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Notices

of the American Mathematical Society

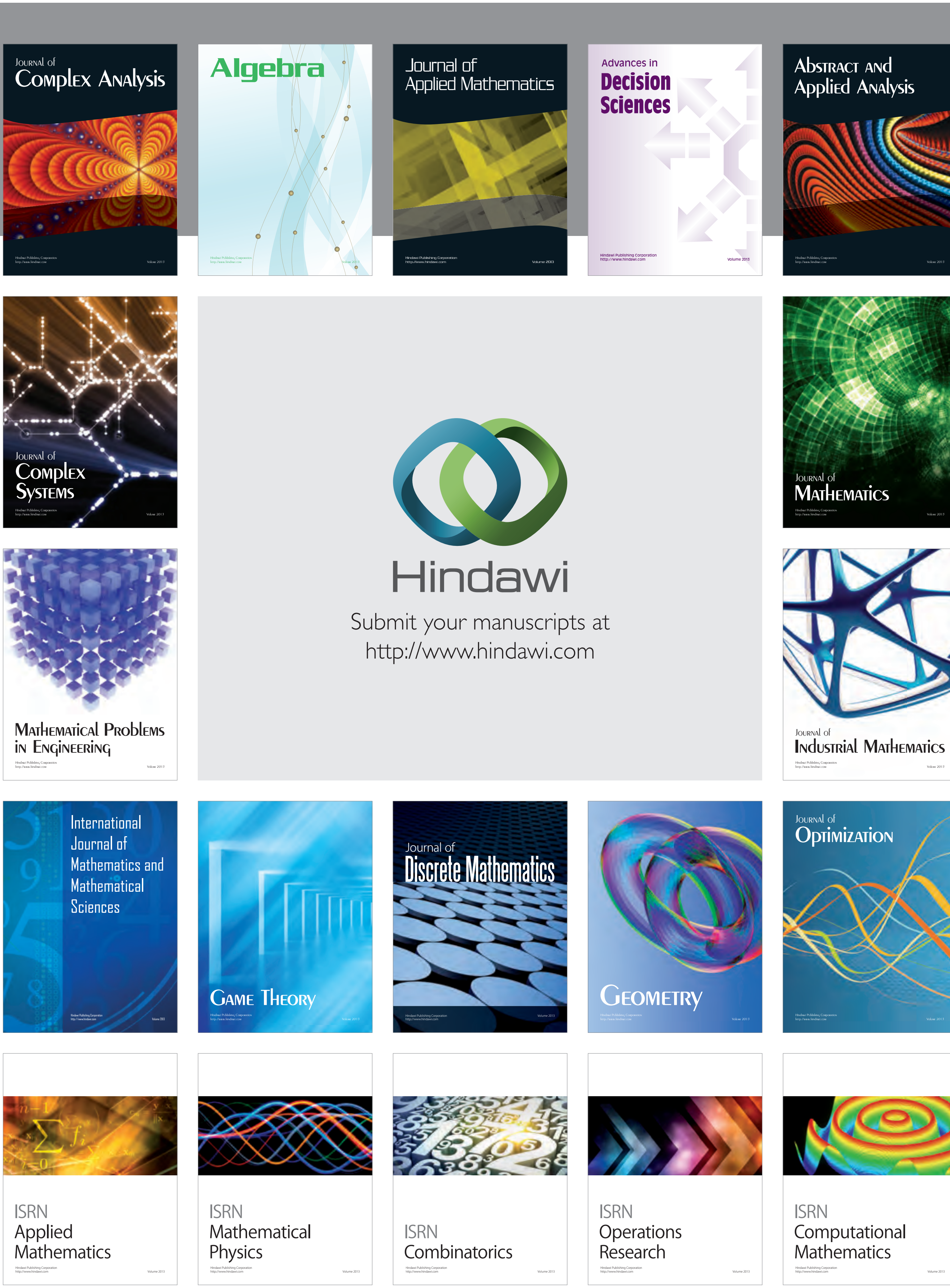
June/July 2013

Volume 60, Number 6

125th Anniversary

AMS
American Mathematical Society

Slicing the Antikythera Mechanism (see page 740)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American Mathematical Society

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Photo by Sam Vandervelde at MathPath

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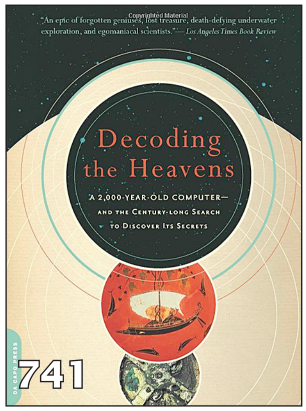

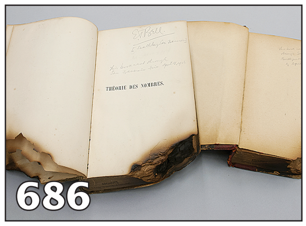

This month features an article about Eric Temple Bell and mathematics at Caltech in the between-the-wars period. It also has an unusual article on cryptography. The piece about the Eureqa symbolic regression program will acquaint readers with a new analytic tool. Finally, the distinguished differential equations scholar James Serrin is remembered.

—*Steven G. Krantz, Editor*

Features

Communications

Commentary

Notices

of the American Mathematical Society

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Departments

Opinion

Set the Default to "Open"

Reproducible Science in the Computer Age. Conventional wisdom sees computing as the "third leg" of science, complementing theory and experiment. That metaphor is outdated. Computing now pervades all of science. Massive computation is often required to reduce and analyze data; simulations are employed in fields as diverse as climate modeling and astrophysics. Unfortunately, scientific computing culture has not kept pace. Experimental researchers are taught early to keep notebooks or computer logs of every work detail: design, procedures, equipment, raw results, processing techniques, statistical methods of analysis, etc. In contrast, few computational experiments are performed with such care. Typically, there is no record of workflow, computer hardware and software configuration, or parameter settings. Often source code is lost. While crippling reproducibility of results, these practices ultimately impede the researcher's own productivity.

The State of Experimental and Computational Mathematics. Experimental mathematics[1]—application of high-performance computing technology to research questions in pure and applied mathematics, including automatic theorem proving—raises numerous issues of computational reproducibility.[2] It often pushes the bounds in very high precision computation (hundreds or thousands of digits), symbolic computation, graphics, and parallel computation. As with all computational science, one should carefully document algorithms, implementation, computer environments, experiments, and results. Even more emphasis needs to be placed on unique aspects of the discipline: (a) Are precision levels (hundreds or thousands of digits) adequate? (b) What independent consistency checks were employed to validate results? (c) If symbolic manipulation software was employed (e.g., Mathematica or Maple), which version was used? What precise functions were called? What parameter values and environmental settings were used? (d) Have numeric spot checks been performed for derived identities, etc.? (e) Have symbolic manipulations been validated, say, using two different packages? Such checks are crucial, because even the best symbolic and numerical computation packages have bugs and limitations, often exhibited only during hard computations.

The ICERM Workshop on Reproducibility in Computational and Experimental Mathematics. Such concerns motivated a workshop in December 2012, held at the Institute for Computational and Experimental Research in Mathematics at Brown University.[3] Participants included computer scientists, mathematicians, computational physicists, legal scholars, journal editors, and funding agency officials representing academia, government labs, industry research, and all points in between. While different types and degrees of reproducible research were discussed, an overwhelming majority argued that the community must move to "open research": research using accessible software tools to permit (a) "auditing" computational procedures, (b) replication and independent verification of results, and (c) extending results or applying methods to new problems. Of course, the level of validation should be proportional to the importance of the research and strength of claims made.

"It says it's sick of doing things like inventories and payrolls, and it wants to make some breakthroughs in astrophysics."

ScienceCartoonsPlus.com.

Workshop Conclusions. *First, researchers need persuasion that efforts to ensure reproducibility are worthwhile*, leading to increased productivity, less time wasted recovering data or code, and more reliable conversion of results from data files to published papers.

Second, the research system must offer institutional rewards at every level, from departmental decisions to grant funding and journal publication. Current academic and industrial research systems place primary emphasis on publication and project results and little on reproducibility. These systems penalize those devoting time to developing or just following community standards.

The enormous scale of state-of-the-art scientific computations, using tens or hundreds of thousands of processors, presents unprecedented challenges. Numerical reproducibility is a major issue, as is hardware reliability. For some applications, even rare interactions of circuitry with stray subatomic particles matter.

It is regrettable that software development is often discounted. It is typically compared to, say, constructing a telescope rather than doing real science. Thus, scientists are discouraged from spending time writing or testing code. Sadly, Web projects funded by the National Science Foundation remain accessible only about a year after

[1]*Exploratory experimentation and computation, by David H. Bailey and Jonathan M. Borwein,* Notices*, November 2011.*

[2]Mathematics by Experiment*, CRC Press, 2008.*

[3]*See* `http://icerm.brown.edu/tw12-5-rcem`.

DOI: http://dx.doi.org/10.1090/noti1014

funding stops. Researchers are busy running new projects without time or money to preserve the old. Given the ever-increasing importance of computation and software, such attitudes and practices must change.

Finally, standards for peer review must be strengthened. Editors and reviewers must insist on rigorous verification and validity testing, along with full disclosure of computational details.[4] Some details might be relegated to a website, with assurances this information will persist and remain accessible.

Exceptions exist, such as where proprietary, medical, or other confidentiality issues arise, but authors need to present such issues upon submission, and reviewers and editors must agree such exceptions are reasonable.

Many tools help in replicating past results (by the researcher or others). Some ease literate programming and publishing computer code either as commented code or as notebooks. Others capture provenance of a computation or the complete software environment. Version control systems are not new, but current tools facilitate use for collaboration and archiving complete project histories.

The U.S. has followed the UK, Australia, and others in mandating public release of publicly funded research, including data.[5] We hope this brings a cultural change in favor of consistently reproducible computational research.[6]

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[4] *Redefine misconduct as distorted reporting, by Daniele Fanelli,* Nature*, February 13, 2013.*

[5] *Increasing access to the results of federally funded scientific research, memorandum of the Office of Science and Technology Policy, February 22, 2013.*

[6] *See the workshop report at* http://www.davidhbailey.com/dhbpapers/icerm-report.pdf *and on Wiki at* http://wiki.stodden.net.

Letters to the Editor

Who Should Teach Mathematics Courses?

I was both pleased and dismayed by the article in the October 2012 *Notices* about the PCAST report, and the accompanying Opinion piece. Pleased, because both articles say good things at the end about how to move forward. Dismayed, because the dominant message is one of outrage that we, the only experts in town, weren't consulted.

Yes, mathematicians are entitled to a seat at the table; we should have been part of PCAST, and we should be "actively engaged" in the process of improving all STEM education, not merely in mathematics. But please, let's acknowledge reality. Of course faculty from "mathematics-intensive disciplines other than mathematics" can teach such mathematics courses as calculus, linear algebra, and differential equations. Quite possibly better than we can—they're bilingual, having mastered our treatment of the mathematics as well as the treatment appropriate to their own discipline. They know better than we do what's important for the vast majority of our students, who do not aspire to become professional mathematicians.

Does this mean we should cede control over these courses, or over the training of future mathematics teachers? Of course not. But we should acknowledge not only that others have a right to be at the table, but also that we have failed to adequately meet their needs. What is needed is true collaborative discourse, treating the PCAST report as a wakeup call and making an honest effort to explore all reasonable solutions. And yes, involving those pesky physicists and engineers in the teaching of our courses is reasonable.

—Tevian Dray
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(Received October 15, 2012)

Is Your Journey Really Necessary?

"Is your journey really necessary?", asked the posters in wartime Britain. This question has to be asked again now that catastrophic climate change has become an imminent threat. Trips to meetings and conferences are, of course, good for mathematicians and for mathematics, but the health of the planet is more important. In the last two years I did not go to any conferences involving otherwise unnecessary air travel. In a sense this is easy for me: I am at the end of my career. Yet I feel an intense regret each time I turn down such an invitation, especially when it is coming from good friends.

—Adam Koranyi
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(Received February 19, 2013)

Fellows Program

It is with great sorrow that I resign my membership in the AMS. I have been a member for many years but I cannot stomach the silly, elitist Fellows Program which was rammed down the throats of the members despite having been initially voted down. The theory as originally proposed was that mathematicians have not received the respect they deserve from the rest of the scientific community and having a Fellows Program should help the profession and its members to be taken more seriously. I feel certain that this will not happen. Mathematicians have not received the respect and recognition they deserve for a variety of historic reasons, one of which is surely funding stops. Researchers are busy running new projects without time or money to preserve the old. Given the ever-increasing importance of computation and software, such attitudes and practices must change.

Finally, standards for peer review must be strengthened. Editors and reviewers must insist on rigorous verification and validity testing, along with full disclosure of computational details.[4] Some details might be relegated to a website, with assurances this information will persist and remain accessible.

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(Received February 19, 2013)

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(Received February 11, 2013)

Author-Pay Solution for Math Journals

I was frightened when I read about the author-pay solution for the math journals, in your interview with President Friedlander [*Notices*, February 2013]. And the figure you mention: US$2,000 per article!

What this means is that mathematicians from poor countries—and I don't have to go farther than the Portugal where I live now—will be prevented from publishing in such journals. This is a cynical way of killing research in many countries!

People are usually paid to work. For many of us mathematicians, to work means to publish. So we will be charged when we work. Unbelievable!

Sorry for sending you such a politically incorrect letter!

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(Received February 20, 2013)

Steklov on Severi

In their interesting article (*Notices*, September 2012), J. Goodstein and D. Babbitt show how Francesco Severi, a one-time member of the Italian Socialist Party, turned into a protagonist of Mussolini's Fascist regime. The following excerpt from *The Recollections* of the Russian academician V. A. Steklov (see *Scientific Legacy* **17** (1991), "Nauka", Leningrad, pp. 271–272; translation from the Russian is mine), describes an event that happened in the summer of 1912. (Steklov was a professor at St. Petersburg University at that time, and the same year he was elected to the Russian Academy of Sciences as a Full Member.) In my opinion, this excerpt sheds some light on the above-mentioned conversion of Severi because he was an adherent of brute-force actions to defend his point of view.

"A part of summer [vacations] we [Steklov and his wife Olga] spent in several towns located on the lake shores in Northern Italy. […] Then we went to Padua via Desenzano. In Padua, I visited professor Tullio Levi-Civita in his luxurious flat (a part of the house belonging to his father—a mayor of Padua). […] T. Levi-Civita had acquainted us with with d'Arcais, N. Cisotti, Loria and Francesco Severi—professors of mathematics in Padua. One evening they gave a dinner party for us in the best restaurant. […]

"During the dinner, we talked about the current situation in universities in Italy and in my country, about customs prevailing in these institutions, teaching methods, etc. Meanwhile, they told me about seeing off their colleague Francesco Severi to a one-month exile to Bologna that had to happen within a few days. (Severi—one of the brightest Italian scientists—was at that dinner as well.) The thing is that the separation of church and state was discussed during our trip to Italy. The University of Padua had supported the separation. A part of students (Roman Catholics) was dissatisfied; they initiated a wave of protests, but some professors began to argue with students. The hot Tuscan F. Severi was the most zealous. Some students began to press him hard and one of them said something harsh. The response of F. Severi—a strong man—followed immediately; he, putting it simply, smashed the student's face. Thus, the controversy about the separation of church and state passed, as they say, into a completely different plane. The conflict had been considered by a certain newly established panel of judges, and their verdict was to exile F. Severi to Bologna for a month. To my question what must happen when the exile term expires my hosts responded plainly that after his rest from lectures Severi would return to his duties in Padua as if nothing had happened."

To finish the story of the relationship between Steklov and Severi, it is worth mentioning that, twelve years after the described events, Steklov initiated the procedure of election of Severi (along with J. C. Fields, G. H. Hardy, A. Kneser, E. Landau, P. Painlevé, and S. Zaremba) to the Russian Academy of Sciences as a Foreign Member. Steklov was a vice president of the Academy from 1919 to his untimely death in 1926, and his work was crucial for the survival of Russian science during that hard time.

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(Received February 21, 2013)

Dyson in von Neumann's Garden

Freeman Dyson's "A walk through Johnny von Neumann's garden" (*Notices*, February 2013) is a charming personal view of a broad swath of mathematical research. Unfortunately, in his treatment of game theory, Dyson makes two errors.

On page 156, he writes: "Johnny found the answer, which turned out to be a deep mathematical theorem. For a game with only two players, there exists a unique strategy which gives each of them the best outcome on the average." The errors in this statement are easily corrected. von Neumann's Minimax Theorem does not hold for all two-person games. He proved it for zero-sum, two-person games with a finite number of pure strategies. Also, the optimal strategies need not be unique.

I also find Dyson's translation of the title of von Neumann's 1928 paper as "Theory of Party Games" strange and, more important, contrary to von Neumann's intentions. The correct translation is "On the Theory of Games of Strategy" (see *Annals of Mathematics Study* **40**, for the translation of the 1928 paper which was made by Sonya Bargmann).

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(Received February 27, 2013)

Mathematicians Surviving WWII in Poland

In an otherwise interesting article by Freeman Dyson "A walk through Johnny von Neumann's garden" [*Notices* **60** (2), February 2013], there is a disturbing statement concerning Polish mathematicians. The author, describing his contact with Hugo Steinhaus, states that "…those [mathematicians] who survived [World War II] in Poland were all Gentiles". This type of sweeping generalization is never true but what Freeman Dyson is apparently unaware of is that he contradicts himself. Hugo Steinhaus was a Polish Jew, who survived the war hiding among Poles in Poland. One can read about it in his autobiography (Hugo Steinhaus, *Wspomnienia i Zapiski (Remembrances and Notes)*, in Polish, Aneks Publishers, London 1992, ISBN 0-906601-99-1). He was, certainly, not the only Jew who survived the war in Poland, and not the only major mathematician. There were many more, Kazimierz Kuratowski and Edward (Szpilrajn) Marczewski, among others.

Hugo Steinhaus seems to have "bad luck" in recent American mathematical publications. In a biography of Alfred Tarski (*Life and Logic* by Anita Burdman Feferman and Solomon Feferman, Cambridge University Press, 2004, ISBN 0-521-8240-7), the authors claim in turn (p. 68) that Steinhaus was "…the only Jewish [university mathematics] professor in [pre-war] Poland." This is, again, not true. Kazimierz Kuratowski, a Polish Jew, was a full professor in both Lwów and Warsaw Universities (Kazimierz Kuratowski, *A Half Century of Polish Mathematics, Remembrances and Reflections*, Pergamon Press, 1980, ISBN 0-08-023046-6).

It is expected that the information provided in the *Notices of the AMS* should be accurate especially since the publication has such a wide impact in mathematical communities.

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(Received April 11, 2013)

Response to Kranz and Kuhn

I am grateful to Przemo Kranz and Harold Kuhn for correcting my mistakes.

To Przemo Kranz I can only apologize for my carelessness. I was reporting what I remembered and did not check the facts.

To Harold Kuhn I would reply that the translation of "Gesellschaftsspiele" is a matter of taste. Kuhn's "Games of Strategy" is a free translation. My translation "Party Games" is literally correct and is supported by the fact that von Neumann explicitly mentions poker as an example to which his theory applies.

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(Received April 22, 2013)

On "Drowning in the Data Deluge"

George E. Andrews's retiring presidential address (*Notices*, August 2012) deserves careful rereading. It starts by noting that the NSF's [National Science Foundation] director of the DMS [Division of Mathematical Sciences] wants its name changed to the Division of Mathematical and Statistical Sciences and then raises hard questions about measuring value and the impact of the mountains of data we are generating.

Mining those mountains for information that may affect our lives is essential, but anyone who has experienced the sudden flash of insight that solves a problem knows its limits. How much of our resources should go into the mines and how much into the search for insight? To answer we must measure value. Andrews quotes some who would reduce it to a single number and in rebuttal presents the singular case of Henry B. Mann. Born in 1905 to a Jewish family in Vienna, he arrived a refugee in 1938, supporting himself by tutoring students. His 1942 paper proving the Schnirelmann-Landau conjecture had only 28 citations but won the 1946 Cole Prize for Algebra, while his 1947 paper introducing the Mann-Whitney U-test, a standard tool in non-parametric statistics, accumulated thousands of citations but no prizes. What measures value better, the judgment of those who awarded the prize or the statistics of citations? Both papers are invaluable; we would be poorer without either.

To complicate matters further, Andrews observes that only four Fields Medalists have written papers with more than five hundred citations. Not mentioned is that others have written more than one paper with over 500 citations, none honored with prizes. It is easy to tell when an outstanding problem is solved, harder to know when a new idea is fundamental. Prizes mark the first, accumulating citations the second. Some oft-cited but unhonored papers are the ones that introduced the concepts framing problems whose solutions earned prizes. If the prizes suggest that we would be poorer without the solutions then we would certainly be poorer still had the problems themselves not even been recognized. The conclusion Andrews forces on us is that there is no single measure of value, and whatever it is, sometimes only time reveals it.

To return, what's in a name? A choice of name can subtly influence the allocation of resources.

Recognizing that other disciplines and society at large need to understand the impact that mathematics can have, in 1966 I initiated the joint AMS-AAAS symposia on Some Mathematical Questions in Biology. The Society later abandoned them. The subject was right and its importance has grown but perhaps the name was wrong. Changing the name of the DMS may augur a shift in resources from seminars to mines; the name highlights our measure of value. Andrews warns us to be watchful.

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Received March 1, 2013

Raoul Bott at the Center of a Celebration

I greatly enjoyed the article in the April 2013 *Notices* "Remembering Raoul Bott". I knew Raoul as both an undergraduate (class of 1970—he was my advisor) and a Ph.D. student at Harvard. I wanted to share with you one picture to add to the wonderful collection in the article. It was taken on May 2, 1981, with Raoul in the center. From left to right are the mathematicians Ian Morrison, David Mumford, Barry Mazur, RB, myself, and John Morgan, holding Judy Moore, who was for a long time the administrator of the Harvard Math Department. This was on the day of our wedding.

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(Received March 25, 2013)

Stereotyping Mathematicians

It's not bad enough that the general public stereotypes mathematicians? Do we have to do it to ourselves? Ronald Lipsman's opinion piece, "The Math Gene: A Ticket to Wealth or Nerdiness" (*Notices*, December 2012) stereotypes mathematicians as socially awkward, unathletic, unkempt, impractical introverts. It represents an instance of "friendly fire" against the public image of mathematicians and goes so far as to advocate perpetuating this stereotype to the next generation of potential mathematicians. This stereotype, like many before it, is undeserved. I don't know with whom Lipsman "hangs out", but my observations show that: mathematicians are athletic and they can not only change the oil in their cars, but can replace water pumps and alternators. They are musicians and actors and, if they miss "poker night" once in a while, it is because they are busy studying a beautiful, profound, vast subject with far-reaching consequences, not just "cracking numerous mathematical puzzles." They are socially skilled; they exhibit "… extraordinary creativity, and originality…a willingness… to take great risks, an aggressive, self-confident, and strong-willed personality; persistence and single-mindedness; an ability to read people and gauge their desires, an inclination to defy convention, and a lack of concern about what others think of them." He is right to say that mathematicians lead lives of "honesty, fulfillment, a sense of doing something worthy"; have "a camaraderie with others who are similarly endowed"; and receive respect from the people they serve, but stops short of believing they are admired. In *my* experience they also receive admiration from the people they serve. Whether or not mathematicians dress well is a matter of opinion, but some have collaborated with designer Dai Fujiwara using Riemannian geometry to design groundbreaking new styles of dress. They are leaders of men (and women) and are definitely "cool!". And, yes, there are many examples of mathematicians acquiring great wealth.

I'm certain Lipsman meant no harm but it's not cute anymore for anyone, especially ourselves, to stereotype mathematicians as nerds or think that some people have the math gene and others don't. The perpetuation of this image of mathematicians is bad for our profession. These negative, nerdy images get stuck in the collective subconscious of the populace, and can affect recruitment into mathematics as well as policy and funding decisions for the mathematical sciences.

Stop it. We are not nerds.

—Martin Engman
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E. T. Bell and Mathematics at Caltech between the Wars

Judith R. Goodstein and Donald Babbitt

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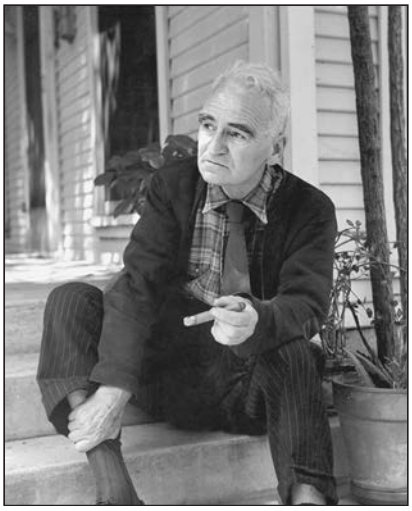

Eric Temple Bell (1883–1960), ca. 1951.

E. T. (Eric Temple) Bell, number theorist, science fiction novelist (as John Taine), and a man of strong opinions about many things, joined the faculty of the California Institute of Technology in the fall of 1926 as a professor of mathematics. At forty-three, "he [had] become a very hot commodity in mathematics" [Rei 01], having spent fourteen years on the faculty of the University of Washington, along with prestigious teaching stints at Harvard and the University of Chicago. Two years before his arrival in Pasadena he had received the American Mathematical Society's coveted Bôcher Memorial Prize for outstanding work appearing in the Society's *Transactions*.[1] His swift election to the National Academy of Sciences was expected.

Bell had been lured to Pasadena by the renowned experimental physicist Robert A. Millikan, who was in the act of transforming what had been a modest technical school into one of the country's foremost scientific institutes. It had started out in 1891 as Throop University (later, Throop Polytechnic Institute), named for its founder, philanthropist Amos G. Throop. At the end of World War I, Throop underwent a radical transformation, and by 1921 it had a new name, a handsome endowment, and, under Millikan, a new educational philosophy [Goo 91].

Catalog descriptions of Caltech's program of advanced study and research in pure mathematics in the 1920s were intended to interest "students specializing in mathematics...to devote some of their attention to the modern applications of mathematics" and promised "to provide definitely for such a liaison between pure and applied mathematics by the addition of instructors whose training and interests have been in both fields [CIT 28]". Indeed, the mathematical physics faculty at Caltech at that time was probably as good as anywhere in the country. Even if he did not write the catalog copy himself, Millikan saw the application of mathematics to other fields as a major consideration from the very beginning of his decision to expand mathematics at Caltech.

Before Bell's arrival the mathematics faculty consisted of William Birchby, Harry Van Buskirk, Luther Wear, and Harry Bateman, all holdovers from the Throop era. Birchby and Van Buskirk taught elementary courses; they were primarily mathematics teachers rather than researchers. Although he had earned a Ph.D. in mathematics from Johns Hopkins University, Wear, who handled some of the more advanced courses, did no research. Bateman, an English mathematical physicist, was the only member with sterling academic credentials. Following his graduation from Cambridge University (B.A. in 1903; Smith Prize, 1905; and M.A. in 1906), Bateman had studied

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[1] *The theory Bell advanced in his long and fundamental memoir ("Arithmetical Paraphrases", I and II) provided many applications to the theory of numbers. (Co-winner Solomon Lefschetz's paper offered essentially a complete topological theory of algebraic surfaces.)*

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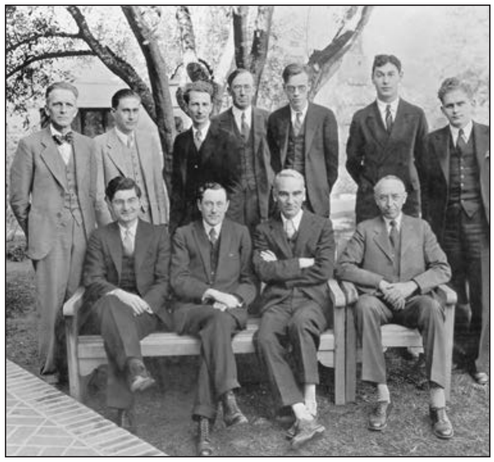
at Göttingen and in Paris. He later taught at the University of Liverpool and the University of Manchester before immigrating in 1910 to the United States. Like Wear, he had a Hopkins doctorate (1913).

Throop Polytechnic Institute hired Bateman in 1917 as a professor of aeronautical research and mathematical physics. By then he had already compiled an impressive record as a mathematician: some seventy scientific papers on topics ranging from geometry to earthquake waves, a British Association report on the history and theory of integral equations, a Cambridge University monograph on Maxwell's equations, and a textbook in press on differential equations.[2] To make ends meet, he lectured at the Bureau of Standards and reviewed papers for the Weather Bureau. At Throop, Bateman was given a free hand to develop the theoretical side of aeronautics, to suggest experimental work in a small wind tunnel under construction on campus, and to offer some advanced courses. He taught the first courses in aerodynamics and related subjects at the institute, including propeller theories, aerology, and elasticity [Gre-Goo 84].[3] Bateman's forte was not the kind of "applied mathematics" that the Hungarian-born engineer Theodore von Kármán, the first director of Caltech's Guggenheim Aeronautical Laboratory, later brought to bear so successfully on the problems of the aircraft industry. The theoretical physicist Paul Ehrenfest, writing to his wife from Pasadena in 1924, marveled at Bateman's uncanny mathematical ability but was not persuaded that the mathematician grasped the physics underlying his calculations. Ehrenfest describes a discussion he had with Bateman about some of his papers in mathematical physics as follows: "After a few questions over a half hour I could hardly see what he did or did not accomplish. He is a very pleasant fellow … can calculate wonderfully, i.e., he has 'calculational intuition', but jumps around helplessly in the volcano of his calculations, he has no physical intuition" [Ehr 24].

Millikan had apparently given Bell some indication that he might build up pure mathematics at the institute now that matrices had come into fashion in physics, thanks to the recent invention of matrix mechanics as a way to formulate quantum theory. But Bell came to understand even before setting foot on the campus that Millikan's "conversion" was something of a delusion. As he told Aristotle Michal, a job-hunting postdoc in mathematics whom he had met at Harvard, "Our first job will be to convert Millikan to pure mathematics—he thinks he is already converted, but he hasn't passed the half of his salvation" [Bel 26a]. In a letter to Harvard mathematician George Birkhoff, he noted that the institute's stars were the theoretical physicist Paul Epstein, an expert on quantum theory; the "inexhaustible" Harry Bateman, who wore many scientific hats; and Richard Chace Tolman, who was "a mathematician gone wrong on chemistry" [Bel 26b].



Caltech mathematics faculty and teaching fellows, 1932. Front row, from left: Aristotle Michal, Harry Bateman, Eric T. Bell, and Harry C. Van Buskirk. Rear row: William Birchby, James H. Wayland, Carlton C. Worth, Luther E. Wear, Robert S. Martin, [unknown], and J. Lawrence Botsford.

