an invaluable, inspiring resource.

Volume 5; 2011; 300 pages; Softcover; ISBN: 978-0-8218-6873-7; List US$49; AMS members US$39.20; Order code MCL/5

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