In short, Bell was well aware of the lesser status of pure mathematics at Caltech, but he had hopes of turning Millikan around. "To my way of thinking," he told Michal, "Pasadena has the most interesting possibilities of anyplace in the United States" [Bel 26b]. In the same letter, Bell spoke of the institute's need "to build up the library and, by prevailing on Millikan to take on a few good young men, to make the place as strong in mathematics (pure) as it is in applied." Millikan, according to Bell, had given him a free hand "to work out my own problems," with the understanding that Bell was to "help with the math. physics," a task Bell thought more suitable for H. P. Robertson, who had been his student at the University of Washington.

Bell had reasons for optimism. Pure mathematics had blossomed into an active and expanding discipline in the United States in the decade following the end of World War I. In 1926 his own publishing record, which had begun at Washington in 1915, ran to sixty-eight titles, a substantial number for a ten-year period (and just a fraction of his career total of more than three hundred, not counting his fictional output as John Taine). It was a number probably matched only by Leonard Dickson, who specialized in algebra and number theory at Chicago. Nevertheless, before hiring Bell, Millikan had polled Dickson, Birkhoff, and

[2]*Cambridge University also published Bateman's monumental tome* Partial Differential Equations of Mathematical Physics *in 1932, which is still available as a print-on-demand paperback.*

[3]*In addition to various topics in analysis, Bateman did research in "classical" areas of physics (electrodynamics, relativity, and hydrodynamics) and taught vector analysis, potential theory, transcendental functions, hydrodynamics, and integral equations—the sorts of things that every young classical theorist of his generation was expected to know. Between 1918 and 1928 most of his publications dealt with electromagnetic theory, which later prompted MIT mathematical physicist and polymath Edwin Bidwell Wilson to call him "probably the most powerful and consistent mathematician now working in this field"* [Wil 27].

A gathering of H. P. Robertson's friends on the steps of the Athenaeum, 1936. Standing, from left: Virginia Thomas, Tracy Thomas, Howard Percy Robertson, Ethel Bateman, Pipo von Kármán, Angus Taylor, Patsy Taylor, Toby Bell, Eric Temple Bell, Mary Bowen, and Aristotle Michal. Seated, from left: Hazel Mewborn and Luddye Michal .

Princeton's Oswald Veblen—research-minded mathematicians who had put the University of Chicago, Harvard, and Princeton on the map as outstanding centers in mathematics. More important from Millikan's point of view, all three were members in good standing of the National Academy of Sciences. As Millikan wrote to Veblen in late December 1924, "From the standpoint of physics and mathematical physics we are fairly competent here at the Institute to form judgments in which we have some confidence, but from the standpoint of mathematics I feel keenly my own incompetence" [Rei 93]. From the start, Millikan had insisted on inviting only scientists of National Academy caliber to join him in Pasadena, which helps explain why the recently anointed Nobel Prize winner asked his fellow academicians what Bell's chances were of election to the National Academy.

Veblen volunteered only that Dickson thought highly of Bell's work. Birkhoff, winner of the first Bôcher Prize, gave Bell high marks for his specialty ("[H]e is great in his field, theory of numbers") and his publishing record ("very prolific") but questioned whether Bell's long list of papers told the whole story ("[W]hen it comes to papers outside his specialty, his work is not always of high order") [Bir 25]. Dickson, however, lavished praise on Bell, describing him as "an A1 mathematician of very exceptional ability in research of high order on fundamental subjects…I have long been strongly impressed by his unusual originality and his success in research of fundamental character" [Dic 25]. He predicted that Bell would be elected to the academy before Bateman was, which proved correct: Bell would be elected in 1927; Bateman's election followed in 1930, two years after he became a fellow of the Royal Society of London. If Millikan wanted to hire Bell, added Dickson, "You could hardly…get a better man," and he cautioned that Chicago also had its eye on Bell. Nor would the Seattle mathematician likely leave the Pacific Northwest without an annual salary of $5,000 or better, a figure the famously penny-pinching Millikan stored away for future reference.

As Dickson noted, Bell did not lack for academic suitors. Flush with sharing the Bôcher Prize, he spent the summer of 1925 lecturing on his own material at the University of Chicago and the fall semester at Harvard. He also had offers of professorships from the University of Michigan, Bryn Mawr, and Columbia University in his pocket, while Chicago began to woo him. Millikan, in discussing the need for expansion of Caltech's mathematics faculty before his Executive Council in early 1926, concluded that everything short of kidnapping should be done to acquire Bell. Bell, in turn, used Columbia's tantalizing offer of $7,500 to secure a quick response from Millikan. Within a month, he and Millikan had reached an agreement for an annual salary of $6,000.

Mathematics on the West Coast

Bell accepted Millikan's invitation to come to Caltech because the institute had already acquired a certain cachet in scientific circles and, perhaps just as important, because it was situated on the West Coast. A graduate of Stanford University in mathematics in 1904, Bell had earned a master's degree in mathematics from the University of Washington in 1908. He took his Ph.D. (1912) at Columbia University but signed up to teach in the Pacific Northwest even before he had turned in his dissertation. He liked to say that the West Coast, while underdeveloped, had the potential to equal anything the East Coast establishment had to offer. Bell chose Caltech over other institutions in part to prove his point. He railed against the stuffy traditions at schools such as Harvard; indeed, he would later warn at least one younger colleague that "the Eastern places" were "not the whole cheese," adding that even Washington was "better than some potty Eastern college" [Bel 26c]. In the West, one could at least breathe fresh air.

Bell's championing of the Far West mirrors the regional factionalism that accompanied the growth of mathematics in America. His instincts proved sound: during the 1920s and 1930s mathematics on the West Coast began coming into its own. In 1924 E. R. Hedrick, the first president of the Mathematical Association of America (an organization itself born of regional factionalism), left the University of Missouri to become chairman of the mathematics department at UCLA, then a brand new school in Southern California. An able administrator, Hedrick worked considerable improvements in mathematics during his tenure. The thirties saw the arrival at UCLA of refugee

Max Zorn, followed by Angus Ellis Taylor and Tracy Thomas, who was Veblen's best differential geometry student at Princeton. The rise of mathematics at UC Berkeley is an even greater success story. In 1934 Griffith C. Evans, who had built up mathematics at Rice University in Texas, took over the chair of Berkeley's department. With Evans at the helm, it became a department rivaling those of Harvard, Chicago, and Princeton. Evans added a number of mathematicians of the first rank, including the Polish-American mathematical statistician Jerzy Neyman. Similarly, Stanford's mathematics department took off in the 1930s with the arrival of Hungarian refugees Gábor Szegö and George Pólya.

Unlike most American institutions of higher learning, Caltech lacked traditional departments and department chairs. Bell became a member of the Physics, Mathematics, and Electrical Engineering Division, which reported to Millikan. Bell would be responsible for the graduate work in mathematics, and the mathematicians looked to him to speak up for the field and take the lead in dealing with Millikan. Bell's plans to build up mathematics in Pasadena included both Robertson (who would shortly cap off a two-year fellowship in Germany with a fellowship year at Princeton) and Michal, a specialist in Fredholm and Volterra integral transformations and their Fréchet-Gâteaux-Volterra generalized differentials. "I shall first try for Robertson (Millikan wants him), and then for you," he told Michal. "You and he will not conflict; he is primarily an applied mathematician" [Bel 26b]. Bell planned to "ditch" (his word) on Robertson the task of teaching the applied side of mathematics. "I have so many things I really want to do that I can't take time to be expert in math. physics," he wrote to Robertson, just before leaving Seattle. "For instance, I have recently opened up a whole new field in 'General Arith.' where there are hundreds of things to be done, and where the job can be best executed by one man working with a lot of able students" [Bel 26c]. Michal would sign on in 1929, but it took almost two more decades to snare Robertson.

The story of mathematics at Caltech in the interwar years is marked by a tangle of personalities and rivalries among Bell's small group of mathematicians. Relations between Michal and Bell would eventually degenerate into name-calling and shouting.[4] Michal also seemed to be getting the most graduate students, which upset Bell. Above all, there was Bell's tumultuous love/hate relationship with H. P. (Bob) Robertson. Berkeley mathematician Abraham Haskel Taub, a longtime friend and colleague of Robertson's, analyzed it this way: "Bell and Bob were both strong people. Bell taught Bob, learned from him, fought with him in fun and sometimes not in fun, and both cared deeply for each other" [Tau 62].

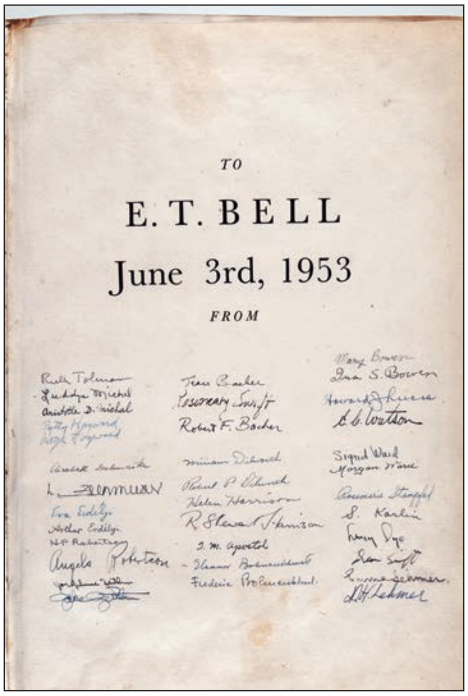
"A Kid Named Robertson"

Our story begins back in 1922, when Bell, who was offering a course in mechanics at the University of Washington, encountered "a kid named H. P. Robertson" in his class who breezed through the assignments. In a letter to Harold Hotelling, a former student who later became a distinguished statistician, Bell marveled: "He was just 19 last month, and he goes through the most difficult problems and theory like a shot. Even complicated set-ups in problems by Lagrange's equations don't bother him in the least…Robertson is a prize" [Bel 22].

Bell took Robertson under his wing—much to the consternation of Washington's conservative mathematicians, who believed that research did not go hand in hand with good teaching—and got him interested in the theory of relativity. Bell taught a relativity course in the university's mathematics department, and Robertson took it in his senior year. Bell also persuaded Robertson to stay another year at Washington to continue studying mathematics, electricity, and relativity, using, for the last, Hermann Weyl's *Raum-Zeit-Materie* as his textbook. "If I were 15 years younger," Bell confided to Hotelling in 1922, "I would go into relativity; as it is, I hate to scrap the detailed knowledge of the theory of numbers which has taken so long to acquire" [Bel 22].

Robertson, however, followed the path of relativity and never looked back. With a bachelor's degree in 1922 and a master's in 1923 from Washington under his belt, he enrolled at Caltech for advanced graduate work in the fall of 1923 on Bell's recommendation. There were at the time at least three scientists at the institute who were interested in relativity: Tolman, especially as it applied to cosmology; Bateman, in the more technical mathematical problems; and Epstein, Caltech's sole theoretical physicist. At one of Caltech's weekly physics research conferences later that year, Robertson gave a talk on relativity in which he credited Bell with sparking his interest in the subject. Millikan and Epstein, who were in the audience, congratulated Robertson afterward on a fine talk; Robertson dodged the compliment by heaping praise on Bell. Millikan filed the name away. "Thanks for tooting my horn," Bell later wrote to Robertson. "I know what they want and they've got him—Bateman" [Bel 24]. Still, Bell appeared ready to pack his bags and head south. As he told Robertson

[4]One of Michal's main goals in the thirties was to generalize the analysis and geometry on finite-dimensional manifolds to abstract infinite-dimensional manifolds, although he does not seem to have proved any new deep theorems. Other mathematicians at the time, including Bell, viewed it as abstraction for its own sake, with no sense of problem. Subsequently, however, these topics became important and active fields in pure and applied mathematics.



List of contributors to E. T. Bell's retirement gift in 1953. More than thirty friends and colleagues signed the flyleaf of the 1670 edition of Diophantus' *Arithmetica*, including Jake Zeitlin, the legendary Los Angeles rare book dealer who brokered the sale.

in closing, "I'd sell my left foot to get into a job in California."

Before Bell managed to plant both feet in the Southland, Robertson had obtained a Caltech Ph.D., with a major in mathematical physics and a minor in mathematics. He learned quantum mechanics and physical hydrodynamics from visiting scientists Ehrenfest and Vilhelm Bjerknes; statistical mechanics, electricity and magnetism, and advanced dynamics from Epstein; and various other subjects under Bateman's guidance, including vector analysis, potential theory, transcendental functions, and integral equations. He completed his dissertation in 1925 on a topic in relativity, "On dynamical space-times which contain a conformal Euclidean 3-space", under Bateman's direction and then crossed the Atlantic for a year's study in Germany as a National Research Council Fellow in mathematics. The fellowship was renewed for a second year with the promise of a third either at Harvard or Princeton. Robertson spoke of permanently locating in Pasadena from 1928 on, "but that is as yet unsettled," he wrote in spring 1927 to a family friend [Abe 27]. "I have had suggestions from other universities looking for an assistant professor [of] mathematics or mathematical physics, and it may be to our advantage to go to one of these in spite of our preference for Pasadena." By this time, as he later recalled in a brief autobiographical sketch, "I found myself very much more interested in the physical application than in the mathematics itself" [Rob 51a].

In June 1927 Millikan wrote to Robertson, who was still in Germany and expecting to continue his N.R.C. Fellowship at Princeton, and offered him a faculty position, effective September 1928, with the status of assistant professor of mathematics on leave until that time. Robertson seemed delighted by the invitation and quickly sent back his acceptance letter. From then on, Bell began hounding his former student to publish, publish quickly, and publish often. By this time, the chemist Linus Pauling had begun to create a stir at the institute, and Bell warned Robertson that there was "one and only one way to beat him. You know what it is as well as I do" [Bel 27a].

There is no evidence to suggest that Robertson cared one way or the other about who was top dog on campus, but judging by this admonition it might have mattered to Bell, who in any case seems to have enjoyed lecturing Robertson on the need to write up his work and submit it for publication. "Millikan and the lot are watching you to see whether you can do it…for your own sake, if not God's, make good, and do it in a hurry" [Bel 28].

In the spring of 1928 Robertson asked Millikan if he could remain at Princeton for a second year. The German mathematician Hermann Weyl was set to arrive, and it seemed too good an opportunity to pass up, especially as Weyl's book on relativity theory had played an influential role in Robertson's undergraduate education. The request was granted, and soon Robertson embarked on an English translation of Weyl's celebrated book on group theory and quantum mechanics [Wey 31]. Late that fall, Caltech officials authorized Bell to open negotiations with Aristotle Michal, who had moved on to a teaching position at Ohio State University. Michal had emigrated from his native Smyrna to the United States in time to go through high school, which he followed with undergraduate work at Clark University and graduate work at Rice, culminating in a Ph.D. under Griffith Evans. Michal played hard to get, but in March of 1929—four months and a flurry of letters later, mainly over how much he would be paid—he sent Bell a telegram accepting a salary of $4,500 and an associate professorship effective September 1930. In the meantime, Robertson was expected back in Pasadena to begin teaching in the fall. Events then took an unexpected turn.

The Contretemps with Robertson

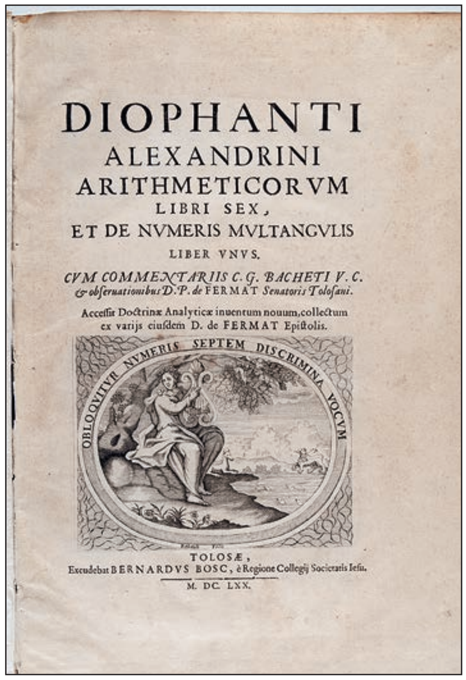
On March 20, a day after receiving Michal's telegram, Bell wrote an uncharacteristically icy letter to Robertson in Princeton—a letter totally out of keeping with the usually informal, sometimes bawdy, tone of the correspondence between the two friends—in which he intimated that Robertson might be better off teaching somewhere other than at Caltech. "This is rather an official letter, written at the request of [Millikan's assistant, Earnest] Watson and Dr. Millikan," Bell began by way of explanation. "They want to know whether you are definitely planning to return here next year… As you know, the rule here is no advancement in either rank or salary unless a man is productive. So if you see anything that you consider more attractive, please let us know as soon as possible. We must know definitely by April 1st." While "I personally hope you will accept, and fight it out on the lines proposed," Bell wrote in closing, he emphasized again that there was "absolutely no chance here for a man who is not productive" [Bel 29a]. On April 1 , Robertson sent Millikan a telegram saying that "under present circumstances" he felt obliged to request release from his appointment. Marietta Fay, Robertson's daughter, recalls that "both my parents were deeply hurt by Bell's letter. They never forgave him" [Rei 93].

A few days later, in a letter to Bell and Millikan, Robertson explained that he had gotten the impression that "the Institute is not satisfied with my work during the two years which have elapsed since the appointment" [Rob 29a]. On April 20, Bell replied, wondered if they were still on speaking terms, and said that he thought Robertson had "made the mistake of your life in turning down what was offered" at Caltech. As a "final parting piece of advice," he warned Robertson to "get busy, and show the world that you are doing something," all the while insisting that he took "personally the full responsibility" for the events that caused Robertson to resign [Bel 29b]. Robertson responded that there were no hard feelings but that Bell's apparent change of attitude toward him in the space of one year, and what seemed to Robertson to be the institute's view of him as an inadequate "producer", had left him no alternative but to resign, as "the only self-respecting thing to do" [Rob 29b].

Robertson's mother visited Bell and his wife, Toby, in Pasadena the following year and added her own postscript to this bizarre tale. It seemed to her, as she wrote to her son and daughter-in-law, that the Bells' admiration for her son was mixed with jealousy, stemming from the esteem in which both Richard Tolman and Princeton's mathematicians held him [A M Rob 30].

Just how "unproductive" had Robertson actually been? According to his bibliography, he published eleven papers between 1924 and 1929 on topics ranging from differential geometry and quantum theory to relativistic cosmology, including an article in 1929 in *Physical Review* on the uncertainty principle, which remains to this day among his most cited papers [Rob 29c]. It was not a great number, to be sure, compared with the twenty-nine papers Bell had whipped out in the first six years of his own career. Bell put a premium on showmanship, visibility, and a high profile, which is probably why he kept telling Robertson to publish his work in bits and pieces and to do it quickly rather than wait until he had pulled things together. The American mathematics community, Bell argued, likely wouldn't understand it either way. Bell continually admonished Robertson to put himself forward in every way possible—to line up offers of positions at other institutions, for example, which would impress Millikan, who "eats up this sort of thing" [Bel 28]. He seems to have feared that Robertson would end up like the diffident Bateman, whose priority in certain matters concerning special relativity, Bell believed, went unappreciated [Bel 24]. However, Robertson's intransigence suggests that he simply did not like being told what to do by other mathematicians.

After he turned Caltech down, Robertson was offered a position in Princeton's mathematics department. He refused that offer and requested instead a position like the one he had just spurned from Caltech, which would have allowed him to teach physics as well as mathematics. The university countered by offering him an assistant professorship of mathematical physics with a seat in both departments, a situation he accepted but would later vow never to repeat [Rob 51a]. With the exception of a one-year sabbatical leave in 1935–1936 (which he spent in Pasadena "at the scene of some of my former indiscretions" [Rob 35a]), Princeton remained his academic home until his permanent return to Caltech in 1947. During his tenure at Princeton, Robertson rose to prominence as one of the pivotal figures in the United States in the working out of the general theory of relativity. So when he returned to Caltech, he did so on his own terms. As he later recalled, "I had had enough of two sets of department meetings and of the intellectual arrogance of mathematicians, and elected to go into the Physics Department, although I had been offered my choice" [Rob 51a].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TOLOSÆ,
Excudebat BERNARDVS BOSC, è Regione Collegij Societatis Iesu.
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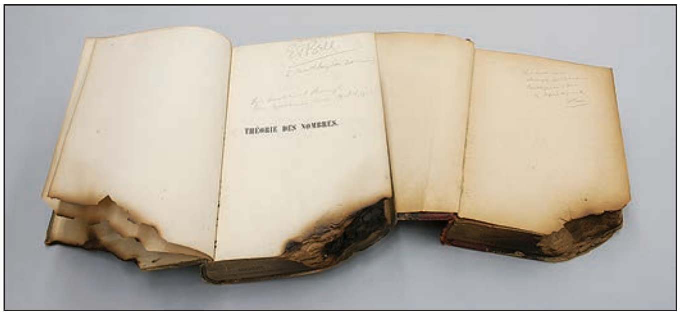
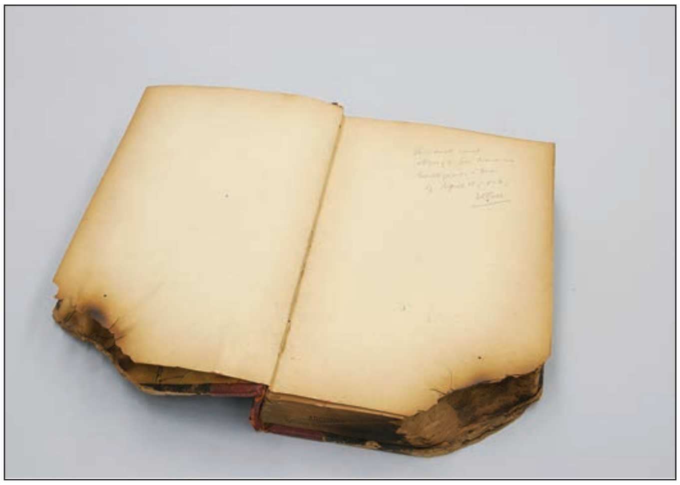
Title page of Bell's *Arithmetica*. The 1670 edition includes the claim made by Fermat that he had proved what became known as Fermat's Last Theorem but lacked space in the margin to show his work. Bell's long-time research interest in Diophantine equations set the stage for his own book about Fermat's Last Theorem, *The Last Problem*, published posthumously in 1961.

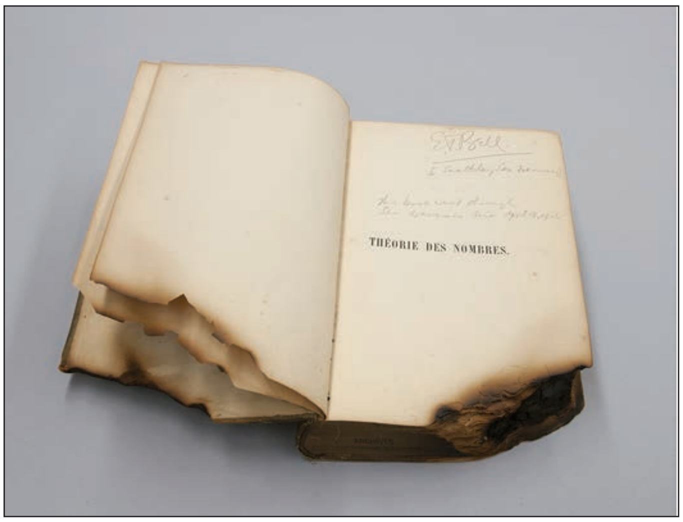
Bell never quit hounding his protégé to publish more often. He wrote to Oswald Veblen in the winter of 1931, "If you happen to think of it, would you mind jogging Robertson up to get out some of his stuff on mathematical physics? As it is, other people are running away with bits of it under his nose" [Bel 31a]. Even Robertson's election to the National Academy in 1951 provided Bell with ammunition. "This is something many years overdue, mainly your own fault, for straddling the fence



Bell was living in a boarding house in San Francisco at the time of the 1906 earthquake and buried these two math books in the backyard.



Several days later, Bell rescued his copy of *Théorie des Nombres*, Édouard Lucas's 1891 classic text in number theory, from the scorched earth.



Beneath his name and the names of two cities, Seattle and San Francisco, Bell wrote the following inscription: "This book went through the San Francisco Fire April 16, 1906." Although Bell discarded most of his correspondence in later years, he kept these two charred books, which are now housed in the Caltech archives.

between two sciences and not letting your fellows know on which side your balls hung," he wrote [Bel 51]. Robertson, no stranger to such repartee, replied in kind, "Thank you for your obscene congratulations…You attribute the delay in me sitting on the fence with one orchid hanging over on either side; I say they were only waiting for them to shrivel up and drop off before I would be ripe for the honor" [Rob 51b].

Bringing Up the Next Generation

Morgan Ward, Bell's first graduate student, entered Caltech in 1924 (where he was one of only forty-eight graduate students altogether) after earning his bachelor's degree at UC Berkeley. He became Caltech's first Ph.D. in mathematics, receiving his degree summa cum laude in 1928 with a dissertation on the foundations of general arithmetic;[5] this was followed by his appointment as a research fellow. Like physics and chemistry at Caltech, mathematics tapped its own students from the 1920s on. In 1929 Ward joined the faculty as an assistant professor of mathematics and, aside from a year at Princeton in 1934–1935, remained at Caltech until his death in 1963. His research interests ranged from recurring series, Diophantine equations, abstract arithmetic and lattice theory[6] to functional equations and numerical analysis. Like Bell, he had a deep interest in the theory of numbers and a "great contempt for those who proliferate easy empty generalizations of the great classic ideas of mathematics," according to Derrick H. Lehmer, who got to know Ward while spending the 1930–1931 academic year at Caltech on an N.R.C. Fellowship in mathematics [Leh 93].

The onset of the Great Depression in 1929 may have dampened Bell's spirits a bit. In response to a 1931 letter from Veblen hinting that he would welcome an invitation to visit Pasadena while Albert Einstein was in residence, Bell wrote:

> I fear it is out of the question. The financial stringency has hit us hard. The mathematicians never did have any funds available to pay outside lecturers. The one time when we did pay a lecturer, namely Harald Bohr,

[5]*This is how Ward viewed his thesis: "We have now reached a logical stopping place. In Part I, we have subjected the concept of a class and a binary operation to a careful scrutiny, and shown that for the purposes of general arithmetic, where all classes are denumerable, we can assume the class ordered without any loss of generality, or replaced by the numbers one, two, three, …We have thus 'arithmetized' general arithmetic in Kronecker's sense."* `http://resolver.caltech.edu/caltechETD:etd-03042005-135853`.

[6]*Eighteen papers on these topics appeared in the* Annals of Mathematics, *then (and now) the leading American journal of mathematics.*

> was provided for by a crumb dropped from the physicists' banquet…I was to have got a new man this year, but the money wasn't forthcoming. In the past they have usually paid railway fare to essential meetings; this year that also is cut out, so I shall have to pay my way to New Orleans. However, this depression can't last forever. [Bel 31b]

In fact, the Depression dragged on, and no new faculty appointments were made in mathematics until the early 1940s.

While at Princeton, Ward confided to Robertson that he was not entirely happy with his situation at Caltech. In a letter to H. S. Vandiver at the University of Texas, Robertson said that Ward "would welcome an opportunity for a change; this is, of course, most confidential" [Rob 35b], and on the same day he wrote to J. Robert Oppenheimer at Berkeley: "The purpose of the present note is to find out whether and to what extent you have the ear of Evans or other influential people in the Mathematics Department. Because if you have, they might be interested to know…that Morgan Ward has always had a soft spot in his heart for Berkeley…I have gotten to know Ward much better this [year] and have reason to believe he would by no means resent an opportunity for a change" [Rob 35c]. Ward in fact received a promotion and a raise at Caltech soon after his return, prompting Robertson to remark, "I suppose that makes things look different there, doesn't it? I must say it increases my respect for your Chief [Millikan]" [Rob 35d].

Angus Taylor, Aristotle Michal's first student and one of his best, was another promising star. Taylor and the other graduate students in mathematics at Caltech in the 1930s were pushed to the research frontier as quickly as possible. Because he already knew the theory of functions of a complex variable, Taylor skipped Bateman's course, which leaned heavily on Whittaker & Watson's *A Course of Modern Analysis.* (He later described Bateman as "a very gentle and nice man…in a little rut all by himself" [Tay 81].) Instead, under Michal's guidance, Taylor became proficient in Lebesgue measure and integration, the theory of abstract spaces and functional analysis, and Riemannian and non-Riemannian geometry. "Michal did some lecturing, but made the students do quite a bit of it themselves," Taylor recalls [Tay 81]. He studied abstract algebra under Bell, who, he says, "didn't lecture. He had all the students tell the class what was in the books, so the students did all the lecturing; Bell commented and criticized." In a memoir for the Mathematical Association of America, Taylor characterized Bell as "a stimulating person, given to expressing strong opinions [but] I don't think he spent much time preparing what he was going to say in class" [Tay 84]. The curriculum had gaps, particularly in combinatorial topology and point-set topology, subjects offered at Princeton, Texas, Virginia, and Michigan. "There really was not a mathematics department in an administrative sense," Taylor remembered. "I don't think there was much planning of curricula. There was very little guidance of graduate students" [Tay 81].

Be that as it may, early in 1936 Veblen asked Robertson, then at Caltech on sabbatical, for his opinion of Angus Taylor. Robertson replied:

> I do know Taylor fairly well, and I do think he is really very good…But the fly in the ointment is this, as you probably know by this time: Taylor has just yesterday accepted an instructorship here at the Institute, and has withdrawn his application for an N[ational] R[esearch] F[ellowship]. I am sorry he has done this just now, for I think he would profit much more at this point by contact with other schools of analysis—particularly the Johnny [von Neumann]-operator-school! But he seems quite sure that he is doing the best thing by staying on here—and teaching brats on a twelve-hour basis. [Rob 36]

Veblen refused to accept Taylor's decision and managed to persuade him to accept the fellowship from the National Research Council and come to Princeton as a postdoc, where he worked with Salomon Bochner. Taylor's fellowship was renewed for 1938–1939, and then, unexpectedly, he received an offer of appointment at UCLA for that academic year. Keen to return to California, he tried to find out whether Caltech planned to ask him back in 1939. "So there I was, in April or May of 1938, a bit up in the air about my future," he later recalled. "Then unexpectedly, I received word from E. T. Bell urging me to accept the UCLA offer. That told me what I hadn't known for sure about Caltech's interest in me. After discussing the matter with people at Princeton, and against their advice, I resigned the second year of the fellowship and took the job at UCLA. I've never regretted it" [Tay 81]. Morgan Ward, who was hoping Taylor would return to Pasadena, blamed Bell. Taylor, he wrote Robertson, would have done "his fair share of the work, something which A. D. Michal and E. T. Bell avoid successfully." Bell, he added, "seems down [on] him, but I cannot find out exactly why—he seems to have made the wrong remark to him some time ago, and Bell has treasured it" [War 38].

In 1939 Ward received an offer from Johns Hopkins and, perhaps with Taylor's fate in mind, asked Millikan "what my immediate prospects might be" [War 39]. He also took the opportunity to announce that his student Robert Dilworth, who had done his graduate work on a new algebraic theory of lattices, had just been awarded a prestigious

Sterling Fellowship at Yale in case Millikan was thinking of hiring an assistant professor in the future. While at Yale, Dilworth continued this research, which is well documented in his book (with Peter Crawley) *Algebraic Theory of Lattices*, published in 1973.[7] Meanwhile, Bell told Millikan that if Hopkins wanted Ward, Caltech "should do the utmost we can to make it worth his while to stay" in Pasadena [Bel 39]. Ward was promoted to professor the following year.

The first substantial revamping of Caltech's mathematics faculty in more than a decade came during the war. In 1942 a new assistant professor in mathematics was needed to replace the retiring Van Buskirk. Ward's former student Robert Dilworth and Michal's former student Angus Taylor were the candidates. The screening took place "in house". Millikan turned to several physicists at the institute for advice. They assured him that Dilworth's research was potentially of greater use to physicists, although the spectroscopist William Houston questioned the criteria Millikan appeared to be using in deciding between the two mathematicians ("I was rather surprised to have it mentioned [by you] that he [Dilworth] seemed to be more inclined toward the applications of mathematics than many other mathematicians" [Hou 42]). In a letter to one of us [JRG] many years later, Taylor wrote that he knew "that Bell and Michal were at odds over getting me to go back to Caltech from Princeton…Millikan made it quite clear, it seemed to me, that he was only interested in what Dilworth or I might be useful for in teaching the physics graduate and undergraduate students, and not at all in our scholarly potential in research" [Tay 91]. But he had no idea that he had been a candidate for a tenure-track position at the school along with Dilworth several years later. "I would not have left UCLA for Caltech then [in 1942], in any event" [Tay 81], he later reported to John Greenberg, a historian of mathematics from Pasadena.

Millikan, in his letter to Michal explaining his decision to appoint Dilworth instead of Michal's former student, assured him that "there has never been any question about the excellence of Taylor's teaching work," while advancing an argument that Michal was in no position to challenge: "Our trustees thought it undesirable to try to run the risk of creating unpleasant feeling between UCLA and the California Institute by trying to pull Taylor away from them…and so decided to try to get Dilworth here for next fall. There is of course never anything permanent about a first appointment" [Mil 42]. Dilworth returned to Caltech as an assistant professor in 1943 and two years later was promoted to associate professor. In the last year of the war, he served as an analyst with the 8th Air Force in Great Britain. In 1951 Dilworth would become a full professor (and a major figure in lattice theory), and while continuing his research in algebra he also worked in other fields, including probability theory and statistics.

Bell was disappointed by the turn of events. If Millikan wanted a mathematician more tuned to applied mathematics, then Robertson was the man. Others on the campus, including Ward and von Kármán, who had turned to Robertson for help on a turbulence problem during his Pasadena sabbatical, also plugged for Robertson. But Millikan, as Bell wrote to Robertson, was unwilling to "spend any real money," and Bell "frankly" saw "no chance until, if ever, Pa [Millikan] retires and a more enlightened financial policy is adopted" [Bell 42].

In 1945 Robert Millikan retired as Caltech's head, and the following year physicist Lee A. DuBridge became the institute's president. Substantial salary increases went into effect shortly after DuBridge took office. Bell's original band of mathematicians also passed into history: Harry Bateman, the AMS's Gibbs lecturer in 1943, died three years later en route to New York to receive an award from the Institute of Aeronautical Sciences.[8] Aristotle Michal died of heart disease in 1953. That year, E. T. Bell retired from Caltech, twenty-seven years after coming to Pasadena. The transformation of the mathematics faculty, which Millikan had largely regarded as a service department, into a first-class research group began under the inspired leadership of H. Frederic Bohnenblust, who arrived as a full professor of mathematics in 1946. Applied mathematics as a distinct discipline came to Caltech in the mid-1960s. To avoid friction with the pure mathematicians, it was organized as a research school within Caltech's engineering division.

Bell's Legacy

Whereas Bell was a prolific writer of novels, poetry, and science fiction under his pseudonym of John Taine, he achieved true rock star recognition, or something approaching it, among mathematicians and nonmathematicians alike for *Men of Mathematics* [Bel 37], published in 1937. Still popular today, *Men of Mathematics* discusses the personalities and mathematics of a host of great mathematicians, including Niels Henrik Abel, Carl Friedrich Gauss, David Hilbert, and Bernhard

[7] *"He is also well known for 'Dilworth's Theorem' in combinatorics, which arose in work on posets," notes Alfred Hales, a student of Dilworth's* [Hal 2012].

[8] *The Bateman Manuscript Project, based in part on notes he left, started up several years later under the direction of Arthur Erdélyi and aided by three research associates, Wilhelm Magnus, Fritz Oberhettinger, and Francesco G. Tricomi, culminating in three volumes of* Higher Transcendental Functions, *supplemented by two volumes of* Tables of Integral Transforms.

Riemann, concentrating on those born from the eighteenth century on. Bell followed his account of men (and the occasional woman) in mathematics with *The Development of Mathematics*, issued by McGraw-Hill in 1940, with a revised edition five years later [Bel 45]. This was a sweeping account of the history of mathematics, starting with its beginnings in ancient Babylonia and Egypt and charting its progress to 1945.

Readers of *The Development of Mathematics* will require some mathematical sophistication to fully appreciate it. In his review in *Isis*, I. Bernard Cohen, the dean of American historians of science at that time, wrote, "Within one restriction, the present book is excellent; that restriction consists in the fact that it really begins on p. 99, with ch. 7: 'The Beginning of Modern Mathematics, 1637–1687.' In the first 98 pages, there are many statements that one will take exception to" [Coh 41]. Cohen's objections included Bell's breezy description of al-Khwarizmi's algebraic methods ("a psychiatrist might say it was the death instinct having its way") and "the grand manner" in which Bell demolished Plato's detractors ("Of all changes that mathematical thought has suffered in the past 2,300 years, the profoundest is the twentieth-century conviction, apparently final, that Plato's conception of mathematics was and is fantastic nonsense of no possible value to anyone"). Like Cohen, most reviewers gave the book high praise while also calling attention to Bell's unorthodox style. D. R. Curtiss, writing in *National Mathematics Magazine*, noted, "After a few drier pages there is always a pungent remark on human frailties, a bit of grim humor, sometimes an aside of a half page or more on what dictators are doing to mathematics, and what philosophers or theologians would do if they could" [Cur 41]. Rudolph Langer, who reviewed the book for *Science*, probably spoke for many when he declared, "The presentation of the whole is admirable. It is flowing and graceful and often characterized by a genuine and delightful humour" [Lan 41].

Bell also had his detractors, some of whom accused him of being flippant. Reviewers of *Men of Mathematics* complained of his inclination to sacrifice historical accuracy for a more colorful story. The most blatant example is his exaggerated account of the life of Évariste Galois, who died at twenty following a celebrated duel. Did Galois really create group theory in its entirety during the last night before the duel? Not according to Tony Rothman, who in *Genius and Biographers: The Fictionalization of Evariste Galois*" [Rot 82] accuses Bell of inventing history. Based on his research on Galois, Rothman concludes that Bell "consciously or unconsciously saw his opportunity to create a legend … Unfortunately, if this was Bell's intent, he succeeded." Today's historians of mathematics are even less generous in their praise of Bell as a historian. Ann Hibner Koblitz, who has written about Sonia Kovalevskaya, thinks "[Bell] might well become known to future generations of mathematicians and historians as the legend maker of the history of mathematics. It is to him that mathematicians are largely indebted for distorted impressions of their predecessors" [Joc-Efr]. Koblitz's tart remarks are echoed by Roger Cooke, who deems Bell's treatment of Kovalevskaya an "infuriatingly patronizing, innuendo-laden mistreatment" [Joc-Efr]. Nevertheless, E. T. Bell was undoubtedly one of America's leading mathematicians in number theory and combinatorics in the first half of the twentieth century. (For another nontechnical discussion of Bell's mathematical work, see Lincoln K. Durst's interesting Appendix to [Rei 01].) He was awarded the Bôcher Prize for his 1921 papers in the *Transactions of the American Mathematical Society* on arithmetical paraphrases, a notion due to Bell himself [Bel 21]. Its number theory application is to derive a huge number of identities for various arithmetic functions. An example of the principle of arithmetical paraphrase is the following: Suppose there are integers n_1, a_1, $b_1 \cdots n_k$, a_k, b_k such that $n_1 \sin(a_1 x + b_1 y) + \cdots + n_k \sin(a_k x + b_k y) = 0$ as function of integers x, y. Then, for any odd function f of two integral variables, we have: $n_1 f(a_1, b_1) + \cdots + n_k f(a_k, b_k) = 0$. If f is an odd arithmetical function, then this would be an identity for this arithmetical function.

In 1926 Bell was selected to give the distinguished AMS Colloquium Lectures that led to his 1927 Colloquium publication *Algebraic Arithmetic* [Bel 27b]. This volume expanded on his notion of arithmetical paraphrases and Euler algebra in a very general and abstract way. Leonard Dickson, in his review in the *Bulletin of the American Mathematical Society*, writes:

> This book of marked originality is of vital interest to advanced students in various branches of mathematics, including the theory of numbers, abstract algebra, elliptic and theta functions, Bernoullian numbers and functions and the foundation of mathematics… A leading feature of the book seems to the reviewer to be its success in a systematic attempt to find a unified theory for each of various important problems in the theory of numbers,

[9]*Bell gave Tom M. Apostol, the number theorist who took Bell's place at the institute in 1950, his own personal copy of* Algebraic Arithmetic, *signed and dated 12 December 1927. Apostol recalls discussing the book with his student Basil Gordon "and both of us agreed that it was impenetrable"* [Apo 2012]. *Gian-Carlo Rota told Constance Reid that he doubted "if anyone has read it all the way through"* [Rei 93]. *Apostol is of the same opinion.*

including its interrelations with algebra and analysis. [Dic 30]

However, it seems that most mathematicians who were interested in understanding what *Algebraic Arithmetic* was all about had a difficult time figuring it out, especially with regard to Bell's discussion of the "umbral calculus". Dickson may well have been one of the very few people (or perhaps the only one) who understood the mathematical content of the book.[9]

Some of Bell's major contributions were:

Bell series [Bel 15]. These series are important arithmetic series in number theory and were so named by T. M. Apostol in [Apo 76].

Paraphrases [Bel 21], for which he won the Bôcher Prize.

Euler Algebra [Bel 23]. The Euler algebra, roughly speaking, is the formal algebra generated by the Cauchy algebra C of power series in one variable and the Dirichlet algebra D of Dirichlet series. It has been an important tool in the theory of generating functions.

Algebraic Arithmetic [Bel 27b]. In this book, Bell puts his theory of paraphrases and Euler algebra into an abstract setting. Included is a heuristic and impenetrable discussion of the classical umbral calculus of Blissard. The remainder of the book is also very difficult reading. The umbral calculus was not sorted out and made rigorous until the 1970s by Gian-Carlo Rota, his students, and others. See, for example, [R, K, & O 73].

Bell polynomials [Bel 34]. These were called exponential polynomials by Bell. Although we do not know when they were first called Bell polynomials, they were so called by John Riordan in his classic 1958 book on combinatorics [Rio 58].

Bell numbers [Bel 38]. These were called iterated exponential integers by Bell and are important in the theory of partitions (among other areas of combinatorics) [Rot 64]. They were so named in 1948 by Becker and Riordan in [B & R 48].

Appendix

Bell's Contributions to Combinatorics

by John Greenberg[10]

Authors' note: Bell's most significant mathematical contributions were in the field we now call combinatorics. The following description of Bell's contributions to combinatorics is the work of the late John Greenberg, who received his Ph.D. in history in 1979 from the University of Wisconsin under the direction of Daniel Siegel. This essay was to be part of his unfinished history of the Caltech mathematics department.

E. T. Bell would have been surprised to see where his real influence upon mathematics lay, at least in recent times. During the Second World War, artificial intelligence came of age, alongside the invention of the digital computer. The study of networks for simulating the central nervous system helped to motivate graph theory and, in general, helped to stimulate a revival of combinatorial theory after the war. Bell's work on exponential and iterated exponential numbers, exponential polynomials, and the symbolic or "umbral" calculus was much cited in the literature on combinatorial analysis of the fifties and sixties. Chief among the mathematicians who referred to his work were Leonard Carlitz, a one-time NRC Fellow at Caltech (in 1930), and John Riordan of the Bell Laboratories, a one-time collaborator of Claude Shannon, the founder of artificial intelligence in the U.S. Bell contributed, among other things, to the development of formal power series and generating functions as tools for obtaining recurrence relations, which are important for treating combinatorial problems in a unified way. The solution of recurrence relations derived from some kind of counting problem is perhaps the most common, basic, and elementary application of generating functions in combinatorial theory [Tan 75].

Bell numbers and Bell polynomials often figure as an important feature of combinatorial and probabilistic problems. (For an example of the influence of Bell's use of generating functions in a combinatorial setting, see [Rio 57], [Rio 58].) It struck two mathematicians as odd that it took so long for the followups to what they deemed Bell's "classic paper" on exponential polynomials to appear [G & H 62]. Rota acknowledged the widespread role that Bell's exponential numbers played in a great many problems of enumeration and of probability [Rot 64]. Thus so did the Bell polynomials manifest themselves as an important feature of many combinatorial and statistical problems [Rio 58].

Rota later tried to do what Bell failed to do in 1940, namely, put the "umbral calculus" or "symbolic calculus" on rigorous foundations. Rota's purpose was to provide even greater unity to the results of combinatorial analysis. In saying that writing the paper was like "assembling a dinosaur from a few charred bones in the desert," the author meant to pay homage to his predecessors, such as Carlitz and Riordan, not to belittle them [R, K, & O 73]. While Bell himself did not provide ironclad foundations for his uses of formal power series and generating functions, Bell, unlike some of the authors who later cited him, also realized the difficulty, and his concerns gave rise to more than one "Bell Problem" [Gou 74].

Though Bell took note himself of "the interest in combinatorial analysis and elsewhere" of some of the objects of his attention [Bel 38], it's hard to imagine that he wouldn't have been surprised at the fact that this was the area where his greatest

[10]*John Greenberg was a postdoc for one of us (JRG) in the Caltech archives for three years (1981–1984).*

influence lay. As a historian of mathematics, Bell ridiculed the late eighteenth-century German combinatorial school, labeling it a "ridiculous interlude" [Man 75]. Bell ridiculed the German formal manipulation of binomial and multinomial coefficients and formal expansion of powers of infinite series. It seems like a strange edict for someone as well versed in the combinatorial art as Bell himself! "Bell [was an] inveterate combinatorialist and number theorist, [a] person well versed in operations with series" [Gou 74]. There is some irony that the revival of combinatorial analysis was brought about in large part by the advent of the computer and the wholesale creation of branches of mathematics to minister to computer science, for if mathematics was a science that stood on its own, as Bell seemed to think, his own work with the greatest impact was that which was pressed into the service of other sciences. If Bell abhorred the applied mathematician, he nevertheless helped to open up new areas of applied mathematics in spite of himself. Millikan, his old nemesis, would have been tickled to death! For all the clairvoyance, wit, and sagacity that ushered forth from the pen of Bell the science fiction writer, Bell the mathematician never could have foreseen or anticipated the uses to which his work would be put after his death.

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Although he wrote at length about the lives of other mathematicians, E. T. Bell glossed over many details of his own biography. Bell also systematically destroyed much of his professional correspondence before he retired. H. P. Robertson, his friend and colleague, declined to write Bell's biographical memoir for the National Academy. Constance Reid's *The Search for E. T. Bell, Also Known as John Taine*, published in 1993, provided the first authoritative portrait of the Scottish-born mathematician who concealed much about his family and his childhood in San Jose, CA. Reid's book, which reads like a detective story, is the starting point for anyone studying Bell. A rich source of information about Bell and mathematics at Caltech between the wars can be found in the H. P. Robertson papers, housed in the Caltech archives, which Reid consulted. However, materials were given in installments, beginning in 1971 (and processing was begun by then archivist Carol Finerman) and ending in 1998. Following the final donation in 1998, the entire collection was integrated, rearranged, and described by Dr. Erwin. We have made extensive use of these supplemental materials.

The following abbreviations are used: AM, Aristotle Michal papers; RAM, Robert Andrews Millikan papers; HPR, Howard Percy Robertson papers, all in the Institute Archives, California Institute of Technology; GB, George Birkhoff papers, Harvard University Archives; OV, Oswald Veblen papers, Library of Congress.

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Recalling James Serrin

Howard Levine and Hans Weinberger, Coordinating Editors

Photo by Patrizia Pucci.

Jim Serrin in his backyard.

James Serrin was born in Chicago on November 1, 1926, and grew up in Evanston, Illinois. He did his graduate work at Indiana University under the direction of David Gilbarg. He received his doctorate in 1951, with a profound thesis on the hydrodynamical theory of cavitation.

In the next few years he wrote several papers on cavitation, some very influential papers on compressible flows, and an important paper on the Harnack inequality for elliptic equations. These papers very quickly established his reputation as a rising star in the area of partial differential equations. This reputation led to his being selected to write the article "Mathematical principles of classical fluid mechanics" for the *Handbuch der Physik*, VIII/1, Springer, 1959, pp. 125–263, which is still a standard reference in the subject.

Jim Serrin served as a Fine Instructor at Princeton University in 1951–1952 and as a C. L. E. Moore Instructor at MIT in 1952–1954. In 1952 he married Barbara West, who remained his companion and helpmate for the rest of his life. See the last section of this article for details of this courtship.

Jim came to the University of Minnesota in 1954, and with the exception of numerous visiting positions, he remained there for his entire career, even after his retirement in 1995. At Minnesota he served as head of the School of Mathematics in 1964–1965 and was appointed Regents' Professor of Mathematics in 1969.

Jim Serrin was the recipient of many honors. He received honorary doctorates from the University of Sussex in 1972, the University of Ferrara in 1992, the University of Padua in 1992, and the University François-Rabelais at Tours in 2005. He received the George David Birkhoff Award in Applied Mathematics from the American Mathematical Society in 1973. He was a member of the National Academy of Sciences and the American Academy of Arts and Sciences, and was a foreign member of the Finnish Academy of Sciences.

Jim Serrin was president of the Society for Natural Philosophy in 1969–1970. He served on the Council of the American Mathematical Society from 1972 to 1974 and also was a member of three AMS committees. He was a coeditor of the *Archive for Rational Mechanics and Analysis* from 1969 to 1986. He was also on the editorial boards

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of many other journals. He gave a multitude of invited addresses, including two at International Congresses of Mathematicians.

During his teaching career, James Serrin directed the research of twelve students.

Serrin published almost two hundred papers. His research activities lasted until his death, and two of the manuscripts are still in the publication process. He was also a joint author with Patrizia Pucci of the book *The Maximum Principle*, Birkhäuser, 2007. A book *The Selected Works of James B. Serrin* is in the process of publication by Springer, Basel.

Donald Aronson

Jim Serrin was a truly great mathematician and a wonderful person. I first met Jim in 1953 when I was a graduate student at MIT and he was a Moore Instructor. He was teaching the graduate course in partial differential equations. I had become interested in PDE from the lectures of I. J. Schoenberg at UCLA in the summer of 1951 and was subsequently completely turned off by the course I took at MIT in 1952. For reasons I cannot recall, I decided to attend Jim's elegant lectures in 1953 and was totally captivated. This was a crucial turning point in my career. I had hoped to do a dissertation under Jim's supervision, but he left MIT too soon.

Jim's presence in Minnesota was a very large factor in my decision to come there. I continued to learn from him by attending some of his lectures, such as his beautiful courses in differentiation theory and boundary layer theory. Eventually we collaborated, and that was another aspect of Jim's influence. He was a very fastidious and lucid writer, and I hope that some of that rubbed off on me.

Collaboration with Jim was not easy. Although we mostly saw eye-to-eye mathematically, we had seemingly endless arguments over phrasing and notation. However, it all worked out in the end. We wrote two papers on divergence structure parabolic equations. One, which I suspect has never been read, concerns a maximum principle. The other was a derivation of the Harnack principle and has proven to be quite useful. For example, it is one of the main ingredients in my derivation of the Gaussian estimates for the fundamental solution of linear divergence structure equations. These two papers were Jim's only forays into the parabolic realm, but he continued his groundbreaking research on elliptic equations and the calculus of variations.

Jim was friendly and gregarious, and I miss the wonderful hospitality shown by Jim and Barbara. Although we usually disagreed on politics, we shared, in addition to mathematics, many interests in art, music, and literature. We will not see his equal any time soon, and I certainly miss him as a friend and colleague.

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Photo courtesy of Don Aronson.

From left: Hans Weinberger, Grisha Barenblatt, Don Aronson, Jim Serrin.

Alberto Farina

I met James Serrin in June 2008 in Perugia (Italy). He invited me to visit him in Minneapolis in October 2008, and we immediately started working together on our first article. This was the beginning of our collaboration and of our friendship. After James's passing, I realized that we had exchanged more than five hundred emails. I wish to share with you some he sent me (written around Christmas 2008).

This is the way I remember you, James. An outstanding mathematician, of a fine elegance, full of energy and enthusiasm, always pursuing excellence. A man who lived and worked with the respect of the people around him: family, friends, and collaborators. A person sensitive to the beauty of life and of the surrounding world.

————

Date: 21 Dec 2008 13:25:02 -0600 [21.12.2008 20:25:02 CET]
Dear Alberto,
We are now in Montana in the mountains, in the middle of a snowstorm (beautiful, but making us temporarily isolated). I am still thinking about the counterexample for Theorem 3 […]
Buon Natale!
James

————

Alberto Farina is professor of mathematics at Université de Picardie Jules Verne, Amiens, France. His email address is alberto.farina@u-picardie.fr.

Date: 22 Dec 2008 20:40:02 -0600 [23.12.2008 03:40:02 CET]
Dear Alberto,
In the interest of saving time, I decided to write the file for Example 7 (Section 8) now instead of waiting for the full file to arrive later […]
The mountains remain absolutely beautiful for Christmas.
All best wishes,
James

————

23 Dec 2008 20:50:55 -0600 [24.12.2008 03:50:55 CET]
Dear Alberto,
Here in the mountains with snow everywhere, I can't stop thinking of the paper!
In fact, to obtain a complete counterexample for Theorem 1 we should still treat the case of Example 3 when [...]
Have a very nice Christmas!
James

————

Date: 24 Dec 2008 14:50:41 -0600 [24.12.2008 21:50:41 CET]
Dear Alberto,
Yea, I thought you might have been away from your home. I hope you are having a nice time with your family, as I am. Concerning the remaining case of Theorem 1, I have made one kind of progress, […]
Barbara joins me in wishing you "Merry Christmas".
James

————

Date: Mon, 29 Dec 2008 15:31:09 -0600 [29.12.2008 22:31:09 CET]
Dear Alberto,
Everything looks good. […] Great progress!
James
PS: I will be in the office Wednesday morning.

The result of this correspondence was the joint paper "Entire solutions of completely coercive quasilinear elliptic equations", *J. of Differential Equations* **250** (2011), 4367–4408.

Avner Friedman

Jim Serrin was more than a friend, more than a colleague. He set high standards scientifically and personally. His research was characterized by crisp theorems and elegant proofs. He was very supportive of me throughout my career, especially in my early years. I remember our first meeting in 1958 at Indiana University, where I was a lecturer. Jim had graduated from Indiana University seven years earlier and came for a short visit unbeknownst to me. There was a knock on my door one afternoon, and in he came and introduced himself. "Are you THE Jim Serrin?" I asked in disbelief and awe, having read some of his amazing papers already as a graduate student.

It is impossible to review here, even very briefly, Jim's seminal contributions to mathematics and its applications. So let me just say a few words about his very early work. Jim received his Ph.D. in 1951. In 1952–1953 he published four outstanding papers [1]–[4] on free boundary problems that arise in fluid mechanics: cavities formed by fast-moving bodies in an infinite body of fluid and jets bursting from a nozzle into the air. These topics were very active research areas in the early 1930s but thereafter remained dormant until Jim revitalized them with the above four papers. Jim introduced new variational approaches and new comparison principles, including the "under-over theorem" and the "single intersection property". As it turned out, around 1980, W. Alt, L. Caffarelli, and I used these two theorems in a crucial way to establish the existence of the "infinite cavity problem". Between 1953 and 1980 Jim wrote many other important papers in fluid mechanics, PDEs, and differential geometry.

For years the University of Minnesota meant to me Jim Serrin. He and his gracious wife, Barbara, often hosted dinners to which young, and later on not-so-young, faculty were invited. Dinner at the Serrins' included stimulating discussions on all topics, such as mathematics and mathematicians, politics and politicians. Jim usually held the minority opinion; I thought he liked the role of arguing against the common wisdom. And his arguments, especially in politics, were always based on well-documented sources, although not necessarily unbiased. Jim's library was impressive in its breadth, from books of art, to science, to history. In fact, when we first arrived in Minnesota he hosted me and my wife in his home, and I got a chance to leaf through his rich selection of books in the library where we slept.

Over the years I became increasingly aware of Jim's important contributions not only in PDEs but also in many other areas, such as Navier-Stokes equations, minimal surfaces, surfaces of mean curvature, Prandtl's boundary layers, and singularity of solutions, to name just a few. His papers developing the mathematical principles of fluid mechanics [5] and thermodynamics [6] are classics. Jim loved mathematics; mathematics was his life. He will be missed, but his legacy will persist.

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Giovanni Leoni

During my college years I spent one month studying English at the Evergreen State College in Olympia. It was such a fun experience that I decided to do my Ph.D. in the U.S., thinking (yeah, I was that naive) that it would be the same. So I asked my undergraduate advisor (in Italy you write a thesis for your bachelor's), Patrizia Pucci, for advice. She told me that she was working with a professor in Minnesota and that if I wanted she could contact him. I still remember when she said, "But keep in mind that Minneapolis is very cold," and I thought, "How cold can it possibly be?" I know better now.

This is how I met James Serrin. When I started my Ph.D. in 1990, I had no idea of who he really was. Looking back I guess it was a blessing. If I had known that my advisor was one of the outstanding analysts of this century, my interactions with him would have been quite different. Instead, in my blessed ignorance, for me he was just a really kind gentleman. He and Barbara quickly became a second family for me. I often had dinner at their beautiful house. Jim loved history and art and had been in Italy several times. It was a pleasure listening to him. Well, I quickly learned never to discuss politics with him. He knew people considered him a reactionary, and I think he enjoyed shocking them with his statements. When he would go "overboard", I would just smile and nod, and eventually Barbara would change the conversation with an affectionate/exasperated "Oh, Jimmy."

I liked his witty/quirky sense of humor. There was still a child inside him. I was foolish enough to tell him that during my college years I worked as a swimming instructor, and, as a result, every summer until I graduated I almost drowned in his swimming pool because he wanted to time how long I could swim underwater. While Barbara often swam with me, I never managed to get him into the pool! I have very fond memories of my years in Minneapolis.

I often wondered why Jim did not have more Ph.D. students. It is hard for me to judge him as a Ph.D. advisor. Looking back at my experience with my own students, I think I was much more independent. I would often stop at his office to say hi, tell him what I was doing, and to show him my progress, but I never went to him when I was stuck on a proof. Pride, I guess.

But I still learned a lot from him, especially simplicity and elegance in mathematics. I think his love for art and beauty affected his taste in mathematics. While his papers could be technical, whenever he would talk with me or give talks, he would always start with a simple example that still contained most of the difficulties of the general problem.

At one of the symposia to celebrate his birthday (can't recall if it was his sixty-fifth or seventy-fifth), I was asked to say a few words about him. I am terrible at giving public speeches, but I do remember that I said something like, "If I learned an ε of math, I owe it to you," at which Jim stood up and said laughing, "What do you mean? I taught you this much math" and he spread his arms wide, "and you only learned an ε?" It was the funniest moment of that day!

A few years after I went back to Italy, I changed my area of research and moved to calculus of variations. Since I did not have as many chances to meet Jim at conferences, I started sending him and Barbara a gift every Christmas, usually something that I brought back from Italy. As soon as they got it, they would call me and we would spend a nice time catching up. They would both tell me I should stop, but we all knew I would not. Last Christmas, instead of a phone call, I got a long letter from Jim. Something had changed.

I last saw Jim in June. I went to Minneapolis for a summer school, and Irene Fonseca and I took Barbara and Jim out for dinner at their favorite restaurant. Jim's mind was as sharp as usual, but his health had deteriorated a lot and he looked very frail. When we were driving back, Irene and I looked at each other and said, "This will probably be the last time we see him alive." Sadly, we were right. This year there will be no Christmas gift.

I love you, Jim.

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Howard Levine

In the fall of 1969, I joined the University of Minnesota mathematics department as a green and timid assistant professor. I was in awe to the point of being terrified of Jim and the other PDE giants in the department, but with respect to Jim, these fears were unfounded. One day he asked me to referee a paper that had been submitted to the *Archive for Rational Mechanical Analysis*. I gave him the report a few days later. After reading it carefully, he set down his glasses, looked up at me, and said, "You know, Howard, the *Archive* does not have a refereeing system. So with your permission, I'd like to send this fine report to the authors, mentioning that you wrote it and that the authors should acknowledge your contribution to improving their paper." That gesture of generosity turned out to play a pivotal role in my life, not only professionally but also personally. But that is another story.

At Minnesota I attended a number of his lecture series, including those on his papers "The swirling vortex" and "The problem of Dirichlet for quasilinear elliptic differential equations with many independent variables". The lectures were an inspirational lesson as to what could be done in mathematics if one set one's mind to it.

He followed the careers of young people whom he felt had promise whether they stayed at Minnesota or went elsewhere. Over the years he invited me to several conferences he organized on elliptic and parabolic equations, further proof that my fears had been unfounded. Then he paid me the ultimate compliment of asking me to collaborate with him and Patrizia Pucci in working on the stability-instability dichotomy for semilinear hyperbolic equations, a collaboration that resulted in four articles. He was also instrumental in helping many fine international mathematicians secure positions in the United States, perhaps the best known of whom is Grozdena Todorova, now at the University of Tennessee.

I can only echo the remarks of others in this article: he was not only an outstanding mathematician but also a good friend.

Lawrence Markus

This casual note is dedicated to the memory of my dear friend, Jim Serrin, who was my colleague and mentor in the School of Mathematics at the University of Minnesota for over a half-century. In our boyhood and youth we shared many similar experiences, although we never met until we were both established members of the Minnesota faculty. For instance, we both attended primary school in Evanston near Chicago, graduated from Midwestern universities, and began our careers with postdoctoral appointments and faculty positions in various eastern "Ivy" universities. Furthermore, we both had serious professional interests in diverse physical sciences and engineering subjects, particularly in the foundations of mechanics and thermodynamics. At the University of Minnesota we individually found congenial interdepartmental cooperation within the Institute of Technology.

Since Jim and I were near-neighbors in Minneapolis, it was natural that we frequently shared the drive to the university. During these times we carried on a continuing conversation about the cosmos according to Newton and later Leibniz (the foundational problems we considered belong also to Einstein's special and general relativity)—for instance, the physical reality of uniform motion with constant velocity: relative to the family of inertial observers, but the absolute nature of rotational motion seems mysterious.

We introduced the concept of locally Newtonian spaces, as distinct from global Newtonian space, and used these ideas to try to reinterpret the phenomena of the anomalous angular velocity of some spiral galaxies (an alternate explanation to the existence of dark matter) and further the cosmological red shift (in place of expansion). We never attained the complete mathematical theory we sought and so did not publish our partial results, which we euphemistically entitled "The General Theory of Everything Else". However, I did record some of our ideas in a preliminary Research Report of the School of Mathematics, *Cosmology of Classical Mechanics* (1991).

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Bryce McLeod

I first met Jim Serrin at a meeting at the University of Edinburgh in 1968. The UK Science Research Council (as it then was) was anxious to stimulate the study of differential equations in the UK and had organized a 2-week meeting to be addressed by three mathematicians of international standing in the general area of differential equations, the audience to consist of mathematicians from all the UK universities. One of the three invited speakers was Jim Serrin, who delivered a course of lectures on the Navier-Stokes equations, then a major research interest of his. I found the lectures fascinating. My interests until then had been almost exclusively in linear problems, particularly the spectral theory of the Schrödinger equation, but Jim's lectures opened my eyes to the richness of nonlinear problems. In particular, one of his lectures was on similarity solutions (i.e., solutions which are solutions of ordinary differential equations), and he concluded with a number of unsolved conjectures. I was lucky

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enough to be able to see how to solve one of these. I mentioned it to Jim, and this was the beginning of a fruitful collaboration and, more importantly, of a lifelong friendship. Jim was at that time visiting the UK frequently, particularly at the University of Sussex, and I naturally invited him to Oxford. He and his wife, Barbara, stayed with us, and our wives formed an instant bond (it was not difficult to like Barbara), which again has lasted ever since, and in due course extended to our families, particularly reinforced when my son Kevin became a research student of Jim's.

For all this closeness, the fact remained that we were on opposite sides of the Atlantic, so that we did not meet as often as we would have liked. But we did spend one sabbatical leave at the University of Minnesota and lived in a house which essentially backed on to the Serrins', and this gave us an opportunity to experience to the full the Serrin hospitality. Jim was not a practicing artist as his brother Dick was, but one could not enter his beautiful home without realizing that this was a man whose artistic taste was impeccable. From the elegant dining room to the gorgeous library above, this was testimony to a true sense of style, and yet any suggestion that this might lead to an atmosphere of stiffness or formality was instantly dispelled by Barbara's charm and efficiency. An evening spent with them was just a family evening spent in beautiful surroundings. Once (I cannot remember the exact details) the Serrin family wanted to celebrate a family occasion in England and asked if they could use our house for a few days, to which we readily agreed. Of course, our house was incredibly scruffy by comparison with theirs, but I have always treasured the fact that if they chose it, then it must in some way have measured up to their standards.

Jim would not have been Jim without his eccentricities. There was of course his ceaseless war against airports and airlines (particularly NorthWest). His only difficulty was that without their aid he would not have been able to maintain his continuous international journeyings. But even his criticism of these (and others) was eased by a sense of his own extremism. Having offered a particularly damaging comment, he would look at you quizzically, as if to say, "What do you think of that, then?" And from Barbara there would come an exasperated, "Oh, Jimmy!" Jim was a great mathematician, a great character, and a great friend. Eunice and I, and all our family, will miss him very much.

Photo courtesy of the Serrin family.

Jim Serrin, Haim Brezis (back row), Bryce McLeod, Bert Peletier, Paris, 1998.

Kevin McLeod

I arrived in Minneapolis in August of 1978, fresh from completing my undergraduate education in England and knowing almost nobody within a radius of several thousand miles. It was my great fortune that I did have some connections: my father had often worked with James (Jim) Serrin, and our families had previously met both in England and in the USA. Jim met me at the airport and drove me to the Serrins' beautiful house in south Minneapolis, a house that was to become my second home during the time I spent in Minnesota, as the Serrins (Jim, his wife, Barbara, and their daughters, Martha, Elizabeth and Janet) were to become my second family.

Some of my fondest memories from the next six years are of the conversations around the Sunday dinner table, with Jim at the head, sometimes listening intently, sometimes gently guiding or questioning, and sometimes being deliberately (one supposed) provocative. My first impressions of Jim had been of a quiet and unassuming man. He was unassuming, especially given his accomplishments, but I came to understand that under the quiet surface he was intensely passionate about many things: about his mathematics, of course, but also about art and music, about Italy, about politics, and about the Minneapolis airport (his house stood directly under one of the flight paths). Most of all, he was passionate about his family. His love for Barbara and the girls was deep and abiding, and they in turn adored him.

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Jim was a superbly polished lecturer and an excellent teacher. His courses on continuum mechanics and thermodynamics impressed me so much with the power and clarity of the arguments that I asked him to be my thesis advisor. In this role, also, he was everything I could have asked for, providing support and guidance when necessary, while allowing me to develop mathematical independence whenever possible. That independence eventually led me away from Jim's areas of research and ultimately into working in mathematics education, but Jim remained interested in my work until the end, still gently guiding or questioning and still sometimes being deliberately (I supposed!) provocative. He was a great mathematician, a great family man, and a great friend, and I will miss him greatly.

Photo courtesy of the Serrin family.

Left to right: Johannes Nitsche, Louis Nirenberg, and James Serrin.

Lambertus "Bert" Peletier

Luck can play an important part in life and mine was that I met Jim and his wife, Barbara, when, in 1967, right after completing my Ph.D., I moved to Sussex University. Jim did too for the academic year 1967–1968. There, Jim became an active and stimulating presence in what was referred to as the PDE group, which then included David Edmunds, Robin Dyer, and Peter Bushell. What stands out for me were the numerous wide-ranging lunchtime conversations in which Jim demonstrated an eclectic interest and knowledge, ranging from math to history to politics and to the fear of flying.

During the course of that year Jim gave a deep course on his recent work on quasilinear elliptic equations and solved a fascinating open problem in boundary layer theory: how to explain the ubiquitous nature of the special Falkner-Skan self-similar velocity profile. This had a profound influence on my taste for problems: beautiful math used to elucidate problems in science and technology.

But Jim also fostered relations between Minnesota and Sussex: he encouraged Charlie McCarthy and Don Aronson from Minnesota to follow him and spend a year in Sussex, and I was invited to spend a year in Minnesota. Jim followed up his 1967–1968 visit to Sussex with two further long-term visits, one in 1970 and one in 1972. These visits were so inspiring to so many people that Sussex granted him an honorary doctorate.

The year in Minnesota spawned many collaborations. I learned a lot from Jim, not least how to write papers. With Jim this was no trivial undertaking: his organization of the material and style of writing were extremely rigorous, and up till this day I write my introductions following the Serrin blueprint. Understandably, the number of iterations a manuscript went through was near infinite. In the precomputer age this usually resulted in thick wads of paper bulging with layer upon layer of Pritt. His high standards carried over to the way he perceived his responsibilities for the *Archive for Rational Mechanics and Analysis*, which he edited for many years, together with Clifford Truesdell. He could spend long hours revising manuscripts, accepted on mathematical grounds but falling short on his standards of presentation.

Jim and Barbara were the center of an active social life. We all remember the numerous visits to the ever-hospitable elegant Serrin home on Dupont Avenue South, with its library well stocked with art books. There the PDE community frequently gathered for dinner parties and, in summer, for parties at the pool and always for spirited conversation.

In the early eighties there was a danger of losing Jim for PDE: he became very much involved in the fundamental theory of thermodynamics and the nature of such concepts as Force. Fortunately for us, in the early 1980s, the appeal of the many exciting questions surrounding the existence and uniqueness of ground states and singular solutions of semi- and quasilinear elliptic equations, and the new results of Brezis and Nirenberg succeeded in luring him back to PDE, and so began a new, extremely productive period.

Jim took an active interest in promoting the subject. He was often seen at conferences and organized a fair share himself. I remember the meetings at MSRI (Berkeley) and in Gregynog (Wales) on Nonlinear Diffusion Equations and Their Equilibrium States, as well as many other meetings, not infrequently in his honor. He actively engaged with younger mathematicians, including my own graduate students, who invariably found their way to Minneapolis.

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James Serrin and Patrizia Pucci, Perugia, October 19, 1996.

I remember Jim as a central and inspiring person in the PDE community, a great mathematician, and a lifelong friend.

Norman Meyers

I came to the University of Minnesota in 1957 as an instructor. Like Jim Serrin, I had been a student of David Gilbarg at Indiana University. So, I suppose, he felt responsible for me, and I saw a good deal of Jim and his family socially.

Professionally, we wrote several papers. As I remember, he or I would bring up a problem. We would briefly discuss it, possibly in the hallway. Sometime later, we would look at what we had. We did not stand at a blackboard and work together. He preferred to think it through alone. I want to emphasize that he was very generous and encouraging to me.

Jim's manner was neither cocky nor arrogant, but he had great confidence in his ability, and he was proud of what he had accomplished.

I think of him every day.

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Photos this page courtesy of Patrizia Pucci.

Stanislav I. Pohozaev, Patrizia Pucci, James Serrin, Enzo Mitidieri, Trieste, October 1995.

Patrizia Pucci

My formation as a mathematician was greatly influenced by James Serrin, and a very large part of my research life was connected with him. I attended James Serrin's courses, beginning with his SAFA IV seminars in Naples in March 1980, but I was introduced to him by Lamberto Cesari at the University of Michigan a few months later in August 1980 during the conference on the occasion of Cesari's retirement. Professor Serrin was already a giant in the subjects of partial differential equations, fluid mechanics, and thermodynamics. His fundamental contributions, especially in real analysis and in the calculus of variations, were already well known and often cited in Italy since the 1960s. In 1981 Lamberto Cesari invited James Serrin to the conference held in Bologna to celebrate the seventieth birthday of Cesari in Italy. On that occasion, during a conversation along Via Zamboni, Lamberto told me to attend the course that James was going to deliver at the SMI school in Cortona, and at the same time asked James to propose to me some topics on which I could report at the summer school. (Presenting such reports was a teaching tool for the young mathematicians at the advanced courses in Cortona.) In August 1981 James Serrin and Lawrence Craig Evans gave courses at the Cortona summer school, and James gave me some papers on elliptic overdetermined problems and on the Mountain Pass Theorem by Antonio Ambrosetti and Paul Rabinowitz. This was the starting point of my long fruitful collaboration with James. At that time I was only an assistant professor, and in 1983 I got a position as associate professor at the University of Perugia, while in 1987 I became full professor at the University of Modena. James came for frequent visits in both towns, delivering unforgettable, exceptional lectures until 2012.

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Photo courtesy of the Serrin family.

Jim and Barbara Serrin with Hiroshi Matano in the hall of the Serrins' house. The painting is by Jim's brother, Richard.

Since those Cortona lectures, I continued to learn much from him at his remarkable seminars held year after year. I recall his masterly courses in Milan in 1982 and in Varenna in 1983. James always devoted a surprising amount of time and effort to young mathematicians, giving mathematical consultations even to people unknown to him. Between 1984 and 2012 we wrote more than forty papers and a monograph on the maximum principle together. I cite only the papers [1]–[5], which inspired other work and which we liked very much. At the end of writing one of these papers, James and I used to celebrate the event by going out with his wife, Barbara, to some Italian restaurant in Minneapolis. It was lovely to celebrate with Barbara, since without her patience, help, and hospitality I could never have written all these joint papers with James.

James very much liked to lecture in Italy, since he loved to visit small Italian villages as well as the splendid masterpieces of the famous art towns of my country. His genuine interest in coming to Italy was based mainly on the fact that his brother, Richard Serrin, has lived in Florence with his family since the 1960s. James even joined the Unione Matematica Italiana as a member from 1990 on. But also the Italian mathematical schools very much admired his achievements and invited him to deliver talks to countless outstanding international conferences held somewhere in my country. Furthermore, beyond the many prestigious honors he received for his work from everywhere, he was awarded the degree *laurea honoris causa* by the Universities of Ferrara and Padua in 1992. The Society for Natural Philosophy commemorated James Serrin in the opening address of its fiftieth meeting, held at Udine in October 2012.

My long association with him has been for me a wonderful experience. It was a great pleasure not only to see the elegance and the beauty of his way of thinking about mathematics but also, when possible, to share with him and Barbara, in moments of rest, an interest in classical music, in good reading, and in Italian art. The great master James Serrin was for me above all a steady friend since I met him in 1980. He was an enthusiastic organizer of the May conference held at Perugia in 2012 on the occasion of my sixtieth birthday, where several of our best friends and colleagues on PDEs came from all over the world and gave brilliant talks. The speakers celebrated not only me, but also James, addressing special words to him, with sincere affection and profound esteem. Even though at the time of the conference he was already not well, he attended all the talks and delivered an exceptional and unforgettable opening lecture. His presence in Perugia at the conference was for me the most appreciated gift I received for my sixtieth birthday.

James was a great mathematician and an exceptional man. His work has inspired generations of mathematicians and will continue to influence the future of mathematics. His loss is inconsolable for anyone who had the good fortune to meet him, as I had.

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David Sattinger

I first met Jim Serrin when he visited UCLA during the 1968–1969 academic year. I had read two of his articles on the Navier-Stokes equations, and we had a number of conversations during his visit. Those conversations ultimately persuaded me to leave sunny Southern California for the frigid winters and mosquito-infested summers of Minnesota.

I arrived in Minneapolis in the fall of 1971. Sometime during that first year we met in his office to go to lunch at the Campus Club, and he

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started complaining about the referee on a recent submission of his, "The swirling vortex", in the *Philosophical Transactions of the Royal Society of London*. He had worked out a rigorous theory of vortex flow for the Navier-Stokes equations, not an easy thing in itself, in which a semiinfinite vortex line meets a planar surface. He reduced the problem to a system of integral equations whose existence he could demonstrate in certain cases, and he carried out numerical computations of the solutions. The mathematical analysis itself was not in question; it was Jim's assertion that these solutions were relevant to a mathematical theory of tornadoes and his insistence on including photographs of tornadoes in the manuscript. There was also some kvetching about the boundary conditions.

It is a beautiful paper, and it epitomizes Jim's holistic approach to mathematics, combining scholarship, careful physical reasoning, pure mathematical analysis, and numerical analysis, and ultimately an attempt to relate the mathematics to an especially challenging physical problem—modeling tornadoes.

Jim worked on problems in pure mathematics as well, especially problems involving the strongly nonlinear elliptic partial differential equations arising in classical surface theory. His myriad variations on the maximum principle are rivaled only by Mozart's genius at chromaticism. His ingenuity, at times diabolical, expressed itself in careful attention to the tiniest of analytical details in order to gain a significant extension.

Jim was also very interested in the foundations of mechanics and in presenting an axiomatic, deductive treatment of fluid mechanics from the basic axioms of thermodynamics and conservation of energy, mass, and momentum. He wrote many papers on the foundations of thermodynamics, especially the second law. He was strongly influenced by Clifford Truesdell, who founded the *Archive for Rational Mechanics and Analysis*, and Jim was on the original editorial board.

Jim always bought used cars and invested the savings in a superb art collection. Some of his pieces were on loan to the Minneapolis Institute of Arts, and his home on Dupont Avenue was decorated with a number of beautiful paintings, including some wonderful ones by his brother, Richard. Jim and Barbara loved to entertain, and there were many memorable parties at their home. Jim told me that human culture had peaked in the eighteenth century, and he loved Mozart, Hayden, and Handel, so I was surprised to see him once at a performance of Mahler's *Resurrection Symphony*. Jim was always full of surprises.

Juan-Luis Vazquez

Jim Serrin is one of the most prominent figures in pure and applied mathematics of the twentieth century. I had the good fortune of meeting him during my first visit to the United States in the academic year 1982–1983, with a grant from the Fulbright Foundation. This was a crucial period in my mathematical life; I was to discover life in an American university, so different from my previous experiences in Madrid and Paris. I spent in Minneapolis a long winter and short spring full of new experiences, new acquaintances, lots of mathematics, and of course all the cold weather you can imagine. My first office was on the ground floor of Vincent Hall, and the large office across the aisle was Jim Serrin's.

My research program was focused on studying free boundary problems for porous medium type flows with D. Aronson and L. Caffarelli, which I did. The open atmosphere of the School of Mathematics gave me the opportunity to converse and discuss many appealing topics with them and other renowned mathematicians, such as H. Weinberger, W. Littman, and D. Kinderlehrer, who were legendary figures for me. I was immediately seized by the opportunities and challenges of so favorable a situation. With Serrin close by, discussing elliptic problems and getting interested in fluid mechanics came naturally.

One very important moment in the fall came—Thanksgiving. I did not know how special this was for American families, since family time in Spain is Christmas. I was not expecting much of a celebration for me, a foreigner just arrived. It is then that I discovered another side of Jim's character, his human side: I was invited to his house on Dupont Avenue. Thanksgiving with Jim and his family in the fall of 1982 was for me like a revelation that this visit was maybe the beginning of a deep connection with the country, which has continued ever since for me and my family.

One of Jim's most appealing characteristics for me was that he was a humanist, with deep interest in different branches of culture. Mathematics ranked paramount, and being at the time at a mature stage of his career, he was incredibly active. Talking to him meant also talking about culture, and I soon discovered his love for Italy, which was also to be a marked trait of my personal life. He talked also about politics, where he was sometimes controversial, and I learned from him the duty of arguing honestly, even against our own or another's previous firm positions if the evidence leads to it. And then, he was so family

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Photo courtesy of Hans Weinberger.

From left: Hans and Laura Weinberger, Jim and Barbara Serrin, Boulder, Colorado, 1957.

Photo by Patrizia Pucci.

Barbara Serrin, Clifford Truesdell, and Jim Serrin, Venice.

Photo courtesy of the Serrin family.

James Serrin and Laurent Veron.

oriented that we have kept in contact for all these years. When I met Jim he had a solid reputation for being strict in his devotion to high standards in mathematics, as well as life. I was to discover that Jim enjoyed immensely the meetings that were organized in his honor that went on as long as he was active, which means during his lifetime, and we all enjoyed them.

The mathematics that I learned from Jim and that I often used was his early work on the regularity of nonlinear elliptic and parabolic equations. His work and writing in fluid mechanics was one of my motivations for teaching courses on the topic at UAM in Madrid and then writing my notes as a book in Spanish. His interest in thermodynamics was always out of bounds for me, but in some sense the effort I have devoted during the last ten years to understanding and using entropy functionals (in the sense of Boltzmann) for nonlinear heat equations has a relation with that topic of his.

The major common interest I had with Jim was the maximum principle, and there I had a proof of his insight and generosity. I had written a short paper in 1984 on the strong maximum principle for nonlinear elliptic equations (*Appl. Math. Optim.* **12**, 191–202) which I had more or less forgotten in subsequent years. I was then delighted when Jim Serrin, in collaboration mainly with Patrizia Pucci, took up the results as part of a series of brilliant research articles, and they gave lavish praise for that work of mine. In time their broad investigation led to the book *The Maximum Principle* (Springer, 2007), which is a basic reference on that classical subject. That paper of mine went on to be my most cited paper.

I would like to conclude by saying that for me James Serrin is a prominent example of the enlightened scientist that I found in my American experience—wise people who devote their lives to science at the highest level and to forming a community of open, critical, hard working, and friendly minds. It is the embodiment of the happy times that I was fortunate to enjoy.

Hans Weinberger

While I had met Jim Serrin when he visited the University of Maryland in the early 1950s, I did not really get to know him until 1957. That summer there was a meeting at the University of Colorado which set the agenda in the field of partial differential equations for at least the next three decades.

My wife and I were newlyweds, and Jim and Barbara were there with their first daughter, Martha, who was then three or four. My wife and I were in the dormitory for childless people, while the

Jim and Barbara in their living room on Jim's 75th birthday.

Photos this page courtesy of the Serrin family.

From left: Elizabeth, Janet, Martha (daughters of James and Barbara Serrin), and James Serrin, 1998.

Serrins were in another dormitory, but we somehow got together. The entertainment for the meeting consisted largely of strenuous mountain hikes, but the Serrins and we found that we enjoyed more leisurely outdoor activities and had a very good time together.

This pleasant contact played an important part in our decision three years later to go to the University of Minnesota. When we arrived in Minneapolis in the summer of 1960, the Serrins were away, but they graciously let us and our one-year-old daughter live in their house until we could find more permanent housing. When they returned, we soon became fast friends, and that friendship lasted until Jim's death. The activities certainly became less strenuous and less outdoorsy, but the friendship endured.

Jim and I found that we had rather similar attitudes about mathematics. Even though we wrote only three joint papers, none of which was earth-shaking, we often discussed new results and their implications. The choice of topics for several of my papers was influenced by Jim, even though he did not work on the details. He was a good friend and a great mathematician.

Janet Sucha, Elizabeth Conley, and Martha Stack

Trying to sum up our feelings, emotions, and stories about our father, James Serrin, has been a monumental task. As one friend wrote, "Jim was an amazing man—a huge presence. Important in his work and in his life; interesting, intelligent, quixotic, fun and difficult at the same time. He will be missed, not only by his family, but by a wide range of people." Already our lives feel smaller, missing his quirky smile, his joy of having family around him, his interest in our pursuits, and willingness to share his insights. Dad was the center of our family, bringing us together for any excuse he could find. Time spent together was warm and festive. In his personal life our father had a love of beauty and a deep appreciation for great works of music, art, architecture, and literature, along with a love of ideas and a special regard for the life of the mind. A true and natural teacher, he inspired us and those around him to appreciate beauty and knowledge at every opportunity, enriching our lives forever. Among the myriad of treasures he gave to his family and friends was the gift of laughter; he was always ready to tell a new joke, play a trick, or repeat a funny story. He encouraged our love for great music and art. He would spend hours examining a painting or engraving (sometimes too long for a young child's attention) or lying on the floor with eyes closed immersing himself in a particular piece of music (rock & roll not included). He shared his love of great literature and great ideas with us through his extensive library of beautiful books. These books were works of art in themselves, beautifully designed and richly bound. Our mother shared his passion for books, saying recently, "I could spend my whole life reading." He also gave us the gift of feeling joy at the marvels of nature. As a young man he loved canoeing, playing tennis and squash, biking, throwing a Frisbee, orchestrating picnics, and taking walks through beautiful gardens and around his beloved Lake Harriet. Later in life he continued to enjoy exploring by driving to out-of-the-way places he

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had discovered on a map or in a book. He was an avid photographer, patiently searching out the perfect composition and waiting for the ideal lighting to create his vision of the world through his camera lens. He found beauty in what he saw.

Dad gave us all a passion for travel and an appreciation for other cultures. He spent a good deal of his time as a visiting professor at foreign universities, often taking the family with him. This gave us the opportunity to submerge ourselves in other cultures while attending foreign schools and developing friendships within the worldwide math community. Our first trip abroad was to Sussex, England, when he was on sabbatical in 1967–1968. Our trip to and from Europe was almost as wonderful as being there, as we crossed on the S.S. *United States*, learning to love the joys of ocean travel that afforded us the time to appreciate the journey. While in England we toured extensively, visiting as many of the great houses, parks, and cathedrals as we could possibly fit into our family schedule. As his work became more recognized, his invitations to visit foreign countries increased, and we returned as a family several more times to spend semesters at Sussex and visit other European universities. He was honored to be a part of one of the first American academic delegations to China in 1981, to travel to the USSR, and to Poland before the fall of the Berlin Wall.

Dad's brother moved to Italy in 1963 and after that, family reunions often took place in Florence. Eventually our father began collaborating with Italian colleagues, thus combining his love of math, family, and travel. Everywhere he went, he touched people's lives through his commitment to learning and understanding. His great intellectual curiosity always made time spent in his company interesting, usually leaving you with a bit more information and insight than you had before. Still, with all his many friends and acquaintances, his most significant relationship was with our mother, his "beautiful wife". They complemented each other in so many ways. Their story began with our father going to New York City the summer before he moved to Cambridge with the idea that it was time to broaden his experience (hitherto strictly limited to his mathematical career) and to develop his social skills. He calculated NYC would have the largest number of eligible, single, and intelligent women in the smallest geographical area, and thus it was where he was most likely to satisfy his goal of meeting "someone interesting". He joined the youth group of Riverside Church and fell in love with our mother who was coordinator of the youth group, and who, from that time on, effortlessly coordinated so much of his daily life. Our parents were married in September 1952, just in time to report to MIT for the fall term. He had given himself three months to accomplish this task of finding someone with whom to share his life, and fortunately, as with so many things he did, he chose well. She was his greatest helpmate and supporter, and together they created a world of friends, making connections and lasting relationships in all corners of the world. They welcomed people into their home, no matter where home was, and always made others feel at ease, sharing a cup of tea or a glass of lemonade. These friendships are some of the gifts we received from our parents.

Dad enjoyed life and took what he could from every opportunity. He was committed to learning and sharing his knowledge. He was purposeful in his living and accomplished the goals he set for himself. He died at 3:30 p.m. on Thursday, August 23, 2012. He directed his death just as he directed his life. He passed in dignity, strength, and peace. In our mother's words, "Jim and I loved each other, we had a good life together, we had three wonderful daughters and nothing but good memories."

Can the Eureqa Symbolic Regression Program, Computer Algebra, and Numerical Analysis Help Each Other?

David R. Stoutemyer

Eureqa is a symbolic regression program described by Schmidt and Lipson [11], freely downloadable from [13], where there are press citations, a bibliography of its use in articles, a blog, and a discussion group. In contrast to typical regression software, the user does not have to explicitly or implicitly provide a specific expression containing unknown constants for the software to determine. With little or no guidance, symbolic regression determines not only unknown coefficients but also the class and form of the model expression. See [9] for quick insight into the underlying "survival of the fittest" paradigm for symbolic regression. An Internet search on "symbolic regression" reveals that there are other such programs. However, my skeptic's curiosity was aroused by such extreme press praise as

> Move over, Einstein: Machines will take it from here. [10]

> There are very clever "thinking machines" in existence today, such as Watson, the IBM computer that conquered *Jeopardy!* last year. But next to Eureqa, Watson is merely a glorified search engine. [5]

> By one yardstick, Eureqa has even discovered the answer to the ultimate question of life, the universe and everything. [5]

The program is designed to work with *noisy experimental data,* searching for, then returning a set of result expressions that attempt to optimally trade off conciseness with accuracy. However, I was curious to learn if the program could also be used as a supplementary tool for *experimental mathematics*, *computer algebra*, and *numerical analysis*. In the first few weeks of using this tool, I have already found that:

1) Eureqa can sometimes do a job of exact simplification better than existing computer algebra systems if there is a concise equivalent expression.
2) Eureqa can often discover simple expressions that *approximate* more complicated expressions or fit a set of numerical results well.
3) Even when the fit isn't as accurate as desired, the *form* of a returned expression often suggests a class of forms to try for classic regressions, interpolations, or series expansions giving higher accuracy.
4) Eureqa could do an even better job if it supplemented its search with exploitation of more computer algebra and numerical methods, including classic regression.
5) There are important caveats about how to use Eureqa effectively.
6) The most extreme press quotes are exaggerations, but Eureqa really is quite impressive.

This article has examples that illustrate these findings, using Eureqa 0.93.1 beta.

Regarding computing times reported herein, the computer is a 1.60GHz Intel Core 2 Duo U9600 CPU with 3 gigabytes of RAM.

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Exact Simplification and Transformation

A Trigonometric Simplification Example

Here is a Maple 15 assignment of an input trigonometric expression to a dependent variable y:

$$y := \cos(x)^3 \sin(x) + \frac{\cos(x)^3 \sin(x)}{2} + 2\cos(x)^3 \cos(2x)\sin(x) + \frac{\cos(x)^3 \cos(4x)\sin(x)}{2} - \frac{3}{2}\cos(x)\sin(x)^3 - 2\cos(x)\cos(2x)\sin(x)^3 - \frac{\cos(x)\cos(4x)\sin(x)^3}{2}. \quad (1)$$

The default simplification merely combines the first two terms, which are similar.

However, the simplify(y) function[1] required only 0.03 seconds to return the much simpler

$$4\sin(x)\cos(x)^5\left(2\cos(x)^2 - 1\right). \quad (2)$$

An equivalent expression produced by the Mathematica FullSimplify[...] function in only 0.08 seconds is also much simpler:

$$2\,(\sin(3x) - \sin(x))\cos^5(x).$$

But the equivalent even simpler form discovered by Eureqa is

$$y = \cos(x)^4 \sin(4x). \quad (3)$$

That even the simplified model of evolution in Eureqa can work so well might change some minds.

Caveat: The algorithm uses a random number generator with no current user control over its seeding, which appears to be done by the clock. Therefore sequences are not currently repeatable, and the computing times to obtain expression (3) varied dramatically, from 3 seconds to several minutes. It conceivably could require more time than you would ever be willing to invest. However, although even 3 seconds is much longer than the computer algebra times, it is certainly worth a few minutes wait to obtain such a nice result, and such experiments can be done while away from the computer, such as while eating, sleeping, or playing cell phone games. There is also an option to use parallel cloud computing, which reduces the mean and variance of the elapsed time necessary to obtain a satisfactory result.

Here is how I used Eureqa to obtain this delightfully simple exact result (3):

1) First I plotted expression (1) in Mathematica, revealing that it is antisymmetric and that its fundamental period appeared to be π, with higher frequency components appearing to have a minimum period of $\pi/4$. This was confirmed by TrigReduce[y], which returned the equivalent expression
$$\frac{1}{16}(\sin(2x)+6\sin(4x)+4\sin(6x)+\sin(8x)).$$
2) I decided to use evenly spaced values of x because expression (1) is periodic, bounded, and C^∞ for all real x. I guessed that it might help Eureqa discover and exploit the antisymmetry if I used sample points symmetric about $x = 0$. I also guessed that it might help Eureqa discover the periodicities if I used exactly two fundamental periods. I guessed that using 16 samples within the minimum period $\pi/4$ would be sufficient to resolve it quite well; then I doubled that because Eureqa uses some points for fitting and others for error assessment. This implies 128 intervals of width $\pi/64$ from $-\pi$ through π. I then created a table of 17-digit floating-point pairs of x and y, then exported it to a file by entering
$$\text{Export}\left[\text{“trigExample.csv”, Table}\left[\text{N}\left[\{x,\ldots\},17\right],\{x,-\pi,\pi,\frac{\pi}{128}\}\right]\right]$$
where the ellipsis was expression (1).[2]
3) I then launched Eureqa, opened its spreadsheet-like Enter Data tab, then replaced the default data there with mine by importing file trigExample.csv. In the row labeled var, I then entered x in column A and y in column B.
4) The Prepare Data tab then showed superimposed plots of the x and y data values and offered preprocessing options that aren't relevant for this very accurate data.
5) Figure 1 shows the Set Target tab:
   (a) The pane labeled The Target Expression suggests the fitting model $y = f(x)$, which is what I want, so I didn't change it.
   (b) The pane labeled Primary Options has check boxes for the desired Formula building-blocks used in composing candidate $f(x)$ expressions. The default checked ones are sufficient for the sort of concise equivalent

[1] simplify(...) *has an optional second keyword argument "size" that is intended to minimize size, but for this example the result is less concise than* (2).

[2] *The reason for requesting 17 significant digits was that I wanted Mathematica to use its adaptive significance arithmetic to give me results estimated to be accurate to 17 digits despite any catastrophic cancellations, and I wanted Eureqa to receive a 17th significant digit to help it round the sequences of input digit characters to the closest representable 16-digit IEEE double values, which are used by Eureqa.*

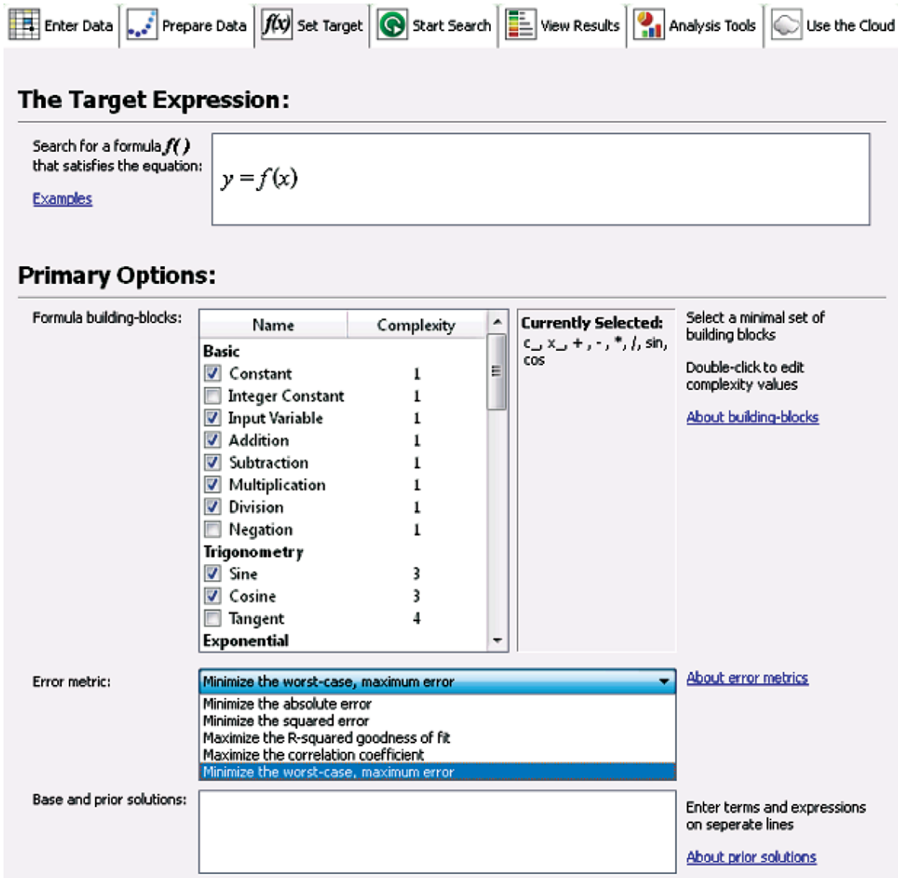

Figure 1. Eureqa Set Target tab for exact trigonometric simplification example.

to expression (1) that I am seeking. Therefore I didn't check any of the other offered functions and operators, not all of which are shown on this screen shot.[3] Formula building blocks also shows the corresponding Complexity measures, which can be altered by the user. The complexity measure of an expression is the sum of the complexities of its parts.

(c) The drop-down menu labeled Error metric offers different built-in error measures for Eureqa to try optimizing. A bound is usually more reassuring than the alternatives, so I chose Minimize the worst-case maximum error. The documentation suggests that Maximize the R-squared goodness of fit or Maximize the correlation coefficient is more scale and mean invariant, which are desirable properties too. However, the data is already well scaled with means of 0.

(d) For the covered Data Splitting drop-down menu the default alternative is to designate a certain percentage of the data points for fitting the data (*training*) and a certain percentage for assessing the error measure (*validation*). The individual assignments to these categories are done randomly, with some overlap if there aren't many data points. For the almost exact data in this article, I would prefer that alternative points be assigned to alternative categories, with the end points being used for training. However, none of the alternatives offered this, so I chose the default.[4]

6) I then pressed the Run button on the Start Search tab and watched the temporal progress of the search. The plot in

[3] *I could have saved search time by unchecking Division, because the floating-point coefficients make a denominator unnecessary for this class of expressions. I could also have saved search time and perhaps obtained a more accurate result by checking the Integer Constant box, because integer coefficients are quite likely for exact equivalent expressions, making it worth having Eureqa try rounding to see if that improves the accuracy. However, I decided to accept the default checked boxes to see if Eureqa could find a good exact equivalent without any more help from me. Other building blocks are described at* [6].

[4] *I have since learned that, with such precise data, another promising alternative would be to use all of the points for both training and validation, which is a current option.*

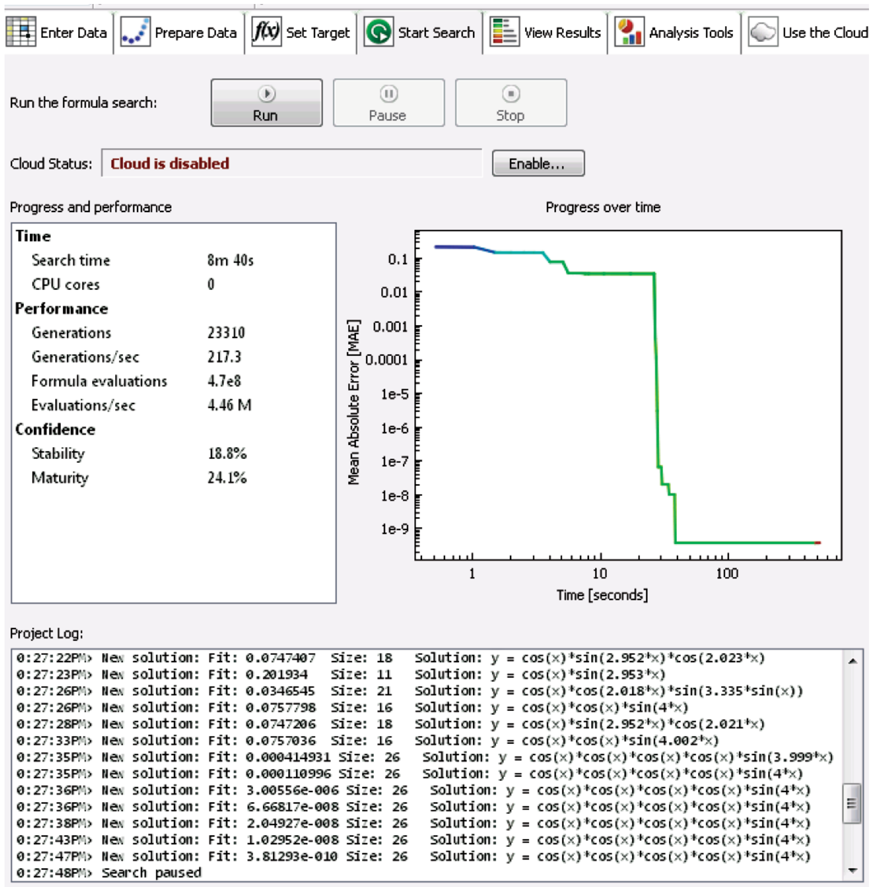

Figure 2. Eureqa Start Search tab for exact trigonometric simplification example.

Figure 2 dynamically zoomed out to show a log-log plot of the best error measure obtained so far as a function of computing time. The Project Log dynamically showed successive candidates that are better than any so far on the basis of either complexity or accuracy. The entertainment of watching the evolution of these panes is very appealing. It is similar to rooting for the home team at a sporting event. Notice that:

(a) Integer powers of subexpressions are represented in the Project Log as repeated multiplications, and their complexity is measured that way. For example, several results are displayed as

(4) $y = \cos(x) * \cos(x) * \cos(x) * \cos(x) * \sin(4 * x)$

with a complexity measure of 26.[5]

(b) Result (4) appears first with a reported Fit of 0.000111, followed by the same expression with monotonically better fits up through 3.81×10^{-10} at 39 seconds.[6] I terminated the

[5] *The complexity measure seems less than ideal: the ultimately reported formula in the View Results tab of Figure 3 is* $\cos(x)^4 \sin(4x)$. *This is more concise and requires only one cosine and two multiplies to compute the* $\cos(x) * \cos(x) * \cos(x) * \cos(x)$ *factor if compiled by any decent compiler.*

[6] *The same displayed formula was associated with such dramatically different error measures because Eureqa always rounds its displayed coefficients to about four significant digits, and in this case it enabled display of an exact result to which it was merely converging. If I had checked the Integer Constant building block, then Eureqa probably would have rounded the coefficients to integers. However,* $y(0.0) = 0.0$ *and the data varies between about* ± 3.8, *so a maximum residual of* 3.81×10^{-10} *is enough to convince most people that the displayed result is exact. Nonetheless, the result expression might not be equivalent to the sampled expression everywhere between samples even if all the residuals are* 0.0. *Also, one or more of those floating-point zeros might be caused by underflow of numbers whose exact values are nonzero. For this example we can prove equivalence for all complex* x *because*

$$\mathrm{TrigReduce}\left[\left(\cos(x)^3 \sin(x) + \frac{\cos(x)^3 \sin(x)}{2} + \cdots\right)\right.$$
$$\left. - \mathrm{Cos}[x]^4\, \mathrm{Sin}[4x]\right] \to 0\,.$$

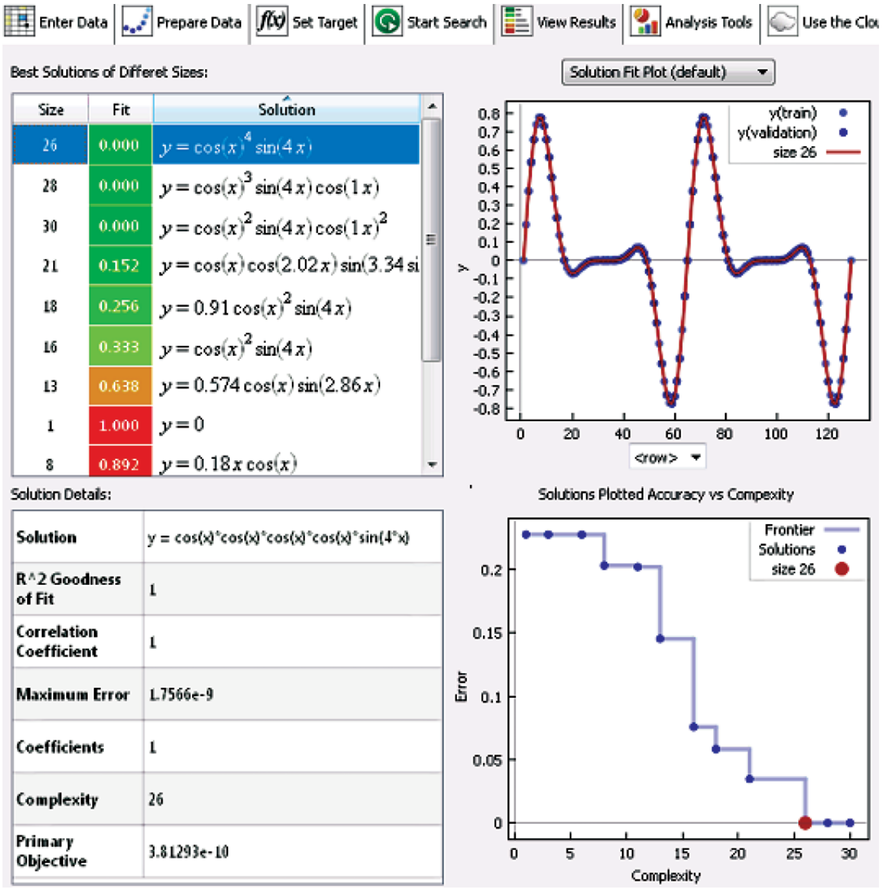

Figure 3. Eureqa View Results tab for exact trigonometric simplification example.

search at 8 minutes, during which Eureqa tried different formulas that didn't fit as well, regardless of how complicated they were.

7) Figure 3 shows the results on the View Results tab:

(a) In the pane labeled Best Solutions of Different Sizes, the first column lists the complexity measure, the second column lists an error measure, and the third column lists the corresponding candidate equation. If you click on a row, the pane in the lower left corner gives more detail, with various rounded error measures, including the Primary Objective that I chose, which was maximum absolute error.

(b) Eureqa does some automatic expression simplification: Whenever a *mutation* produces a new candidate expression or a *crossover* produces two new candidates containing mixtures of the two parents' subexpressions, a few transformations are applied to make the expression more nearly canonical and to avoid having a misleadingly high complexity on account of uncollected similar terms, uncombined numeric subexpressions, etc. This minimal computer algebra is also used to make the displayed results in the Best solutions of different sizes pane more attractive. These transformations include:

- Integer powers and products of sums are expanded to make them more nearly canonical.[7]
- Factors and terms are sorted; then similar factors and terms are collected.
- Numeric subexpressions are reduced to a single number.
- A few rules such as $\text{abs}(\text{abs}(u)) \to \text{abs}(u)$ and $1 * u \to u$ are applied.

However, you will often see a sub-expression such as $1\cos(1x)$. This is because the 1's are a result of rounding noninteger coefficients to the typically displayed 3 or 4 significant digits. Nonetheless, I noticed unexploited opportunities, such as Eureqa unnecessarily trying the sub-expression $\sin(x + 6.283)$. Exploiting symmetry and angle reduction could

[7] *Unfortunately, expanded forms are often less concise than equivalent factored forms that would have smaller Complexity.*

preclude the need to try candidates having constant terms outside a much smaller interval.

(c) The pane in the lower right corner plots an error measure as a function of complexity for the twelve reported optimal candidates, with the currently highlighted candidate as a larger red dot.

(d) The pane in the upper right corner shows a plot of the highlighted expression superimposed on the validation points in dark blue and the training points in lighter blue. The drop-down menu above it offers the option of instead plotting the *residuals* at all of the data points, which gives a much better idea of the fitting errors as a function of x. If these residuals had revealed a nonnegligible recognizable pattern such as being approximately proportional to $\sin(16x)$, then I would have tried another search with the model $y = f(\cos(x), \sin(4x), \sin(16x))$. I would iterate this process until there was no further improvement or the residuals revealed no nonnegligible recognizable pattern.

Instead of searching for the most concise equivalent, one can also search for equivalent expressions of a *particular form*. For example, we could request that expression (1) be transformed into a function without cosines by unchecking that building block. As another example, the request $z = f_1(x) * f_2(y)$ can be used to search for an equivalent form having separated variables. (Nonnegative integer suffixes on variable and function names are pretty-printed as subscripts.)

Some Other Exact Simplification Examples

Using "Assuming[..., FullSimplify[...]]" in Mathematica and "simplify(...), assuming ..." in Maple, I could not make them accomplish the following quickly successful Eureqa simplifications, for which I selected the default building blocks, Integer Constants, and other functions or operators that occur in the specific given expressions:

(5) $$\left\lfloor\sqrt{\lfloor x\rfloor}\right\rfloor + \lfloor\sqrt{x}\rfloor \mid x \geq 0 \rightarrow 2\lfloor\sqrt{x}\rfloor.$$

(6) $$q^2 + \frac{2^{1/3}\left(\sqrt{81q^2-12}-9q\right)^{2/3}+24^{1/3}}{6^{2/3}\left(\sqrt{81q^2-12}-9q\right)^{1/3}} - \frac{2\cos\left(\frac{1}{3}\operatorname{acos}\left(-\frac{3\sqrt{3}q}{2}\right)\right)}{\sqrt{3}} \mid |q| < \frac{2}{3\sqrt{3}} \rightarrow q^2.$$

(7) $$\max(x-y,\,0) - \max(y-x,\,0) \rightarrow x - y.$$

- Example (5) comes from [7].
- I tabulated only the *real* part for example (6), because rounding errors for the principal branch of the fractional powers of the negative quantity $\sqrt{81q^2-12}-9q$ generated some relatively very small magnitude imaginary parts.
- To generate $17^2 \rightarrow 289$ rows of data for example (7), I used

$$\text{Apply[Join,Table[N[}\{x, y, \text{Max}[x-\frac{2}{3\sqrt{3}}y, 0]$$
$$-\text{Max}[y-x, 0]\}, 17], \{x, -1, 1, \frac{1}{8}\}, \{y, -1, 1, \frac{1}{8}\}]].$$

The examples so far illustrate that Eureqa can sometimes determine a simpler exact result than a computer algebra system. However, I constructed these very simple results, then transformed subexpressions in ways that I suspected would be difficult for common transformations to reverse, particularly if applied to the entire expression rather than well-chosen pieces. Despite this it was not easy to find examples for which neither FullSimplify[...] nor simplify(...) could determine the very simple equivalent. Thus, Eureqa should be regarded as an *occasionally* beneficial *supplement* to these functions rather than as a replacement. Also, effective use of Eureqa requires good judgment in:

- the interval spanned by the sample points, their number and spacing;
- the form selected for the target expression; and
- the building blocks that are selected together with their complexities.

Effective use also probably depends on experience with Eureqa. Therefore, the benefits that I have discovered should be regarded as a lower bound because of my novice status.

How to Reduce the Curse of Dimensionality

As illustrated by example (7), data for representing all combinations of n different values for each of m different independent variables requires n^m rows, and we must have $n \geq 2$ for Eureqa to discern any nonconstant dependence on each variable. Thus, for a given n, this exponential growth in data rows with the number of independent variables can greatly increase the time required for Eureqa to find a good fit. Moreover, yielding to the consequent temptation to reduce computation time by reducing n as m increases tends to reduce the precision of the results. Fortunately, there are several complementary techniques that sometimes reduce the effective dimensionality:

1) *Dimensional analysis* can sometimes reduce the number of independent variables, and [15] describes a Maxima program that automates this.

2) If you can partition an expanded or factored form of your expression into two or more components having distinct variable sets, then you can independently fit each of those components. For example, you can separately fit $\max(x-y, 0) - \max(y-x, 0)$ and $\max(y-z, 0) - \max(z-y, 0)$ in the sum of these two expressions, converting a trivariate example into two bivariate examples.
3) If in every term of a given sum the exponents of some subset of the variables sum to the same homogeneity exponent k, then substitute 1 for one of those variables v, fit this isomorphic problem, then multiply every resulting term by the individual power of v necessary to restore the homogeneity.
4) Unlike many experimental situations, for experimental mathematics we usually have complete freedom to choose the data values of the independent variables. In both univariate and multivariate problems there can be *sweet spots* that deliver more accuracy for a given number of samples than does a brute force Cartesian product of uniformly spaced points. These special values are often related to the zeros or extrema of orthogonal polynomials. For example, see the multidimensional integral formulas in Chapter 25 of [1].

Approximate Symbolic Results

Ideally a floating point result is either exact or the closest representable number to the exact result, with ties broken in favor of having the last significant bit be 0. Well-designed floating-point *arithmetic* comes very close to this ideal: If the exact result is representable within the thresholds for overflow and for gradual underflow, then the result is the exact result for inputs that differ from the actual inputs by factors between $1 - \varepsilon_m$ and $1 + \varepsilon_m$, where *machine epsilon* ε_m is about 1.11×10^{-16} for IEEE double, which corresponds to about 16 significant digits. A *relative* error bound of $\pm\varepsilon_m$ is the *gold standard*. There are similar expectations for operations such as exponentiation and for functions such as sinusoids or logarithms that are commonly built into compilers but allowing a few times ε_m, which I call the *silver standard*. It is a matter of professional pride among numerical analysts designing *general purpose* mathematical software to strive for the silver standard for all functions provided with the software, and many users assume this.[8] I was curious to know if Eureqa can help numerical analysis by discovering concise approximate expressions that meet the silver standard.

[8] *For example, early Microsoft Basic computed elementary functions, fractional powers, and integer powers to half the precision of the other arithmetic operators, causing unsuspecting users to have results that were often far less accurate than assumed.*

An Antiderivative Example

Many well-known and special-purpose functions are defined by a definite integral containing a variable that is not the integration variable, a definite integral for which there is no known closed-form expression in terms of simpler known functions. For example, suppose that I want to implement an IEEE double version of the Dogbert W function defined by

(8)
$$W(x) := \int_0^x \frac{dt}{\sqrt{1 - t^2 + \frac{2}{\pi}\cos\left(\frac{\pi t}{2}\right)}} \quad \mid -1 \le x \le 1 .$$

No computer algebra systems that I tried can determine a closed form for $W(x)$.

Plan B: Do a gold standard numeric integration for a sequence of x values in the interval $-1 \le x \le 1$, then use Eureqa to discover a silver standard expression that fits those values well. Here is an abridged account of my attempt to do this.

1) I entered the Mathematica input

$$\begin{aligned} &\text{xWPairs} = \text{Table}[\{\text{N}[x, 17], \\ &\text{NIntegrate}[\frac{1}{\sqrt{(1-t)(1+t) + \frac{2}{\pi}\cos\left(\frac{\pi t}{2}\right)}}, \\ &\{t, 0, x\}, \text{PrecisionGoal} \to 17, \\ &\text{WorkingPrecision} \to 25], \{x, -1, 1, 1/64\}]. \end{aligned} \quad (9)$$

Then I inspected the 129 number pairs to make sure there were no imaginary parts, infinities, or undefined values.[9]

[9]
- *The data in the* Enter Data *tab must currently be integers or finite real floats. A fraction, a floating point infinity, a nan, or a nonreal number is not accepted. If an imaginary part of your data is negligible noise, then replace it with* 0.0. *Otherwise you must separately fit the real and imaginary parts or the absolute value and the arg, which is the* Two-Argument Arctangent *in Eureqa. If your data has an undefined value due to an indeterminate form, then replace it with the value returned by your computer algebra* limit(...) *function. If your table has an infinity, then subtract out or divide out the singularity that is causing it. Don't expect a good fit if you simply omit a value that has infinite magnitude or replace it with an exceptionally large magnitude having the correct sign, either of which can dramatically mislead the search.*
- *I entered* $1 - t^2$ *as* $(1-t)(1+t)$ *in input* (9) *and elsewhere to reduce the magnification of rounding errors by catastrophic cancellation near* $x = \pm 1$.
- *The reason for WorkingPrecision* $\to$ 25 *is that I wanted to further reduce this catastrophic cancellation.*

2) All the values were real and finite, so I then entered

Export ["xWPairs.csv", xyPairs] ;

then I imported the resulting file into Eureqa and tried to fit $W = f(x)$ with the default formula building blocks. After three minutes of search the most accurate formula was

$$W = \frac{0.7773112536\,x}{\cos(0.4696613973\,x^7) - 0.2294845216\,x^2},$$

which is noninsightful and accurate to a disappointing maximum absolute error of about 0.4%.

3) A Mathematica plot of the *integrand* reveals a probable explanation: The integrand has endpoint singularities, and although they are integrable, the resulting integral has infinite magnitude low-order derivatives at the endpoints, which probably makes the quadrature less accurate and the Eureqa search slower than otherwise.

4) The plot of numeric *antiderivative* values on the Prepare Data tab revealed that it looks approximately proportional to $\text{asin}(x)$.

5) So next I did another Eureqa search after disabling the sine and cosine building blocks and making the target expression be $W = f(x, \text{asin}(x))$. I did *not* enable the arcsine building block because I didn't want Eureqa to waste time trying arguments that cause $\text{asin}(\ldots)$ to be nonreal. In 11 seconds Eureqa found the following seven-term expression having a maximum absolute error of only about 3.1×10^{-9}:

$$\begin{aligned}(10)\qquad W = &-1.870027576 \times 10^{-13}\\ &+ 0.7816747744x\\ &+ 0.0147770774\,x^3\\ &- 0.03033616234\,x^2\,\text{asin}(x)\\ &+ 0.07586494202\,x\,\text{asin}(x)^2\\ &+ 0.0818165982\,\text{asin}(x)^3\\ &+ 0.0009144579166\,x^3\,\text{asin}(x)^2.\end{aligned}$$

I aborted the search at 3 minutes with no further improvement. Regarding this result:

(a) To view the coefficients rounded to 10 significant digits rather than about 4, I had to copy the expression from the Best solutions of different sizes pane in the View Results tab into Mathematica or a text editor. Unfortunately there is currently no way to view or access all 16 digits, so I will have to polish a result with classic regression software to obtain a silver standard result.[10]

(b) I edited the copied formula because it contained annoying superfluous parentheses and represented integer powers by repeated multiplication.

(c) The even symmetry of the integrand and the centered integration from 0 imply that the antiderivative should have odd symmetry. Therefore the spurious constant term in expression (10) should be discarded. Terms that are contrary to odd symmetry might arise from the random partitioning of the data into training and validation sets.

(d) Converting the result to recursive form by collecting similar powers of x or $\text{asin}(x)$ can significantly reduce the Complexity. For example, deleting the spurious constant term, rounding the coefficients in result (10) for brevity, then collecting with respect to $\text{asin}(x)^2$ give

$$\begin{aligned}W = &\ 0.78\,x + 0.015\,x^3 - 0.03\,x^2\text{asin}(x)\\ &+ (0.076\,x + 0.00091\,x^3)\,\text{asin}(x)^2\\ &+ 0.082\,\text{asin}(x)^3,\end{aligned}$$

which saves one instance of $*\text{asin}(x)^2$. At the expense of comprehensibility, the Complexity and the floating-point substitution time can be further reduced by *Hornerizing* this recursive representation to

$$\begin{aligned}W = x(0.78 + 0.015x^2) + \text{asin}(x)(&-0.03\,x^2\\ &+ (x\,(0.076 + 0.00091\,x^2)\\ &+ 0.082\,\text{asin}(x))\,\text{asin}(x))).\end{aligned}$$

This is another place where more computer algebra could help Eureqa.

(e) Notice that result (10) has no term that is simply a numeric multiple of $\text{asin}(x)$. Therefore it doesn't model the infinite endpoint slopes associated with the integrand singularities there. But that is my fault, because the target expression contains no special encouragement to include a term of that form, and the plot from the Eureqa Prepare Data tab reveals that the sample points were not closely enough spaced near the endpoints to suggest the infinite slope magnitudes there.

[10] *The rounding of coefficients in the* Project Log *and* Best solutions of different sizes *panes does increase comprehensibility, particularly since those panes are regrettably unscrollable. Even more rounding could justifiably be done for coefficients of terms whose relative maximum contribution is small. For example, if the maximum contribution of a term over all data points is 1%, then its coefficient justifiably could be rounded to two less significant digits than the coefficient that contributes the most over all data points. See* [3] *for more about this idea.*

6) Result (10) suggests that a set of particularly good fits would be a truncated series of the form

$$(c_1 \operatorname{asin}(x) + c_2 x) + \left(c_3 \operatorname{asin}(x)^3 + c_4 x \operatorname{asin}(x)^2 + c_5 x^2 \operatorname{asin}(x) + c_6 x^3\right) + \cdots$$

with numeric coefficients c_k. This can be regarded as a truncated bivariate series in terms having a power of x times a power of $\arcsin(x)$ that have nondecreasing odd total degrees. I could constrain Eureqa to search only within this class of expressions by entering a target expression having a particular total degree, such as

$$W = f_1() \operatorname{asin}(x) + f_2() x + f_3() \operatorname{asin}(x)^3 + f_4() x \operatorname{asin}(x)^2 + f_5() x^2 \operatorname{asin}(x) + f_6() x^3.$$

However, standard regression software is much faster for merely optimizing some parameters in a specific form/and more accurate if done with arbitrary-precision arithmetic. The largest total degree in Eureqa result (10) is 5. Consequently, I next used the Mathematica LinearModelFit[...] function with the 12 basis expressions of the form $x^j \operatorname{asin}(x)^k$ having odd total degree $1 \le j + k \le 5$. After 0.27 seconds I received the following eight-term result, whose significant digits I have truncated for brevity:

(11) $$22.9\,x + 0.012\,x^3 + 0.000097\,x^5 - 22.1 \operatorname{asin}(x) - 0.068\,x^2 \operatorname{asin}(x) + 0.78\,x \operatorname{asin}(x)^2 + 3.09 \operatorname{asin}(x)^3 - 0.078 \operatorname{asin}(x)^5.$$

The maximum absolute error at the tabulated points was about 4×10^{-11}, which is two significant digits more than (10) for the same total degree and only one more term. The 96 percent cancellation between the dominant terms $22.9\,x$ and $-22.1 \operatorname{asin}(x)$ for x near 0 is less than ideal, but the small error measure is very gratifying.

Encouraged, I next tried LinearModelFit[...] with total degree 7, which entails twenty basis terms. However, the most accurate returned result *also* had eight terms and cancellation between the two dominant terms. Moreover, the error measure was only slightly smaller, and the coefficients changed dramatically from those of corresponding terms in (11). Therefore it seems likely that something important is missing from the basis, preventing results from corresponding to economized truncations of a convergent infinite series.

Thus it is not promising to try larger total degrees with this basis in pursuit of a concise numerically stable silver standard. Nonetheless, this has been a nice combined use of Eureqa and Mathematica: After the decision to try a target expression of the form $f(x, \operatorname{asin}(x))$, Eureqa discovered a concise form having 9 significant digits and basis functions of the form $x^j \operatorname{asin}(x)$. I then used Mathematica to obtain a result having only one more term that is accurate to 11 significant digits, which is more than adequate for many purposes. For this example Eureqa has served as a *muse* rather than as an *oracle*.

However, I couldn't help wondering: *Is* there a relatively simple class of forms that Eureqa might have revealed for further polishing to a concise *silver standard* fit by Mathematica?

With the help of the Mathematica Series[...] function and an embarrassingly large amount of my time adapting its results to my desires via a sixteen line *Mathematica* function downloadable from a website [16], I was able to determine an exactly integrable truncated infinite series expansion of the integrand that converged sufficiently fast without undue catastrophic cancellation over the entire interval $-1 \le x \le 1$. Using Assuming$[-1 \le x \le 1$, Integrate[...]], the Hornerized representation of the corresponding *antiderivative* is

(12)

$$\tilde{W}(x) := c_0 \operatorname{asin}(x) + x\sqrt{(1-x)(1+x)}\left(c_1 + x^2\left(c_2 + x^2(c_3 + \cdots)\right)\right).$$

Being a single series bifocally expanded about $x = \pm 1$, it is C^∞ over the entire interior interval $-1 < x < 1$. Notice that, contrary to the previous efforts, $\operatorname{asin}(x)$ occurs only to the first power and that all the other terms are multiplied by $\sqrt{(1-x)(1+x)}$. A good set of basis expressions is thus $\{\operatorname{asin}(x),\ x^{1+2k}\sqrt{(1-x)(1+x)}\}$ for $k = 0, 1, \ldots$. The higher powers of $\operatorname{asin}(x)$ in the previous basis were being used as flawed surrogates for $x^{1+2k}\sqrt{(1-x)(1+x)}$: octagonal pegs in circumscribed round holes—they sort of fit, but in an impaired way.

The Mathematica function that I wrote computes the exact coefficients c_k, which involve $\sqrt{6}$ and powers of π. After writing that function I used LinearModelFit[...] to effectively economize a higher-degree approximation to a lower-degree one having nearly the same precision. For the data I used high-precision numerical integration after using truncated series (12) to subtract out and exactly integrate two terms of the endpoint singularities. This made equally spaced x values quite acceptable. Experiments revealed that using terms through coefficient c_7 gave an approximation to $y(x)$ that had a worst absolute error of about

6×10^{-16} at the right endpoint, where the value was about 1.255. A plot of the residuals revealed that this eight-coefficient approximation has a relative error of about 5×10^{-16}, making it silver standard. Moreover, this plot was essentially noise, revealing no remaining exploitable residual for IEEE double.

Eureqa did not by itself discover this better basis, but that is my fault: I never allowed square roots as a building block. I should have done a little analysis earlier to wisely suggest a target expression of the form $f(x, \text{asin}(x), \sqrt{(1-x)(1+x)})$. With a square root in the integrand denominator, I should have anticipated a square root in a good approximate antiderivative numerator. Better yet, I could have tried the square root that also contains the cosine term. Using Eureqa effectively for computer algebra and numerical analysis should be viewed as a *collaboration* rather than as a *competition*. And Eureqa is not a black box oracle. You cannot leave your brain behind.

Other Possible Approximate Symbolic Results

There are many other possibilities for using Eureqa to find a concise expression or to suggest a good class of expressions that closely approximates a result that would otherwise have to be presented only graphically or as a table. For example,

- *Inverse functions and solving parametric algebraic equations*: Suppose that for the example (8) we also or instead wanted an approximate symbolic expression for the *inverse* Dogbert W function: x as a function of W. Eureqa can search for such expressions if we simply enter $x = f(W)$ or, more efficiently for this example, $x = \sin(f_2()\,W) + f_3(W)$.
- *Solution of differential, integral, delay, and other kinds of functional equations*: For example, suppose that we have a system of first-order ordinary differential equations and a tabulated numerical solution vector $[y_1(t), y_2(t), \ldots]$ for $t = t_0, t_1, \ldots, t_n$. Then we can use Eureqa to separately search for good expressions for $y_1(t), y_2(t), \ldots$. If we want $t_n = \infty$, then we should first make a change of independent variable to map that endpoint to a finite value in a way that doesn't introduce a singularity elsewhere.
- *Implicitization*: A major application of computer algebra is implicitization of parametric equations defining curves, surfaces, or higher-dimensional manifolds. Implicit representations are better than parametric for determining whether a point is inside, outside, or on a closed manifold. However, exact implicitization algorithms are known only for certain classes of parametric equations. For other classes we can try using Eureqa to find approximate implicit equations. (See [12] for tips on how to use Eureqa for this purpose.)

Additional Tips and Tricks

Here are a few additional tips and tricks for using Eureqa effectively in conjunction with computer algebra or numerical analysis:

1) To increase the chance of obtaining exact rational coefficients, reduce your input expression over a common denominator, then separately tabulate and fit the numerator and denominator with the Integer Constant building block checked.
2) To possibly include *foreseen* exact symbolic known irrational constants such as π and $\sqrt{2}$ in your result, for each such constant make a labeled column of corresponding floating-point values, preferably accurate to 16 or 17 digits. For example if a column labeled *pi* contains 3.1415926535897932 and a column labeled *sqrt*2 contains 1.414213562373095, then check the Integer Constant building block and use a target expression of a form such as "$\ldots = f(pi, sqrt2, \ldots)$". These symbolic constants don't contribute much to the curse of dimensionality because they are invariant, so there is no need to include more rows on their account.
3) To see if an unrecognizable floating-point constant in a result is a close approximation to some *unknown relatively simple rational or irrational constant* such as $3/7$ or $\sqrt{7}\pi$, enter all of the computed digits into the remarkable free online Inverse Symbolic Calculator [2] or use the Maple identify(...) function, which is an earlier version thereof.[11]
4) As with most regression software, Eureqa tends to express results in terms of the notoriously ill-conditioned monomial basis $1, x, x^2, x^3, \ldots$. To express your result more accurately in terms of an orthogonal polynomial basis, such as the Chebychev T polynomials, generate columns labeled $T_0, T_1, \ldots, T_n$, the desired constant n at the tabulated values of the independent variables. After 1 in the column labeled T_0 and the sample values of x in the column labeled T_1, successive columns can be computed from these by entering $= 2 * x * T_1 - T_0$ in the column labeled T_2, then $= 2 * x * T_2 - T_1$ in the column labeled T_3, etc. You can then use a target

[11] *Inverse Symbolic Calculator can be regarded as symbolic regression of a single floating-point number to an exact numeric expression that it approximates well. It would be nice if Eureqa included building blocks for at least simple rational constants, quadratic numbers, and multiples of π or e, which is easy to implement.*

expression of the form "$\ldots = f(T_0, T_1, \ldots)$". The T_k variables don't contribute much to the curse of dimensionality because they are totally correlated rather than truly independent. Moreover, these variables have the same Complexity as any other variable, thus preventing them from being discriminated against as they would be if you otherwise equivalently made the target expression be "$\ldots = f(1, x, x^2 - 1, x^3 - 3x, \ldots)$".

Seamless Integration of Software Packages

It is usually somewhat of a nuisance to work between two or more separate software packages compared to working entirely within one that has all of the necessary features built in. The extra effort and the lesser chance of even knowing about two or more complementary software packages is a great deterrent to such use. Thus it is good to know that interfaces are under development for using Eureqa from within Mathematica, MATLAB, Python, .NET, and KNIME, with current versions downloadable from [13]. Such added interfaces are rarely as seamless as features that are built in, but they are often great improvements over communicating by export-import of files or by copy and paste. Among other things, the interfaces can accommodate differences in syntax for expressions.

There is also a different symbolic regression add-on GPTIPS for MATLAB [8] and one named DataModeler for Mathematica [4].

The Need for Automation

At any one time, most of us are amateurs with most of the software that we use. We need all of the help we can obtain. In response to that need, many of the best software packages automate certain portions. However, the previous examples were *not* automatic. Training, experience, and judgment were involved in choosing the data points, target expression, etc. Some of this could and should be automated. A qualitative analysis program such as the Maxima program described in [17] could help in this regard: Given an expression, this program attempts to return bounds and indications of monotonicity, convexity, symmetries, periodicities, zeros, singularities, limits, and stationary points. To the extent that this is successful, this information could be used to choose automatically the function blocks and for each independent variable the endpoints, the number of samples, and perhaps even their distribution. For example:

- If there are poles, then it is best to automatically convert any tangents to sines divided by cosines, then form a reduced common denominator, then use Eureqa to fit separately the numerator and denominator. Neither the numerator nor the denominator will contain a *pole*, but they still could contain a logarithmic singularity that would have to be handled by subtracting or dividing it out.
- It is probably best to choose endpoints that extend modestly beyond all stationary points and the real parts of all zeros, including at least one fundamental period, if any, with enough points to resolve the shortest period.
- If there is a symmetry and the expression is C^∞ at the symmetric point, then it is probably best to center the data values on that point. Otherwise it might be more efficient to make that symmetry point be one of the endpoints.

Even a purely *numeric* program that searches for zeros, singularities, extrema, periodicities, and symmetries could help in this regard.

Conclusions

1) With wise use, Eureqa can *sometimes* determine a simpler exact equivalent expression better than current computer algebra systems or *sometimes* transform an expression into a desired form that isn't provided by a computer algebra system.
2) With wise use, Eureqa can sometimes suggest promising forms of expressions that *approximate* a result for which an exact closed form is unobtainable or excessively complicated. However, often you will want to obtain a more accurate result in a thus-revealed class by using a linear or nonlinear regression program built into a computer algebra system or a statistics package.
3) Some simple interface additions *within* Eureqa could increase its utility for the above two purposes. Interfaces *to* Eureqa within more software packages would encourage more use of Eureqa. Embedding Eureqa within those packages would probably be even more seamless.
4) Eureqa uses some custom computer algebra and some standard numerical methods internally. Eureqa would almost certainly benefit from embedding and exploiting a well-developed full-fledged computer algebra system together with classic regression and powerful numerical methods.
5) Eureqa's most frequent and notable successes will probably continue to be with noisy experimental data, but Eureqa shows promise for purposes (1) and (2) above.
6) Some of the most extreme press praise is poetic license sound bites, but symbolic regression deserves a place in the tool kits of many mathematicians, engineers, and scientists.

Acknowledgments

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Graph Theory and Sports Scheduling

Richard Hoshino and Ken-ichi Kawarabayashi

Introduction

The effects of global warming have been well documented, especially in recent years. As a result, the majority of countries have made a commitment to reducing their greenhouse gas emissions, including many whose national governments have made ambitious and unrealistic promises. Meeting these targets will require a coordinated effort from policymakers, businesses, and large industries, and numerous creative solutions will need to be implemented to achieve the desired goal. One potential solution is based on discrete mathematics, where combinatorial and graph-theoretic techniques are applied to scheduling optimization, leading to economic and environmental benefits.

There are many practical roles for mathematically optimal schedules that reduce total travel distance, including supply-chain logistics and airplane flight assignments. In this paper we describe how to optimize the regular-season schedule for Nippon Professional Baseball (NPB), Japan's most popular professional sports league, with annual revenues topping one billion U.S. dollars.

Given the authors' background as graph theorists, this research was motivated by the innocent question of whether NPB scheduling could be converted into a much simpler shortest-path problem. As we describe in this paper, the answer to this question is affirmative. Consequently, we have succeeded in generating the distance-optimal NPB regular-season schedule which retains all of the league's constraints that ensure competitive balance while reducing the total travel distance by 24.3%, or nearly 70,000 kilometers, as compared to the 2010 season schedule.

To solve the NPB scheduling problem, we have generalized and extended the Traveling Tournament Problem (TTP), a well-known topic in sports scheduling [10]. Our research has produced five papers, [4], [5], [6], [7], [8], describing the theoretical aspects of the problem, providing various heuristics for generating distance-optimal intra-league and inter-league schedules, and applying the results to optimize the NPB league schedule.

Shortly after introducing the Traveling Tournament Problem [2], Easton et al. formed a consulting company to develop schedules for professional sports leagues. Their company, the Sports Scheduling Group, has received the contract to produce the regular-season schedule for Major League Baseball in six of the past seven years. Having now completed all of our research on NPB scheduling, our hope is to obtain the contract to produce future NPB regular-season schedules. We are excited by the possibility of sharing our expertise and passion with Nippon Professional Baseball, working in partnership with the league to produce schedules that save money and reduce greenhouse gas emissions, thus making an important contribution to Japan, both economically and environmentally.

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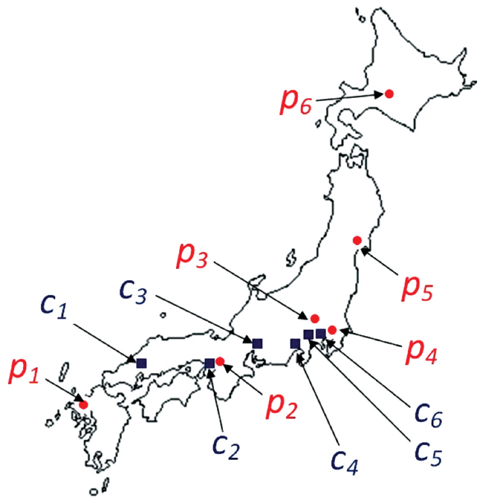

Figure 1. Location of the twelve teams in the NPB.

Summary of Results

Nippon Professional Baseball is split into the six-team Pacific League and the six-team Central League. Each team plays 144 games during the regular season, with 120 *intra*-league games (against teams from their own league) and 24 *inter*-league games (against teams from the other league).

The location of each team's home stadium is given in Figure 1. For readability, we label each team as follows: the Pacific League teams are p_1 (Fukuoka), p_2 (Orix), p_3 (Saitama), p_4 (Chiba), p_5 (Tohoku), and p_6 (Hokkaido); and the Central League teams are c_1 (Hiroshima), c_2 (Hanshin), c_3 (Chunichi), c_4 (Yokohama), c_5 (Yomiuri), and c_6 (Yakult).

Specifically, each NPB team plays twelve home games and twelve away games against each of the other five teams in its league (24×5), in addition to two home games and two away games against all six teams in the other league (4×6). All twenty-four inter-league games take place during a common five-week stretch beginning in mid-May, right near the start of the season.

As in Major League Baseball, nearly all NPB games occur in sets of three games. Thus, we will adopt the same structure when building our distance-optimal schedule. For intra-league play, we have constructed a schedule where each team plays 40 sets of three games, with each team having an opponent in every time slot. (Similarly, for inter-league play, each team plays 12 sets of two games.)

For each team, we define a *trip* to be any pair of consecutive sets not occurring in the same venue, i.e., any situation where a team has to travel from one venue to another to play its next set of games. In Table 1 we list the total distance traveled by all teams under our mathematically optimal schedule, comparing that to the actual distance traveled by the teams during the 2010 season (not including games rescheduled due to weather). We also provide statistics for the number of total trips taken by the teams. Our optimal schedule reduces total distance by nearly 70,000 kilometers.

In this paper we present our analysis for the NPB *intra-league* problem. (We refer the reader to [8] for a detailed analysis of the *inter-league* problem.) In the following section we present the *Multi-Round Balanced Traveling Tournament Problem*, which generalizes the TTP and precisely models the scheduling parameters of the NPB. We then present our shortest-path reformulation and apply it to produce distance-optimal intra-league schedules for the Pacific and Central Leagues.

	Distance (2010)	Distance (Optimal)	Reduction in Distance	Trips (2010)	Trips (Optimal)	Reduction in Trips
Intra-League (PL)	153,940	114,169	25.8 %	208	169	18.8 %
Intra-League (CL)	79,067	57,836	26.8 %	199	170	14.6 %
Inter-League	51,134	42,950	16.0 %	108	101	6.5 %
Total	284,141	214,955	24.3 %	515	440	14.6 %

Table 1. The distance-optimal NPB schedule versus the actual 2010 regular-season schedule.

The Multi-Round Balanced Traveling Tournament Problem

Consider the intra-league schedule given in Table 2, which consists of $n = 6$ teams each playing $k = 4$ *blocks* of ten *sets*. Each block consists of two *rounds*, with each round having $n - 1 = 5$ sets. Thus, each team plays a total of $k(2n-2) = 40$ sets. In this schedule,[1] as with all subsequent schedules presented in this paper, home sets are marked in red.

Let n and k be positive integers. Let D be the $n \times n$ *distance matrix*, where entry $D_{i,j}$ is the distance between the home stadiums of teams i and j. By definition, $D_{i,j} = D_{j,i}$ for all $1 \leq i, j \leq n$, and all diagonal entries $D_{i,i}$ are zero.

For any pair (n, k) and distance matrix D, the solution to the *Multi-Round Balanced Traveling Tournament Problem* (mb-TTP) is an intra-league tournament schedule that minimizes the total distance traveled by all n teams, subject to the following conditions:

(a) The *compactness* condition: The tournament lasts $k(2n - 2)$ sets, i.e., $2k$ rounds, where each team has one set scheduled in each time slot. (Thus n must be even.)

(b) The *each-round* condition: Each pair of teams must play exactly once per round, with their matches in rounds $2t - 1$ and

[1] *For example, team p_1 starts by playing a home set against p_2, followed by three consecutive road sets against p_5, p_3, p_4, then returning home to play three consecutive home sets against p_6, p_3, p_4, and so on.*

Team	R1	R2	R3	R4	R5	R6	R7	R8
p_1	$\mathbf{p}_2 p_5 p_3 p_4 \mathbf{p}_6$	$\mathbf{p}_3 \mathbf{p}_4 p_6 p_2 \mathbf{p}_5$	$\mathbf{p}_2 \mathbf{p}_4 p_6 p_5 p_3$	$\mathbf{p}_6 \mathbf{p}_5 \mathbf{p}_3 p_2 p_4$	$p_2 \mathbf{p}_3 \mathbf{p}_4 p_5 p_6$	$p_4 \mathbf{p}_5 \mathbf{p}_6 \mathbf{p}_2 p_3$	$p_6 p_2 \mathbf{p}_3 \mathbf{p}_5 \mathbf{p}_4$	$p_3 p_5 p_4 \mathbf{p}_6 \mathbf{p}_2$
p_2	$p_1 \mathbf{p}_3 \mathbf{p}_6 \mathbf{p}_5 p_4$	$p_6 p_5 \mathbf{p}_4 \mathbf{p}_1 p_3$	$p_1 \mathbf{p}_3 \mathbf{p}_4 p_6 p_5$	$p_4 \mathbf{p}_6 \mathbf{p}_5 \mathbf{p}_1 p_3$	$\mathbf{p}_1 \mathbf{p}_4 p_5 p_6 p_3$	$\mathbf{p}_5 \mathbf{p}_6 \mathbf{p}_3 p_1 p_4$	$p_3 \mathbf{p}_1 \mathbf{p}_5 \mathbf{p}_4 p_6$	$p_5 p_4 \mathbf{p}_6 \mathbf{p}_3 p_1$
p_3	$p_4 p_2 \mathbf{p}_1 \mathbf{p}_6 \mathbf{p}_5$	$p_1 p_6 p_5 \mathbf{p}_4 \mathbf{p}_2$	$\mathbf{p}_6 p_2 p_5 \mathbf{p}_4 \mathbf{p}_1$	$\mathbf{p}_5 p_4 p_1 p_1 \mathbf{p}_2$	$\mathbf{p}_5 p_1 p_6 p_4 \mathbf{p}_2$	$\mathbf{p}_6 \mathbf{p}_4 p_2 p_5 \mathbf{p}_1$	$\mathbf{p}_2 p_4 p_1 \mathbf{p}_6 \mathbf{p}_5$	$\mathbf{p}_1 p_6 p_5 p_2 \mathbf{p}_4$
p_4	$\mathbf{p}_3 p_6 p_5 \mathbf{p}_1 \mathbf{p}_2$	$\mathbf{p}_5 p_1 p_2 p_3 \mathbf{p}_6$	$\mathbf{p}_5 p_1 p_2 p_3 \mathbf{p}_6$	$\mathbf{p}_2 \mathbf{p}_3 p_6 p_5 \mathbf{p}_1$	$\mathbf{p}_6 p_2 p_1 \mathbf{p}_3 \mathbf{p}_5$	$\mathbf{p}_1 p_3 p_5 p_6 \mathbf{p}_2$	$p_5 \mathbf{p}_3 \mathbf{p}_6 p_3 p_1$	$p_6 \mathbf{p}_2 \mathbf{p}_1 \mathbf{p}_5 p_3$
p_5	$p_6 \mathbf{p}_1 \mathbf{p}_4 p_2 p_3$	$p_4 \mathbf{p}_2 \mathbf{p}_3 \mathbf{p}_6 p_1$	$p_4 p_6 \mathbf{p}_3 \mathbf{p}_1 \mathbf{p}_2$	$p_3 p_1 p_2 \mathbf{p}_4 \mathbf{p}_6$	$p_3 \mathbf{p}_6 \mathbf{p}_2 \mathbf{p}_1 p_4$	$p_2 p_1 \mathbf{p}_4 \mathbf{p}_3 p_6$	$\mathbf{p}_4 \mathbf{p}_6 p_2 p_1 p_3$	$\mathbf{p}_2 \mathbf{p}_1 p_3 p_4 p_6$
p_6	$\mathbf{p}_5 \mathbf{p}_4 p_2 p_3 p_1$	$\mathbf{p}_2 \mathbf{p}_3 \mathbf{p}_1 p_5 p_4$	$p_3 \mathbf{p}_5 \mathbf{p}_1 \mathbf{p}_2 p_4$	$p_1 p_2 \mathbf{p}_4 \mathbf{p}_3 p_5$	$p_4 p_5 \mathbf{p}_3 \mathbf{p}_2 \mathbf{p}_1$	$p_3 p_2 p_1 \mathbf{p}_4 \mathbf{p}_5$	$\mathbf{p}_1 p_5 p_4 p_3 \mathbf{p}_2$	$\mathbf{p}_4 \mathbf{p}_3 p_2 p_1 \mathbf{p}_5$

Table 2. A 40-set (120-game) intra-league schedule for the NPB Pacific League.

$2t$ taking place at different venues (for all $1 \le t \le k$).

(c) The *at-most-three* condition: No team may have a home stand or road trip lasting more than three sets.

(d) The *no-repeat* condition: A team cannot play against the same opponent in two consecutive sets.

(e) The *diff-two* condition: Let $H_{i,s}$ and $R_{i,s}$ be the number of home and away sets played by team i within the first s sets. Then $|H_{i,s} - R_{i,s}| \le 2$ for all (i, s) with $1 \le i \le n$ and $1 \le s \le k(2n-2)$.

For example, one can quickly verify that Table 2 satisfies all five conditions. When calculating the total distance, we will assume that each team begins the tournament at home and returns home after having played their last away set. Furthermore, when a team is scheduled for a road trip consisting of multiple away sets, the team doesn't return to their home city but rather proceeds directly to their next away venue.[2] The mb-TTP is an extension of the well-known NP-hard Traveling Salesman Problem, asking for an optimal schedule linking venues that are close to one another.

We now present an algorithm for solving the mb-TTP, for any $k \ge 1$, by reformulating it as a shortest-path problem on a directed graph. We will create a source node and a sink node and link them to numerous vertices in a graph whose (weighted) edges represent the possible blocks that can appear in an optimal schedule. We then apply Dijkstra's Algorithm [1] to find the path of minimum weight between the source and the sink, which is an $O(|V| \log |V| + |E|)$ graph search algorithm that can be applied to any graph or digraph with nonnegative edge weights.

Shortest-Path Reformulation

By definition, a *block* is a two-round tournament schedule satisfying the conditions of the mb-TTP, with each of the n teams playing $2(n-1)$ sets of games. To solve the mb-TTP, we first compute the set of blocks that can appear in a distance-optimal tournament. We then introduce a simple "concatenation matrix" to check whether two pre-computed blocks can be joined together to form a multiblock schedule without violating any of the five conditions of the mb-TTP. As we will explain, to determine whether two (feasible) blocks B_1 and B_2 can be concatenated, it suffices to check just the last two columns of B_1 and the first two columns of B_2.

Each column of a block represents a set consisting of $\frac{n}{2}$ different *matches*, with each match specifying the two teams as well as the stadium/venue. Thus, a match identifies the home team and away team, not just each team's opponent. For any column, there are $\binom{n}{n/2}$ ways to select the home teams. Also, there are $\binom{n}{n/2} \cdot \left(\frac{n}{2}\right)!$ ways to specify the matches of any column, since there are $\left(\frac{n}{2}\right)!$ ways to map any choice of the $\frac{n}{2}$ home teams to the unselected $\frac{n}{2}$ away teams to decide the set of $\frac{n}{2}$ matches. Hence, there are $m = \binom{n}{n/2}^2 \cdot \left(\frac{n}{2}\right)!$ different ways we can specify the matches of the first column *and* the home teams of the second column. For $n = 6$, we have $m = \binom{6}{3}^2 \times 3! = 2400$.

There are m ways that the first two columns of a block can be chosen as described above, with the first column listing matches and the second column listing home teams. Now use any method, such as a lexicographic ordering, to index these m options with the integers from 1 to m. By symmetry, there are m different ways we can specify the last two columns of a block, with the last column listing matches and the second-to-last column listing home teams. Thus, we use the same scheme to index these m options. To avoid confusion, we write the home teams column in binary form, with 1 representing a home game and 0 representing an away game.

[2] *Thus, after the first block of ten sets, team p_1 will have traveled a total distance of* $D_{p_1,p_5} + D_{p_5,p_3} + D_{p_3,p_4} + D_{p_4,p_1} + D_{p_1,p_6} + D_{p_6,p_2} + D_{p_2,p_1}$.

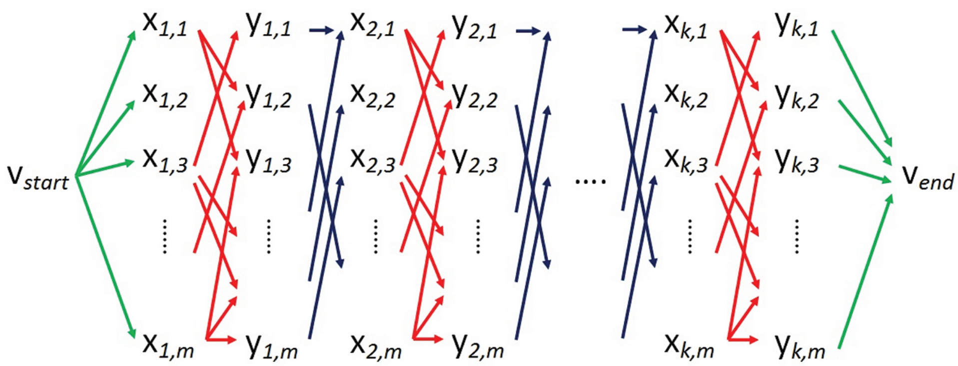

Figure 2. Reformulation of the *k*-block mb-TTP as a shortest-path problem.

For example, $(p_5, p_3, p_2, p_6, p_1, p_4)^T$ is one of the 120 possibilities for the matches column, and $(0, \mathbf{1}, \mathbf{1}, 0, \mathbf{1}, 0)^T$ is one of the 20 possibilities for the home teams column. We remark that if we listed the column of *opponents* rather than the column of matches, there would be only $\frac{120}{2^3} = 15$ unique columns, corresponding to the 15 perfect matchings of the complete graph K_6.

For the NPB Pacific League, there exists some integer q (with $1 \leq q \leq 2400$) that is the index of the instance where the home teams column is $(0, \mathbf{1}, \mathbf{1}, 0, \mathbf{1}, 0)^T$ and the matches column is $(p_5, p_3, p_2, p_6, p_1, p_4)^T$. Similarly, there exists some r (with $1 \leq r \leq 2400$) that is the index of the instance where the two columns are $(p_2, p_1, p_6, p_5, p_4, p_3)^T$ and $(\mathbf{1}, \mathbf{1}, 0, 0, 0, \mathbf{1})^T$. In Table 2 the last two columns of block 1 have index q and the first two columns of block 2 have index r.

For each pair (u_1, u_2), with $1 \leq u_1, u_2 \leq m$, define C_{u_2,u_1} to be the $n \times 4$ *concatenation matrix* where the first two columns list the home teams and matches with index u_2, and the next two columns list the matches and home teams with index u_1. For the indices x and y from the previous paragraph, we have

$$C_{q,r} = \begin{bmatrix} 0 & p_5 & p_2 & \mathbf{1} \\ \mathbf{1} & p_3 & p_1 & \mathbf{1} \\ \mathbf{1} & p_2 & p_6 & 0 \\ 0 & p_6 & p_5 & 0 \\ \mathbf{1} & p_1 & p_4 & 0 \\ 0 & p_4 & p_3 & \mathbf{1} \end{bmatrix}$$

Note that $C_{q,r}$ has no row with four home sets, no row with four away sets, and no row with the same opponent appearing in columns 2 and 3. As we describe in Theorem 1, these three properties are a necessary and sufficient condition for whether two feasible blocks can be concatenated to produce a multiblock schedule satisfying the conditions of the mb-TTP.

Before we proceed with Theorem 1, let us explain the role of m and C_{u_2,u_1} in the construction of our directed graph. Let G consist of a source vertex v_{start}, a sink vertex v_{end}, and vertices $x_{t,u}$ and $y_{t,u}$ defined for each $1 \leq t \leq k$ and $1 \leq u \leq m$.

We now describe how these edges are connected with a pictorial representation of G in Figure 2. For notational simplicity, denote $v_1 \to v_2$ as the directed edge from v_1 to v_2.

(i) For each $1 \leq u \leq m$, add the edge $v_{start} \to x_{1,u}$.
(ii) For each $1 \leq u \leq m$, add the edge $y_{k,u} \to v_{end}$.
(iii) For each $1 \leq t \leq k$ and for each $1 \leq u_1, u_2 \leq m$, add the edge $x_{t,u_1} \to y_{t,u_2}$ iff there exists a (feasible) block for which the first two columns have index u_1 and the last two columns have index u_2.
(iv) For each $1 \leq t \leq k-1$ and for each $1 \leq u_1, u_2 \leq m$, add the edge $y_{t,u_2} \to x_{t+1,u_1}$ iff the concatenation matrix C_{u_2,u_1} has no row with four home sets, no row with four away sets, and no row with the same opponent appearing in columns 2 and 3.

The following theorem [4] shows that the k-block mb-TTP can be reformulated in a graph-theoretic context for any $k \geq 1$.

Theorem 1. *Every feasible solution of the mb-TTP can be described by a path from v_{start} to v_{end} in graph G. Conversely, any path from v_{start} to v_{end} in G corresponds to a feasible solution of the mb-TTP.*

Having constructed our digraph, we now assign a *weight* to each edge using the distance matrix D so that the shortest path (i.e., path of minimum total weight) from v_{start} to v_{end} corresponds to the optimal solution of the mb-TTP that minimizes the total distance traveled by the n teams.

For any block, we define its *in-distance* to be the total distance traveled by the n teams within that block, i.e., starting from set 1 and ending at set $2(n-1)$. Note that the in-distance does not include the distance traveled by the teams heading *to* the venue of set 1 or *from* the venue of set $2(n-1)$. We will use this definition in part (c) below:

Team	R1	R2	R3	R4	R5	R6	R7	R8
c_1	$\mathbf{c}_2\mathbf{c}_5c_4c_6c_3$	$\mathbf{c}_4\mathbf{c}_6\mathbf{c}_3c_2c_5$	$c_3\mathbf{c}_2\mathbf{c}_5\mathbf{c}_6c_4$	$c_5c_6\mathbf{c}_4\mathbf{c}_3c_2$	$c_4c_2\mathbf{c}_3\mathbf{c}_6\mathbf{c}_5$	$c_3c_6c_5\mathbf{c}_4\mathbf{c}_2$	$c_4c_2\mathbf{c}_3\mathbf{c}_6\mathbf{c}_5$	$c_3c_6c_5\mathbf{c}_4\mathbf{c}_2$
c_2	$c_1\mathbf{c}_3\mathbf{c}_5c_4c_6$	$c_5\mathbf{c}_4\mathbf{c}_6\mathbf{c}_1c_3$	$c_4c_1\mathbf{c}_3\mathbf{c}_5\mathbf{c}_6$	$c_3c_5c_6\mathbf{c}_4\mathbf{c}_1$	$c_3\mathbf{c}_1\mathbf{c}_6\mathbf{c}_5c_4$	$c_6c_5\mathbf{c}_4\mathbf{c}_3c_1$	$c_3\mathbf{c}_1\mathbf{c}_6\mathbf{c}_5c_4$	$c_6c_5\mathbf{c}_4\mathbf{c}_3c_1$
c_3	$\mathbf{c}_4c_2c_6c_5\mathbf{c}_1$	$\mathbf{c}_6\mathbf{c}_5c_1c_4\mathbf{c}_2$	$\mathbf{c}_1c_6c_2c_4\mathbf{c}_5$	$\mathbf{c}_2\mathbf{c}_4c_5c_1c_6$	$\mathbf{c}_2c_5c_1\mathbf{c}_4\mathbf{c}_6$	$\mathbf{c}_1c_4c_6c_2\mathbf{c}_5$	$\mathbf{c}_2c_5c_1\mathbf{c}_4\mathbf{c}_6$	$\mathbf{c}_1c_4c_6c_2\mathbf{c}_5$
c_4	$c_3\mathbf{c}_6\mathbf{c}_1\mathbf{c}_2c_5$	$c_1c_2\mathbf{c}_5\mathbf{c}_3c_6$	$\mathbf{c}_2c_5c_6\mathbf{c}_3\mathbf{c}_1$	$\mathbf{c}_6c_3c_1c_2\mathbf{c}_5$	$\mathbf{c}_1c_6c_5c_3\mathbf{c}_2$	$\mathbf{c}_5\mathbf{c}_3c_2c_1\mathbf{c}_6$	$\mathbf{c}_1c_6c_5c_3\mathbf{c}_2$	$\mathbf{c}_5\mathbf{c}_3c_2c_1\mathbf{c}_6$
c_5	$\mathbf{c}_6c_1c_2\mathbf{c}_3\mathbf{c}_4$	$\mathbf{c}_2c_3c_4c_6\mathbf{c}_1$	$\mathbf{c}_6\mathbf{c}_4c_1c_2c_3$	$\mathbf{c}_1\mathbf{c}_2\mathbf{c}_3c_6c_4$	$c_6\mathbf{c}_3\mathbf{c}_4c_2c_1$	$c_4\mathbf{c}_2\mathbf{c}_1\mathbf{c}_6c_3$	$c_6\mathbf{c}_3\mathbf{c}_4c_2c_1$	$c_4\mathbf{c}_2\mathbf{c}_1\mathbf{c}_6c_3$
c_6	$c_5c_4\mathbf{c}_3\mathbf{c}_1\mathbf{c}_2$	$c_3c_1c_2\mathbf{c}_5\mathbf{c}_4$	$c_5\mathbf{c}_3\mathbf{c}_4c_1c_2$	$c_4\mathbf{c}_1\mathbf{c}_2\mathbf{c}_5c_3$	$\mathbf{c}_5\mathbf{c}_4c_2c_1c_3$	$\mathbf{c}_2\mathbf{c}_1\mathbf{c}_3c_5c_4$	$\mathbf{c}_5\mathbf{c}_4c_2c_1c_3$	$\mathbf{c}_2\mathbf{c}_1\mathbf{c}_3c_5c_4$

Table 3. The distance-optimal intra-league schedule for the NPB Central League.

	Distance (2010)	Distance (Optimal)	Reduction in Distance	Trips (2010)	Trips (Optimal)	Reduction in Trips
p_1	33352	21143	36.6 %	35	27	22.9 %
p_2	24128	18713	22.4 %	34	29	14.7 %
p_3	20885	19498	6.6 %	34	28	17.6 %
p_4	23266	16606	28.6 %	36	29	19.4 %
p_5	23710	17975	24.2 %	37	29	21.6 %
p_6	28599	20234	29.2 %	32	27	15.6 %
Total	153940	114169	25.8 %	208	169	18.8 %

Table 4. Comparison of intra-league schedules for the Pacific League.

(a) For each $1 \le u \le m$, the weight of edge $v_{start} \to x_{1,u}$ is the total distance traveled by the $\frac{n}{2}$ teams making the trip from their home city to the venue of their opponent in set 1.

(b) For each $1 \le u \le m$, the weight of edge $y_{k,u} \to v_{end}$ is the total distance traveled by the $\frac{n}{2}$ teams making the trip from the venue of their opponent in set $2k(n-1)$ back to their home city.

(c) For each $1 \le t \le k$, and for each $1 \le u_1, u_2 \le m$, the weight of edge $x_{t,u_1} \to y_{t,u_2}$ is the *minimum* in-distance of a block, selected among all blocks for which the first two columns have index u_1 and the last two columns have index u_2.

(d) For each $1 \le t \le k-1$ and for each $1 \le u_1, u_2 \le m$, the weight of edge $y_{t,u_2} \to x_{t+1,u_1}$ is the total distance traveled by the teams that travel from their match in set $2t(n-1)$ to their match in set $2t(n-1)+1$, where the last two columns of the t^{th} block have index u_2 and the first two columns of the $(t+1)^{\text{th}}$ block have index u_1.

To illustrate (d), consider the first two blocks in Table 2, where the last two columns of block 1 have index q and the first two columns of block 2 have index r. When we concatenate these two blocks, the weight of edge $y_{1,q} \to x_{2,r}$ is the total distance traveled by the teams from their matches in set 10 to their matches in set 11. This sum equals $D_{p_3,p_1} + D_{p_1,p_4} + D_{p_4,p_3}$, the distances traveled by teams p_2, p_5, and p_6, respectively.

By this construction, we have produced a weighted digraph. In part (c), suppose there exist two blocks B and B' for which the first two columns have index u_1 and the last two columns have index u_2. If the in-distance of B is less than the in-distance of B', then block B' cannot be a block in an optimal solution, since we can just replace B' by B to create a feasible solution with a lower objective value. This trivial observation, based on Bellman's Principle of Optimality, allows us to assign the *minimum* in-distance as the weight of edge $x_{t,u_1} \to y_{t,u_2}$, for all $1 \le u_1, u_2 \le m$. As a result, we have a digraph G on $2mk+2$ vertices and at most $2m + (2k-1)m^2$ edges, with a unique weight for each edge. Combined with the previous theorem, we have established the following.

Theorem 2. *Let $P = v_{start} \to x_{1,p_1} \to y_{1,q_1} \to x_{2,p_2} \to y_{2,q_2} \to \cdots \to x_{k,p_k} \to y_{k,q_k} \to v_{end}$ be a shortest path in G from v_{start} to v_{end}, i.e., a path that minimizes the total weight. For each $1 \le t \le k$, let B_t be the block of minimum in-distance selected among all blocks for which the first two columns have index p_t and the last two columns have index q_t. Then the multiblock schedule $S = B_1, B_2, \ldots, B_k$, created by concatenating the k blocks consecutively, is an optimal solution of the mb-TTP.*

Application to the NPB

Therefore, we have shown that the mb-TTP is isomorphic to finding the shortest weighted path in the directed graph G. For the case $n = 6$, we can show that G consists of $4800k + 2$ vertices and $2400 + 2400 + 2618520k + 1486320(k-1) = 4104840k - 1481520$ edges. Given the distance matrices for the NPB Pacific and Central Leagues, we can determine the appropriate weights for each edge in G to determine the shortest path from v_{start} to v_{end} using Dijkstra's Algorithm, which in turn generates the distance-optimal schedule. We wrote our code using Maplesoft; for each league, Maplesoft produced the distance-optimal intra-league schedule after five hours of computation time. The large majority of the running time was spent determining the correct edge weight for part (c) of our construction. For more information, we refer the reader to [7].

The optimal Pacific League intra-league schedule appears in Table 2; the optimal Central League intra-league schedule appears in Table 3.

In Table 1 we produced an overall summary of the results. In Table 4 we provide a team-by-team breakdown for the NPB Pacific League, comparing our distance-optimal schedule to the actual schedule played by the teams during the 2010 regular season.

In addition to the significant 25.8% reduction in total distance traveled, we also remark that this is a more equitable schedule. In the 2010 NPB intra-league schedule, team p_1 traveled nearly $12,500$ kilometers more than team p_3. Under our schedule, the difference between the most traveled and least traveled would reduce to just $4,500$ kilometers. For the Central League, the difference between the most traveled and least traveled would reduce from $7,500$ kilometers to just $4,000$ kilometers.

Implementation

Naturally, there are additional factors involved with the actual scheduling of NPB games at these home stadiums. For example, one of the ballparks hosts a three-day concert each August, and another ballpark is used as the locale of the national high school baseball tournament. Hence those teams must play away games on those particular days. In many sports leagues, rival teams play "derby matches" that need to be scheduled on particular days to optimize revenue and that are often dictated by the wishes of television broadcasters to add drama and boost TV ratings. These constraints must be taken into account when producing an optimal schedule that can be implemented by NPB to ensure no conflicts occur and that the schedule is the best possible for all parties involved.

Epilogue

After the publication of our initial results, the Nippon Professional Baseball (NPB) League invited us (the authors) to visit their head office. Over the course of three meetings in September 2012, we consulted the NPB and helped them design the Central League's 2013 intra-league schedule [3].

When we met with the NPB head scheduler, we learned that the league has additional scheduling constraints, such as the "revenue-balancing" requirement that each team play the same number of weekend home games, weekday home games, weekend road games, and weekday road games. In [9], we describe how we fully solved this TTP-variant for the case $n = 6$, and helped the NPB design the intra-league schedule for the 2013 Central League, reducing the number of total trips by 12 and cutting over six thousand kilometers of total travel distance, as compared to the schedule from the previous season.

We look forward to partnering with the NPB once again, and hope to have the opportunity to help this league produce future regular-season schedules that will result in annual win-wins for the people of Japan, both economically and environmentally.

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Rubik's for Cryptographers

Christophe Petit and Jean-Jacques Quisquater

Presumably hard mathematical problems stand at the core of modern cryptography. A typical security proof for a cryptographic protocol relates its resistance against a particular attack to the hardness of some mathematical problem. Very few problems have survived thorough cryptanalysis, the most established ones being the integer factorization problem and the discrete logarithm problems on finite fields and elliptic curves. Other problems have been suggested, related, for example, to hyperelliptic curves, lattices [42], error-correcting codes [31], or multivariate polynomial equations [35] (the so-called postquantum cryptographic algorithms). They are currently less trusted than the three previous ones, but they might join or replace them in the future.

In this paper we discuss three alternative computational problems: namely the *balance, representation, and factorization problems in finite non-Abelian groups*. Interestingly, these problems can be seen as generalizations of the Rubik's Cube. The famous 3D puzzle is notoriously "hard" [12], but of course not in a cryptographic sense. Computer programs solve it instantaneously, and even human champions need less than ten seconds. Nevertheless, the "extensions" considered in this paper were proposed as the core computational problems underlying the security of *Cayley hash functions*, an elegant construction of a very important cryptographic primitive.

For the cryptographic applications to be secure, the balance, representation, and factorization problems must be computationally hard. These problems are of course easy for the Rubik's Cube. They are also easy in a few other particular cases, but they may still be hard in general. In fact, they are strongly connected to famous problems in group theory and can be seen as algorithmic versions of a twenty-year-old conjecture of Babai on the diameters of Cayley graphs. Although the conjecture is now proved for all parameters of interest in cryptography, many of the proofs are nonconstructive, hence useless, to "break" the functions.

In the last twenty years, the cryptography community (for Cayley hash functions) and the mathematics community (for Babai's conjecture) have been working independently on very similar problems. The goal of this paper is to bridge the results obtained by the two communities, with the cryptographic application in mind. In particular, we review known results coming from both sides, we provide some general attacks and design principles for the Cayley hash function construction, and finally we propose some parameters that can be considered as "safe" from our current knowledge of these problems.

Notation. In this paper, p will always be a prime and n a positive integer. We write $\mathbb{F}_q$ for the finite field with q elements. We identify the finite field $\mathbb{F}_{p^n}$ with $\mathbb{F}_p[X]/(q(X))$, where q is an irreducible polynomial over $\mathbb{F}_p$. If K is a finite field and m is a positive integer, we write $SL(m, K)$ for the special linear group of degree m over K, in other words, the group of m-by-m matrices over K with determinant 1. We write $PSL(m, K)$ for the projective special linear group of degree m over K, which is the quotient of $SL(m, K)$ by the set $\{\lambda I, \lambda \in K\}$. Finally, we write S_n for the group of permutations on n elements.

Outline. The remainder of this paper is organized as follows. In the first section we recall the Cayley

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hash function construction and its main advantages over other cryptographic hash functions. In the second section we define the balance, representation, and factorization problems and show their connection with the security of Cayley hash functions, Babai's conjecture, and the Rubik's Cube. In the third section we describe general methods to solve these problems in particular cases, and we provide particular parameters that appear as a cryptographic challenge today. We conclude the paper in the fourth and final section.

Cayley Hash Functions

In this section we first recall the definition and the main properties of cryptographic hash functions, a very important cryptographic primitive. We then recall the definition of Cayley hash functions, an interesting family of hash functions based on non-Abelian groups.

Cryptographic Hash Functions

Hash functions are a fundamental building block in cryptographic protocols, in particular in digital signature schemes and message authentication codes. A *hash function* is a function that takes as inputs bitstrings of arbitrary length and then returns bitstrings of fixed finite small length. Additionally, the function is typically required to be collision resistant, second preimage resistant, and preimage resistant.

Definition 1. Let $n \in \mathbb{N}$ and let $H : \{0,1\}^* \to \{0,1\}^n : m \to h = H(m)$. The function H is said to be [32]:

- **collision resistant** if it is "computationally hard" to find $m, m' \in \{0,1\}^*$, $m' \neq m$, such that $H(m) = H(m')$;
- **second preimage resistant** if, given $m \in \{0,1\}^*$, it is "computationally hard" to find $m' \in \{0,1\}^*$, $m' \neq m$, such that $H(m) = H(m')$;
- **preimage resistant** if, given $h \in \{0,1\}^n$, it is "computationally hard" to find $m \in \{0,1\}^*$ such that $h = H(m)$.

In cryptographic protocols, the output of a hash function is often used as a small digest of its input aimed to represent this input uniquely. Since hash functions are not injective, this "uniqueness" is of course only "computational". The words "computationally hard" can be understood in two different ways. From a theoretical point of view, it means that no probabilistic algorithm that runs in polynomial time in n can succeed in performing the task for large values of the parameter n with a probability larger than the inverse of some polynomial function of n [17]. On the other hand, from a practical point of view, "computationally hard" means that no big cluster of computers can perform a given task. A computational complexity of 2^{80} operations is currently considered out of reach [16].

Classical hash functions like the NIST's standard hash algorithms [34] mix pieces of the message again and again until the result looks sufficiently random. The design of these functions may somehow look like a sack of nodes that may discourage its study outside the cryptography community. In contrast, Cayley hash functions have a clear, simple, and elegant mathematical design.

A Construction Based on Cayley Graphs

Given a (multiplicative) group G and a subset $S = \{s_1, \ldots, s_k\}$ thereof, their *Cayley graph* is a k-regular graph that has one vertex for each element of G and one edge between two vertices v_1 and v_2 if and only if the corresponding group elements g_{v_1}, g_{v_2} satisfy $g_{v_2} = g_{v_1} s_i$ for some $s_i \in S$. We can build a hash function from this graph as follows. The message m is first written as a string $m = m_1 \ldots m_N$ where $m_i \in \{1, \ldots, k\}$. Then the group product

$$h = s_{m_1} s_{m_2} \ldots s_{m_N}$$

is computed and mapped onto a bitstring. A hash function constructed in this way is called a *Cayley hash function*. The initial and final transformations do not influence the security. In the rest of the paper, we will consider hash functions as functions from $\{1, \ldots, k\}^*$ to G.

The computation of a hash value amounts to a walk in the corresponding Cayley graph. To make the computation more efficient, the four Cayley hash functions proposed in the literature use the matrix groups $SL(2, K)$ or $PSL(2, K)$, where K is either $\mathbb{F}_p$ or $\mathbb{F}_{2^n}$ [48], [45], [9], [38]. Cayley hash functions are rather slow for most parameters, but in some contexts they perform better than the standard SHA-1 [11]. One big advantage of Cayley hash functions over classical hash functions is that their computation can be very easily parallelized: large messages can be cut into various pieces distributed to different computing units, and the associativity of the group ensures that the final result can be recovered from all partial products.

As we will see below, the overall security of Cayley hash functions (their collision, second preimage, and preimage resistance) may depend on the group and the generators used. The group structure also induces some properties that may be undesirable in some applications. For example, given the hash value of m and m', it is possible to compute the hash value of $m||m'$. However, additional design components can solve this problem [36].

Balance, Factorization, and Representation Problems

In this section we introduce the mathematical problems at the core of the security of Cayley hash functions. We then link them to famous problems in group theory and with the Rubik's Cube.

Security of Cayley Hash Functions

The collision, second preimage, and preimage properties of Cayley hash functions can easily be translated into group-theoretic problems.

Definition 2. Let $\mathcal{G}$ be a group and let $S = \{s_1, \ldots, s_k\} \subset \mathcal{G}$ be a set generating this group. Let $L \in \mathbb{Z}$ be "small".

- **Balance problem:** Find an "efficient" algorithm that returns two words: $m_1 \ldots m_\ell$ and $m'_1 \ldots m'_{\ell'}$ with $\ell, \ell' < L$, $m_i, m'_i \in \{1, \ldots, k\}$, and $\prod s_{m_i} = \prod s_{m'_i}$.
- **Representation problem:** Find an "efficient" algorithm that returns a word $m_1 \ldots m_\ell$ with $\ell < L$, $m_i \in \{1, \ldots, k\}$, and $\prod s_{m_i} = 1$.
- **Factorization problem:** Find an "efficient" algorithm that, given any element $g \in \mathcal{G}$, returns a word $m_1 \ldots m_\ell$ with $\ell < L$, $m_i \in \{1, \ldots, k\}$, and $\prod s_{m_i} = g$.

Again, the word "small" can be understood in two different ways. Messages larger than a few gigabytes can hardly make sense in practice. On the other hand, from a theoretical point of view, "small" means polylogarithmic in the size of the group, considering a family of groups with increasing sizes. The word "efficient" means the opposite of "computationally hard".

Without the length constraint, the representation problem would be trivial, since $s^{ord(s)} = 1$ for any $s \in \mathcal{G}$. With the stronger requirement of finding a product of *minimal* length, it becomes NP-hard [15], [22]. The factorization problem was described by Lubotzky as a "noncommutative analog of the discrete logarithm problem" [30, p. 102]. Indeed, both the representation and the factorization problems are equivalent to the discrete logarithm problem in Abelian groups if we forbid trivial solutions [6]. On the other hand, the balance problem becomes trivial in Abelian groups.

In general, the factorization problem is at least as hard as the representation problem, which is at least as hard as the balance problem. Clearly, a Cayley hash function is collision resistant if and only if the balance problem is hard, it is second preimage resistant only if the representation problem is hard, and it is preimage resistant if and only if the corresponding factorization problem is hard. Interestingly, the balance, representation, and factorization problems can be seen as constructive versions of old questions and some long-standing open problems in group theory.

Link with Babai's Conjecture

The first question (coming back to Dixon [14]) is the probability that a random set of elements in a finite non-Abelian group generates the whole group. This probability is arbitrarily close to 1 for sets of two elements if the groups are large enough [25], [29]. Given $\mathcal{G}$ and S, it is then natural to ask for the maximal length of all minimal representations of the elements of $\mathcal{G}$ as products of the elements of S. In other words, we are interested in the *diameter* of the corresponding Cayley graph.

This diameter can easily be lower bounded by $\log_{|S|} |\mathcal{G}|$ using the pigeon-hole principle, but it is not known whether the bound is tight in general. A large source of graphs with logarithmic diameter is provided by *expander graphs* [21]. Roughly speaking, an expander graph is a regular graph such that any set of its vertices has a comparatively large set of neighbors. An intense research effort in the last ten years has recently culminated in proving that, for any non-Abelian finite simple group, there exists a symmetric set of generators such that the corresponding Cayley graph is an expander [8]. Expander graphs are very important for computer science, with a wide range of applications.

In general, Cayley graphs are expected to have *polylogarithmic* rather than logarithmic diameters. More precisely, a conjecture made by Babai in the early 1990s states that the diameter of any undirected Cayley graph of a non-Abelian simple group is bounded by a polynomial function in the size of the group [3], [20]. Directed Cayley graphs can be included as well in the conjecture without strengthening it [2].

Interestingly, the factorization problem discussed in this paper can be seen as providing a *constructive* proof of Babai's conjecture. By definition, "small" factorizations exist in Cayley graphs with logarithmic or polylogarithmic diameter, but this does not imply that they can be efficiently computed with a polynomial time algorithm. In this sense, the cryptanalyst's task seems harder than just proving Babai's conjecture. On the other hand, cryptanalysts may not need a constructive proof for *all* parameter sets but only for a large fraction of parameters in some relevant subfamilies.

A "Toy" Example: The Rubik's Cube

We now express the link between the factorization problem and the Rubik's Cube. Let E be the set of all possible configurations of the Rubik's Cube, including configurations obtained by disassembling and reassembling it. The permutation group $\mathcal{G}$

on E acts naturally on the cube: to each $g \in \mathcal{G}$ we can associate the image by g of the initial configuration of the cube. The *Rubik's group* is the subgroup $\mathcal{G}_R$ that is generated by the six elementary rotations of the faces. The Rubik's group has order $|\mathcal{G}_R| = \frac{1}{12} 12!8!3^8 2^{12}$ and is isomorphic to $(\mathbb{Z}_3^7 \times \mathbb{Z}_2^{11}) \rtimes ((A_8 \times A_{12}) \rtimes \mathbb{Z}_2)$, where $\times$ and $\rtimes$ are respectively the direct and semidirect group products [10]. Solving the Rubik's Cube amounts to solving the factorization problem for the group $\mathcal{G}_R$ and the set S containing the six rotations of the faces.

Rubik's for Cryptographers

After twenty years of research on Babai's conjecture, particularly intense after a breakthrough result of Helfgott in 2005 [20], Babai's conjecture has been proved for any generator set of any group of Lie type with a bounded rank [41], [7]. Helfgott and Seress [19] have also obtained a slightly weaker *quasipolynomial* bound for the diameter of permutation groups. However, most of these proofs are nonconstructive. Constructive proofs are available only for the four parameter sets that were proposed for Cayley hash functions, for permutation groups, and for a few "well-chosen" generator sets in other groups. In this section, we briefly survey these results and we conclude with a cryptographic challenge.

General Techniques

The mathematical structure of Cayley hash functions makes them more vulnerable to attacks that would exploit this structure. Two main attack techniques and design principles can be inferred from our experience.

A first important category of attacks is *subgroup attacks*. If $\mathcal{G}$ has a subgroup tower decomposition $\mathcal{G} = \mathcal{G}_0 \supset \mathcal{G}_1 \supset \mathcal{G}_2 \supset \cdots \supset \mathcal{G}_N = \{1\}$ and if $|G_i|/|G_{i+1}|$ is "small" for all i then, given any set $S = \{s_1, \ldots, s_k\}$, the representation problem can be solved as follows. We generate random products of the s_i until we get an element $s_1^{(1)} \in \mathcal{G}_1$, and we repeat the operations until we get a set $S^{(1)} = \{s_1^{(1)}, \ldots, s_{k'}^{(1)}\}$ that can generate all the elements of $\mathcal{G}_2$. We then recursively repeat the procedure, starting from the group $\mathcal{G}_1$ and the set $S^{(1)}$. A representation with the elements of S can be obtained by substitutions. The complexity of this attack is roughly $\max_i |\mathcal{G}_i|/|\mathcal{G}_{i+1}|$, but it can be reduced to $\max_i(|\mathcal{G}_i|/|\mathcal{G}_{i+1}|)^{1/2}$ using a meet-in-the-middle strategy. These attacks can be extended to solve the factorization problem as well, and the condition that all the quotients $|G_i|/|G_{i+1}|$ are "small" can sometimes be replaced by a weaker one.

A simple example of a subgroup attack is the "level-by-level" resolution method for the Rubik's Cube: each level can be associated to the subgroup of the Rubik's group containing all the permutations that preserve the levels solved so far. Since the order of $\mathcal{G}_R$ is very smooth, many other subgroup attacks can be constructed against the Rubik's Cube. A similar idea was used by Dinai [13] for the group $SL(2, \mathbb{Z}/p^k\mathbb{Z})$ which has the subgroup tower $SL(2, \mathbb{Z}/p^k\mathbb{Z}) \supset SL(2, \mathbb{Z}/p^{k-1}\mathbb{Z}) \supset \cdots \supset SL(2, \mathbb{Z}/p\mathbb{Z}) \supset \{I\}$. If p is "small", then the factorization problem can be solved for any generator set of this group. Finally, two subgroup attacks against a Cayley hash function proposed by Tillich and Zémor [45] were provided in [44], [40]. In matrix groups, the orthogonal, triangular, or diagonal subgroups can typically be exploited.

The simplest subgroup attacks can be prevented by choosing the group $\mathcal{G}$ carefully. The minimal requirement is that the cardinalality of $\mathcal{G}$ has a "large" factor, but additional requirements may be needed depending on the group family.

A second very important category of attacks is that of *lifting attacks*. To describe their principle, let us suppose that $\mathcal{G}$ is $SL(2, \mathbb{F}_p)$. There is a natural homomorphism from $SL(2, \mathbb{Z})$ to $SL(2, \mathbb{F}_p)$ given by the "reduction modulo p". A lifting attack for $SL(2, \mathbb{F}_p)$ will "lift" the generators on $SL(2, \mathbb{Z})$ and then try to "lift" the element to be factored on the subgroup of $SL(2, \mathbb{Z})$ generated by the lifts of the generators. Factoring elements in $SL(2, \mathbb{Z})$ is usually easier (when a factorization exists) than in $SL(2, \mathbb{F}_p)$. This is mainly because factorizations are *unique* in infinite groups if the generators are properly chosen, and the elements composing a factorization can then often be recovered one by one. Once a factorization over $SL(2, \mathbb{Z})$ has been obtained, a "reduction modulo p" provides a factorization over $SL(2, \mathbb{F}_p)$. Therefore the hardest part of a lifting attack is typically the lifting part itself.

This part seems "hard" in general, but it is easier when the generators have a special structure. In the first Cayley hash function proposed by Zémor [48] with $\mathcal{G} = SL(2, \mathbb{F}_p)$, the generator set was chosen as $S = \{\left(\begin{smallmatrix}1 & 1\\ 0 & 1\end{smallmatrix}\right), \left(\begin{smallmatrix}1 & 0\\ 1 & 1\end{smallmatrix}\right)\}$ to improve the efficiency of the function. However, these two matrices are so "small" that they generate the whole group $SL(2, \mathbb{Z}_+)$. Factorizations in this infinite group could be easily computed with the help of Euclid's algorithm [47]. Interestingly, all the lifting attacks against Cayley hash functions have used a connection between 2-by-2 matrices of particular forms and the Euclidean algorithm. In the cryptanalysis of LPS and Morgenstern hash functions [9], [38] using the groups $PSL(2, \mathbb{F}_p)$ and $PSL(2, \mathbb{F}_{2^n})$, the natural lifts of the generators did not generate a dense subgroup of their infinite counterparts.

However the generators (chosen in both cases to achieve an optimal output distribution) had natural symmetries that allowed one to reduce the lifting part to the resolution of a quadratic diophantine equation [46], [37], [36]. Finally, the cryptanalysis of the Tillich-Zémor hash function [45] consisted of lifting and factoring special elements of $SL(2, \mathbb{F}_{2^n})$ on $SL(2, \mathbb{F}_2[X])$ and then of combining these elements in $SL(2, \mathbb{F}_{2^n})$. The lifting part crucially needed the fact that the Tillich-Zémor generators had very "small" coefficients in $SL(2, \mathbb{F}_{2^n})$ [18], [39].

Lifting attacks are harder to prevent than subgroup attacks, since they have become more and more sophisticated over the years. However, the attacks have always required special properties of the generators (either "small" or "symmetric") to perform the lifting part itself. In all cases, simple modifications of the generators were proposed to counter the attacks, and these variants have remained unbroken so far.

Particular "Broken" Instances

While cryptographers have been trying to break Cayley hash functions, mathematicians have studied the diameter of Cayley graphs and tried to prove Babai's conjecture. The conjecture has been proved for almost all sets of generators in symmetric and alternating groups by Babai and Hayes [5]. The proof is constructive, hence permutation groups must be avoided in cryptographic applications (see also [23]). For the group $SL(2, \mathbb{F}_{p^n})$, Babai et al. [4] provided a set of 3 generators such that the diameter of the corresponding Cayley graph is $O(\log(p^n))$, together with a constructive algorithm. Kantor [24], Riley [43], and Kassabov and Riley [26] provided factorization algorithms with shorter and shorter lengths for well-chosen couples of elements in $SL(m, \mathbb{F}_p)$ and $SL(m, \mathbb{F}_{p^n})$, $m \geq 3$. More generally, there exists a constant C such that any finite simple non-Abelian group $\mathcal{G}$ has a set S of at most four generators such that every element of $\mathcal{G}$ can be written as a product of elements of $S \cup S^{-1}$ of length smaller than $C \log |\mathcal{G}|$ [1], [26].

A Cryptographic Challenge

Although Cayley hash functions can be broken for permutation groups and for a few specific parameters in other groups, determining their security remains an open problem in general. In particular, essentially nothing is known for "generic" parameters of special linear groups.

Challenge 1. *Solve the balance, representation, or factorization problem for* $G := SL(2, \mathbb{F}_{2^n})$ *and* $S := \left\{ \begin{pmatrix} t_1 & 1 \\ 1 & 0 \end{pmatrix}, \begin{pmatrix} t_2 & 1 \\ 1 & 0 \end{pmatrix} \right\}$*, where* $t_1 := X^3$ *and* $t_2 := X + 1$.

The Tillich-Zémor parameters were equivalent to a similar set with $t_1 := X$ and $t_2 := X + 1$ [47], [18]. Although our set also contains "small" matrices for efficiency reasons, the core ingredient in the cryptanalysis of the Tillich-Zémor hash function (an algorithm of Mesirov and Sweet related to the Euclidean algorithm [33]) does not seem to generalize to our parameters [18], [39] (in particular in the light of Lauder's results on generalizations of Mesirov-Sweet's algorithm [28]).

Conclusion

Cayley hash functions are very appealing to cryptography. They have a simple and elegant design, a nice mathematical structure, and a natural parallelism. However, their main security properties rely on the hardness of mathematical problems that are nonstandard to cryptography. The recent cryptanalysis of all Cayley hash function proposals (Zémor, Tillich-Zémor, LPS, Morgenstern) has cast doubts on the hardness of these mathematical problems in the cryptography community.

In our opinion, these doubts are unjustified or at least premature. The four Cayley hash functions that were broken had parameters that seem particularly weak a posteriori. The cryptanalysis techniques used against these functions cannot be easily applied to other parameters. In particular, small changes in the four functions make them immune against existing attacks. The mathematical problems supporting the security properties of Cayley hash functions have a rich history in mathematics, if not in cryptography. They originate at least in the work of Babai in the late eighties and in particular to its conjecture on the diameter of the Cayley graphs of finite non-Abelian simple groups. The research on these problems has been very active and has involved distinguished mathematicians such as Babai, Bourgain, Gamburd, Green, Helfgott, Kantor, Lubotzky, Tao,…. Nevertheless, with the exception of permutation groups, very few instances have been solved today after twenty years.

The Rubik's Cube is a notoriously hard mechanical puzzle… for humans. The factorization problem in non-Abelian groups is its natural mathematical generalization. If it turns out to be "hard" enough, this problem could be very useful in cryptography. It is also interesting in its own right, intersecting and connecting group theory, graph theory, number theory, combinatorics, the Euclidean algorithm,…. Any new result on secure and unsecure Cayley hash function instances will be beneficial not only to cryptography but also to the numerous applications of Cayley graphs and expander graphs in mathematics and computer science. From a purely cryptographic point of view, the challenge is to find a set of parameters that leads not only to hard problems but also to reasonably efficient implementations.

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About the Cover

Slicing the Antikythera Mechanism

This month's cover was suggested by the review in this issue of the book by Jo Marchant about the Antikythera Mechanism. The images there are a selection from a sequence made by extremely sophisticated technology that in effect depicted slices of the Mechanism without actually taking it apart. They are taken from an original collection of over 2,500. On the Web page

`http://www.antikythera-mechanism.gr/data/ct`

you can see more of the images from this collection, making up a remarkable animation.The images were provided to us by Tony Freeth, one of the group involved in the Antikythera project, who commented to us:

"The new studies of the Antikythera Mechanism were carried out by an Anglo-Greek research team in cooperation with the National Archaeological Museum in Athens. In order to understand the structure of the Mechanism, we wanted high-resolution 3D X-rays. In 2005 we finally managed to get all the permissions necessary to undertake a new X-ray study and this was carried out by by X-Tek Systems, now part of Nikon Metrology. To make 3D X-rays, it is necessary to penetrate the sample at all angles in a 360º rotation. Luckily, Roger Hadland, the proprietor of X-Tek Systems, developed a deep interest in the Mechanism and this resulted in his company building a special prototype machine with sufficient power for the undertaking.

"The X-ray technique was Microfocus X-ray Computed Tomography (X-ray CT). This consists of rotating the sample on a turntable, while its X-ray image is projected onto a 2D detector. In our study, around 3,000 X-ray projections were gathered covering a complete rotation of the sample. A mathematical technique called filtered back-projection was then used to create a 3D X-ray image of the sample. The 3D image can then be viewed using specialist imaging software—VGSTudio Max by Volume Graphics. We carried out this technique on all 82 surviving fragments of the Antikythera Mechanism.

"The great power of X-ray CT is that a single slice through the sample can be isolated and viewed. This was our primary analysis tool. We expected that the 3D X-rays would reveal the problematic structure of the gearing of the Mechanism. Eventually, this turned out to be true but not in the way that we expected. The first insight came from analysis of Fragment F. X-ray slices through this fragment showed that it contained part of the four-turn spiral dial on the lower back face of the Mechanism. Analysis of the scale divisions and text on this dial showed that it was an eclipse prediction calculator, based on the Saros cycle of 223 lunar months. This discovery forced a complete reassessment of the gearing of the Mechanism and eventually (after a huge struggle) an understanding of the epicyclic system that calculates the Moon's variable motion—an extraordinary insight that revealed the genius of the designer.

"Another surprising revelation was the presence of thousands of new text characters that were hidden inside the fragments. Invisible to conventional X-rays and unread for more than two thousand years, they could be seen in slices through our new 3D X-ray data. A direct result of this was the deciphering of the month names of the 19-year lunar calendar on the upper back face, which turned out to be Corinthian in origin; an understanding of the star calendar at the front of the Mechanism; and the identification of a dial that followed the panhellenic games in Greece—including the Olympic Games. The new X-ray data was at the heart of all our discoveries."

An enormous amount of information about the Mechanism can be found at the home page of the Project:

`http://www.antikythera-mechanism.gr/`

The review of Marchant's book mentions that it is involved in some controversies. Some discussion of this matter can be found at the two sites:

`http://www.connectives.com/decoding-the-heavens-bromley-comments.html`

`http://www.decodingtheheavens.com/blog/post/2009/08/01/Response-to-criticisms-of-Decoding-the-Heavens.aspx`

Freeth tells us that there are also a number of errors in the book, and that corrections can be found at

`http://www.antikythera-mechanism.gr/system/files/Decoding-the-heavens-notes-and-comments.pdf`

As mentioned above, the data making up the images is from X-Tek Systems, now owned by Nikon Metrology. The copyright (dating from 2005) is held by the Antikythera Mechanism Research Project. We thank Tony Freeth for his invaluable help.

—Bill Casselman
Graphics Editor
(`notices-covers@ams.org`)

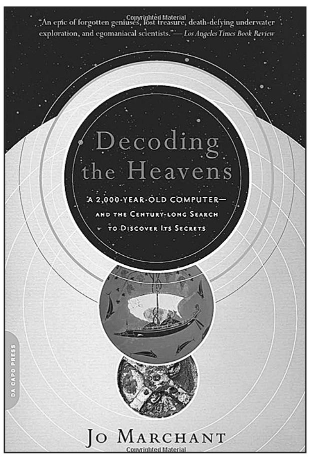
Decoding the Heavens: A 2,000-Year-Old Computer—and the Century-Long Search to Discover Its Secrets

Reviewed by Christián Carman

Decoding the Heavens: A 2,000-Year-Old Computer—and the Century-Long Search to Discover Its Secrets
Jo Marchant
Da Capo Press, February 2009
ISBN-13: 978-03068-174-27

In 1980, Nobel Prize winner Richard Feynman visited the National Archaeological Museum of Athens. While he saw incredibly beautiful statues that expressed the best of Greek art, he became fascinated with just one object: item 15,087. In a letter to his family, he said that he didn't see anything really unusual in the museum except for one thing: "Among all those art objects there was one thing so entirely different and strange that it is nearly impossible. It was recovered from the sea in 1900 and is some kind of machine with gear trains, very much like the inside of a modern wind-up alarm clock. The teeth are very regular and many wheels are fitted closely together. There are graduated circles and Greek inscriptions. I wonder if it is some kind of fake."

Where did this object come from? At the beginning of the twentieth century, a group of Greek sponge divers, led by Dimitrios Kontos, concluded their fishing season in North Africa and returned home. On their way back, while they crossed the channel between Kythera Island and Crete, a severe storm forced them to stop on a small island named Antikythera. After the storm they began to dive off the coast of Antikythera, hoping to supplement their catch. One of the divers, after diving down 42 meters, returned clearly upset, saying he had seen human bodies at the bottom of the sea. Captain Kontos immediately descended and returned minutes later holding a human arm—of a bronze statue. It was the first archeological shipwreck and, so far, the most important. The treasures found fill several rooms today at the National Archaeological Museum of Athens: beautiful bronze statues, jewelry, weapons, and furniture. But there were also fragments that, when they split open, contained what appeared to be some kind of navigation device, the device that caught Feynman's attention and that is now known as the Antikythera Mechanism. *Decoding the Heavens* by Jo Marchant tells the story of this device.



A study of the ceramics and other daily-use items found in the shipwreck—including some coins recovered in a second expedition led by Jacques Cousteau in the 1970s—concluded that the objects date from around 80–50 BC. A sample of the wood of the ship dated by the carbon-14 method showed that the ship had been built at least 100 years before the shipwreck. The fragments of the Mechanism show clear signs of having suffered the inhospitality of the sea for two millennia. However, it is still possible to see clearly many of the gears in the Mechanism, some fragmented scales, a few pointers, and several words in Greek.

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The style of the script of these inscriptions helps to date the construction of the Mechanism between 150–100 BC, although an error of a century before or after those dates cannot be ruled out.

After a century of research, we have a fairly complete idea of the structure and operation of the Mechanism: it was a sort of computer that, when one moved a handle, predicted astronomical and other events through a series of pointers on different scales. The entire Mechanism was made of bronze and was protected by a wooden case the size of a large dictionary. The fact that the Greeks could have built such a complex geared mechanism is certainly revolutionizing our knowledge of the history of technology. Not only is the Mechanism fascinating in itself but the research into its use and the history of its discovery make a compelling story. Marchant's book is simply captivating as it highlights the mysteries of the research in a way more reminiscent of crime novels than of scientific books.

Important research on the Antikythera Mechanism was done in the first half of the twentieth century, but a detailed understanding of its structure and function had to wait until the 1950s. Derek de Solla Price, a scholar from Yale University, with the help of Charalambos Karakalos, was the first to obtain radiographs of the fragments to see in detail how many gears the mechanism had, how many teeth each gear had, and how they were connected. In this way he discovered, for example, that one pointer would show the position of the sun in the zodiac and another the position of the moon and that the moon pointer revolved 254 turns for every 19 turns of the sun pointer (the ancient Greeks knew that in 19 years there are almost exactly 254 lunar sidereal months).

In one of the extant fragments of the Antikythera, there are remnants of two concentric rings. On the inner ring one can read the word *XELAI*, which means Libra in Greek. The marks inscribed on this ring allow us to conjecture that there were 360 marks divided into twelve sections, each one corresponding to a zodiac sign. We can then guess that this was a part of a zodiac dial on which pointers showed the positions of the sun and moon. On the outer ring we can read the names of months in the Egyptian calendar. We can also infer that that ring had 365 divisions, corresponding to the 365 days of the year. We know that Greek astronomers used the Egyptian calendar because of its simplicity, since it always had 365 days without leap years. Because it takes the sun one year to traverse the zodiac, one arrow could show both the position of the sun in the zodiac and the day of the year.

In the inner ring one can see some small letters close to the marks. They are in alphabetical order: alpha, beta, gamma, etc. Price deciphered the meaning of these letters. According to his analysis, they belong to a *parapegma*, which was a stellar calendar that indicated which stars rise or set at the sunset or sunrise. So, when the sun pointer pointed to a certain letter, one could read on the front of the Mechanism what star would rise or set that day. Usually, these parapegmata also include some atmospheric phenomena, such as winds, storms, etc., but as far as we know, there is no mention of atmospheric phenomena in the Antikythera Mechanism.

Price thought that, with his research, the Antikythera Mechanism would be accorded a distinguished place in the history of astronomy and technology, but this was not the case. Otto Neugebauer, the greatest authority on the subject and Price's mentor, published the monumental *History of Ancient Mathematical Astronomy* in 1975, a couple of years after Price's work on the Antikythera. HAMA, as it is often called, comprises 1,456 pages over three volumes and mentions the Antikythera only in one footnote—and a very critical one indeed. Someone said metaphorically that this constituted the second shipwreck of the Antikythera Mechanism.

But the story continues. The next protagonist is Michael Wright, who was curator of mechanical engineering at the London Science Museum. Having read Price's work, Wright found several errors and has worked hard since the 1990s to correct them and to discover new features of the Antikythera. Wright designed and built with his own hands a tomography scanner and for several summers traveled to Athens to study the fragments with an Australian colleague, Alan Bromley.

We can mention three important contributions of Wright. First of all, he proposed that the Mechanism should be understood as a planetarium, i.e., that it shows not only the positions of the sun and the moon but also of the five planets known at the time the Antikythera was built: Mercury, Venus, Mars, Jupiter, and Saturn. There was one pointer for each planet, all concentric like the hands of a clock and each turning at its own speed, with those of the moon and sun and sharing the same zodiac scale. New discoveries published last year confirm Wright's intuition. In addition, the planetary pointers exhibit retrograde motion that reflects the known retrograde motion of the planets. Nevertheless, the exact way in which the Antikythera models planetary motion is conjectural: the gears are missing, so the proposals for how the Mechanism worked cannot be directly tested.

The second of Wright's proposals is related to a strange cap found in the back of one fragment of the Antikythera. The cap has a hole in one of its borders and a gear close to its center. Wright realized the purpose of this strange device. The cap was attached to the moon pointer so that the cap went once around the dial each sidereal month. The gear on the cap turns a little sphere, which rotates at the rate of the synodic month. The sphere, representing the moon, was probably half white (or silver) and half black, and as it rotated it showed the lunar phases.

The third of Wright's contributions is related to the calendar. As already mentioned, the Egyptian calendar has 365 days without leap years. This means that, every four years, the calendar ring would be misaligned by one day with respect to the zodiac ring. Now, Price discovered that below the calendar ring there are little holes, one per day, but he didn't know why they were there. Wright realized that these little holes serve to move the calendar ring by one day. He showed that the calendar ring was not attached to the Mechanism, but it was movable and it could have had pins that, if located in these holes, would keep the ring fixed.

At the beginning of the new millennium, the British filmmaker Tony Freeth and the astronomer Mike Edmunds (Cardiff University) created the Antikythera Mechanism Research Group, an international multidisciplinary team whose aim is to decipher the mysteries of the Antikythera. The team got permission to work directly with the fragments and to apply two new technologies to their examination.

Freeth convinced X-Tek, a company specialized in building very powerful tomography scanners, to build a new scanner designed to look at the Antikythera fragments. The scanner was able to take ten images per millimeter. After uploading all the information into their software, the team was able to reconstruct the fragments in three dimensions, greatly assisting new research.

Second, the team used a technique known as PTM (Polynomial Texture Mapping) developed by Tom Malzbender, an employee of Hewlett Packard, which involves taking pictures of an object with a fixed camera but with flashes at many different angles in such a way that, when you examine the pictures using special software, you can play with light and see even the slightest surface irregularity. This helps in the reading of the Greek characters and scale marks. Malzbender developed this technique so as to show shadows in a more realistic way in animated films. Later he realized that the technique would be very helpful for reading ancient inscriptions.

Using these two technologies, Freeth's team has succeeded in reconstructing much of the Mechanism and has made important new discoveries. One is related to the way the Mechanism showed the sidereal motion of the moon. Although the moon never exhibits retrograde motion, the irregularities in its motion are notorious. Of course, Greek astronomers had a geometrical model reflecting this motion using an epicycle and a deferent. Now Freeth and his team discovered that the same nonuniformity is present in the Antikythera's pointer for the moon, so that the pointer has the same motion that the moon would have according to the geometrical Greek model just mentioned. This nonuniform motion was performed by what is perhaps the most striking and surprising feature of the Antikythera Mechanism: the pin-and-slot device for producing the irregularities in the lunar motion. This clever device, mentioned nowhere in the ancient astronomical literature, produces a back-and-forth oscillation that is superimposed on a steady progress in longitude. The key part of the device is the pin of one gear that, when introduced in a slot in another gear slightly off-center with respect to the first, moves the second gear at the average rate of the first one. However, because of the eccentricity, the second gear has a nonconstant motion. This nonuniform motion is transmitted through a gear chain to the moon pointer.

Freeth's team also managed to understand almost everything on the back of the Mechanism. Their work suggests that on the back of the Mechanism there were two large dials, one next to and above the other, together with some subsidiary rings inside them. The upper ring was a complex luni-solar calendar, while the lower ring was an eclipse predictor.

The lower ring was divided into 223 cells (each corresponding to a synodic month) distributed over four turns of a spiral. Most cells are empty, but in the months in which an eclipse would take place, the cell indicated that an eclipse would happen, the time at which it would happen, and whether it would be a solar or a lunar eclipse. Eclipses repeat every 223 months in a pattern known as the Saros cycle. If a solar eclipse took place today, then 223 months from now a very similar solar eclipse would take place. Therefore, that pointer could be used for predicting eclipses indefinitely. But the prediction of the succeeding cycles is not perfect. From one cycle to another, the occurrence of eclipses shifts 8 hours. The shift is compensated for by a subsidiary mechanism inside the Saros ring: this subsidiary ring turns very slowly (one turn every 54 years, that is, every three Saros cycles), indicating whether one needs to add 8 hours, 16 hours, or nothing to the value of the time inscribed in the cell.

The luni-solar calendar on the upper back ring is based on the Metonic cycle. According to this cycle, 235 synodic months are almost exactly 19 years. Therefore, this calendar repeats every 19 years. It is interesting to note that, because every Greek city had its own calendar, the month names of the extant part of the dial allow Freeth's team to conjecture that the Mechanism was made to be used in Corinth or any of its colonies; one of them was Syracuse.

Now, we know that Archimedes lived in Syracuse, making him an extraordinary candidate for the originator of the Mechanism. It seems that the Antikythera Mechanism was built at least a decade after the death of Archimedes, so he probably is not the maker of this particular device, but he could have started the tradition. As is patent from the complexity of the Antikythera, this is probably not the first such mechanism ever made.

The luni-solar calendar has two subsidiary dials inside: one revolved once every 76 years (i.e., four Metonic cycles) and indicated when one day had to be skipped in the Metonic calendar (once every four cycles) in order to correct it. The second—one of the most amazing—revolved one revolution every 4 years and was divided into four cells: in them we can read the names of the Pan-Hellenic games, so that the arrow indicates what games would be played that year: the Olympics, the Nemean games, etc.

So in one device you can learn the position of the sun and moon (and probably also the planets) in the zodiac, and the day of the year; you have an eclipse predictor that tells you the time and kind of eclipse, and you also know whether you have to add 8 or 16 hours to the time indicated; you have a luni-solar calendar that tells you which years have 12 and which have 13 months, which months have 29 and which have 30 days, which day would be omitted in case you have a 29-day month, when you have to omit one day every 76 years for correcting the calendar; and, finally, you know which Pan-Hellenic games would take place that year. It was like a tablet PC of ancient times!

The research is still in progress, and every year new discoveries arise. The Antikythera Mechanism probably still has some mysteries to reveal, and the best way to be prepared to understand it is to read Jo Marchant's book.

Marchant invested several years in research, and the dedication and seriousness with which she directed that research is reflected in the book. She does not avoid technical issues when they are necessary and usually presents them clearly. It is a self-contained book: you have in it all the astronomical and historical knowledge that you need to understand the story of the Antikythera. Marchant documents her sources well and also provides a Further Reading section. Inevitably, the book contains some imprecisions. Nevertheless, it is, all in all, an excellent book that tells a fascinating story in a fascinating way. *Decoding the Heavens* is, I think, required initial reading for anyone seeking an introduction to the story of the research into the mysteries of the Antikythera Mechanism.

Book Review

Seduced by Logic

Reviewed by Judith V. Grabiner

Seduced by Logic: Émilie du Châtelet, Mary Somerville and the Newtonian Revolution
Robyn Arianrhod
Oxford University Press, 2012
US$34.95, hardcover, 338 pages
ISBN-13: 978-0-19-993161-3

In a world where over 30 percent of American Ph.D.'s in mathematics are earned by women, we forget how rare female mathematicians have been in the past. Counting the women with well-documented contributions to mathematics before the nineteenth century can be done on the fingers of one hand. Each of these women "made it" only because of highly unusual circumstances. For instance, in the case of Hypatia of Alexandria (c. 370–415 CE), her father was the mathematician Theon of Alexandria. Maria Gaetana Agnesi (1718–1799), who had an on-the-make father who showed her off as a prodigy, also benefited from liberal religious trends in eighteenth-century Italy. Sophie Germain (1776–1831) grew up in a Paris home that was a meeting place for intellectuals, and as mathematics in Revolutionary France became more widely accessible through lectures and notes from the École Polytechnique, adopted a male pseudonym to correspond with Lagrange and Gauss. The first actual European Ph.D., Sofya Kovalevskaya (1850–1891), came from an influential Russian family but had to contract a fictitious marriage in order to leave her home country to study mathematics in Germany. As Londa Schiebinger has documented in her magisterial *The Mind Has No Sex* (Harvard, 1989), various theories about the nonintellectual nature of women reinforced

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not the maker of this particular device, but he could have started the tradition. As is patent from the complexity of the Antikythera, this is probably not the first such mechanism ever made.

The luni-solar calendar has two subsidiary dials inside: one revolved once every 76 years (i.e., four Metonic cycles) and indicated when one day had to be skipped in the Metonic calendar (once every four cycles) in order to correct it. The second—one of the most amazing—revolved one revolution every 4 years and was divided into four cells: in them we can read the names of the Pan-Hellenic games, so that the arrow indicates what games would be played that year: the Olympics, the Nemean games, etc.

So in one device you can learn the position of the sun and moon (and probably also the planets) in the zodiac, and the day of the year; you have an eclipse predictor that tells you the time and kind of eclipse, and you also know whether you have to add 8 or 16 hours to the time indicated; you have a luni-solar calendar that tells you which years have 12 and which have 13 months, which months have 29 and which have 30 days, which day would be omitted in case you have a 29-day month, when you have to omit one day every 76 years for correcting the calendar; and, finally, you know which Pan-Hellenic games would take place that year. It was like a tablet PC of ancient times!

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the legal and familial barriers. In modern society, where some people still say, "Math isn't for girls," the history of those who succeeded against such social forces remains instructive as well as fascinating.[1]

The book under review aims to tell the story of two women from the eighteenth and nineteenth centuries, genuine contributors to the mathematical sciences. Gabrielle Émilie Le Tonnelier de Breteuil, Marquise du Châtelet (1706–1749), was the author of a state-of-the-art commentary on Newton's physics and made what is still the definitive French translation of Newton's *Principia*. Mary Fairfax Somerville (1780–1872) wrote the book *Mechanism of the Heavens*, which brought Laplace's ideas to English readers. She also wrote *Connexions of the Physical Sciences*, praised by James Clerk Maxwell for its clear communication of fundamental ideas of physics. It is Mary Somerville after whom Somerville College, Oxford (alma mater of Nobelist Dorothy Hodgkin, politicians Margaret Thatcher and Indira Gandhi, and author Dorothy Sayers), is named. Du Châtelet and Somerville are linked, according to the author, Dr. Robyn Arianrhod, by their common fascination with Newtonian science. As the main title, *Seduced by Logic*, may suggest, the approach here is that of popular biography. Both women, if not seduced, were in a metaphorical Newtonian sense "attracted" to a subject traditionally pursued by men. As popular biographies of women in the history of science go, *Seduced by Logic* is unusual in trying to put the science front and center. Readers of the *Notices* will not need many of the explanations (for instance, we're told that an inverse-square force, if the distance is tripled, is reduced to one-ninth the original value), but Arianrhod also frequently compares the science with modern points of view and explains scientific and mathematical ideas as understood not by us but in the style of the eighteenth and nineteenth centuries. As Arianrhod observes, Newtonian science has developed since the publication of Newton's *Principia* in 1687, and the work of Du Châtelet and Somerville can help explain that development. The goals of the volume under review, then, are admirable and ambitious. Although the book is flawed in a number of ways, it is interesting, and its subjects are worthy of serious study.

About two-thirds of the text is devoted to Madame du Châtelet and her work in science. First her early life is sketched. We learn that her father was the chief of protocol at Versailles under Louis XIV, and when she married the Marquis du Châtelet she continued to move in aristocratic circles. She found intellectual interests, especially in mathematics and science, and when she was twenty-six she and Voltaire fell in love. At this point Arianrhod switches gears to describe the major astronomical and physical discoveries, especially gravity, in Newton's *Principia*. Then we learn how Pierre-Louis de Maupertuis, a leading Newtonian scientist in France, instructed Madame du Châtelet in state-of-the-art mathematics. Meanwhile, Voltaire's politics led him to seek sanctuary with Madame du Châtelet at Cirey, on the estate of the Marquis du Châtelet—what a tolerant man the marquis must have been—and many leading intellectuals came to Cirey to enjoy the literary and scholarly atmosphere created by this unusual couple. We are also told what Voltaire and Madame du Châtelet thought about the science of Kepler and Newton and how they wrote an influential popularization of Newton's ideas, *Elements of Newton's Philosophy*. Arianrhod also relates how Maupertuis and Alexis-Claude Clairaut travelled to the Arctic to test Newton's prediction that the supposedly spherical earth was, because of its rotation, flattened at the poles. Madame du Châtelet wrote an essay (Voltaire wrote one too) for a contest of the Académie des Sciences on "the nature and propagation of fire", dealing with the nature of light and heat (neither won; Euler did), and we learn about Newton's theory of light along the way.

We then see Madame du Châtelet move in a different direction from the Newtonianism of Voltaire as she began to read Leibniz. She was now learning not only advanced mathematics but also philosophy from the Leibnizian Samuel König, as well as from Clairaut, author of a then-definitive book on the shape of the earth. At that time, a major issue, often called the "*vis viva* controversy", centered on whether momentum (mv), or "living force" (mv^2) as championed by Leibniz and his followers, was the key conserved quantity in physical interactions. In the light of modern physics, the experiments, philosophical background, and arguments in this dispute may seem much ado about nothing, but they were important in helping refine notions of energy and in encouraging the mathematization of classical mechanics. In describing the controversy, Arianrhod explains the influential Leibnizian ideas adopted by Du Châtelet, notably the principles of continuity and sufficient reason, and the belief that the universe obeys optimal principles. As an early adopter of the synthesis of Newtonian and Leibnizian ideas, Du Châtelet wrote an introductory book,

[1] *There are excellent books on these women. See, for instance, Maria Dzielska,* Hypatia of Alexandria *(Harvard, 1995); Michael Deakin,* Hypatia of Alexandria: Mathematician and Martyr *(Prometheus Books, 2007); Louis Bucciarelli and Nancy Dworsky,* Sophie Germain: An Essay in the History of the Theory of Elasticity *(Reidel, 1980); Ann Hibner Koblitz,* A Convergence of Lives: Sofia Kovaleskaia, Scientist, Writer, Revolutionary *(Birkhäuser, 1983). A very rapid overview may be found in the Mathematical Association of America's 2008 poster, "Women of Mathematics":* `http://www.maa.org/pubs/posterW.pdf`*, and there is a useful set of biographies maintained by Agnes Scott College online:* `http://www.agnesscott.edu/lriddle/women/women.htm`.

Fundamentals of Physics, conventionally dedicated to her son but obviously of value for anyone wanting to learn the basics of what was going on in physics and astronomy. Later on, beginning in 1744, she undertook a much more important task: translating Newton's *Principia* into French. The translation included explanations and the use of Leibnizian calculus. This work, still used by scholars today and arguably her most important intellectual legacy, was published only after her death.

Meanwhile, her relationship with Voltaire and a return to Cirey after time in Belgium keep the personal part of the story interesting to readers. Voltaire saddened her by falling in love with Marie-Louise Denis, and Du Châtelet herself had an affair with the Marquis de Saint-Lambert, became pregnant, and died just days after the birth of her daughter. Arianrhod describes some events of the French Revolution, including the moving of Voltaire's remains to the Panthéon in Paris, the guillotining of Madame du Châtelet's son, and the scattering of the remains from Madame du Châtelet's grave. But from the standpoint of the history of science, as Arianrhod observes, what matters is that Madame du Châtelet lent a hand to the triumph of the physics of Newton in the mathematical language of Leibniz, Euler, D'Alembert, Lagrange, and especially Laplace throughout the eighteenth century. That observation serves as the book's transition from the life of Madame du Châtelet to that of Mary Fairfax Somerville, who would, Arianrhod says, explain Laplace as Du Châtelet had explained Newton.

Mary Fairfax grew up in semirural Scotland, but her father became an admiral. Britain was not immune to the revolutionary ideas of the eighteenth century. Arianrhod discusses the views of Rousseau, Mary Wollstonecraft, various anti-slavery writers, and the Marquis de Condorcet as part of Fairfax's intellectual background. But then Mary Fairfax became interested in mathematics by being shown a magazine with mathematical problems in it, so she asked her brother's tutor for some mathematics books. In 1804 she married a distant cousin, Samuel Grieg, who died after three years. During that time she was often alone and used the time to study higher mathematics. Upon returning to society after Grieg's death, she met various literary intellectuals in Edinburgh, including John Playfair, professor of mathematics and natural philosophy at Edinburgh, and his eventual successor, William Wallace, both of whom guided her studies in mathematics and physics. She soon met and married another cousin, William Somerville, a physician and diplomat. Meanwhile, starting with a tutor, she had begun the serious study of Laplace's *Mécanique celeste*. With her husband's support, she continued to study and met many famous scientists both in Britain and in France, including Thomas Young, Michael Faraday, Charles Babbage, François Arago, Jean-Baptiste Biot, Simon-Denis Poisson, and Laplace himself. At this point Arianrhod digresses to give a short account of the career of Sophie Germain, who never met Mary Somerville but whose life gives some sense of the situation of women in science in the early nineteenth century.

Aware of Mary Somerville's scientific understanding, Lord Brougham suggested that she write a popular account of the work of Laplace in English, and though Brougham later rejected the result as too advanced for the purpose, the Scottish publisher John Murray, after a favorable report from the astronomer John Herschel, published Somerville's book, *The Mechanism of the Heavens*, in 1831. *The Mechanism of the Heavens*, which covers the principle of least action, the planetary orbits, and the stability of the solar system, was quite successful and came to be used by students at Cambridge preparing for examinations. Somerville wrote an even more successful book, *On the Connexion of the Physical Sciences*, that treated not only mechanics but electricity, magnetism, chemistry, light, and heat. Arianrhod uses her discussion of the book to explain electromagnetism and the wave theory of light, briefly describing the work of Oersted (Ørsted), Faraday, Young, and Maxwell. Later, the Somervilles moved to Italy with their daughters, and Mary Somerville wrote two more books: *Physical Geography* and *On Molecular and Microscopic Sciences*. She actively supported the movement for the right to vote for women and advocated for women's access to higher education. As Arianrhod says, Mary Somerville was able to combine "a happy family life with intellectual challenge," and "gained the respect of the international scientific establishment" (p. 250). Finally, after concluding the twin stories of Du Châtelet and Somerville, the author adds a personal epilogue, arguing for the importance of "female heroines" for women in the sciences.

The text is immediately followed by twenty-five pages of appendices, all accessible to a bright high school student, covering Kepler's second and third laws; the flattening of the earth, the period of pendulums, and triangulation; the laws of reflection and refraction; the calculus, using the concept of infinitesimal and Leibniz's notation; using calculus to derive the conservation of momentum and "*vis viva*" from Newton's Second Law; Newton's demonstration that, if the force of gravity on the earth's surface is inverse-square, the theory predicts the moon's acceleration (deviation from a straight path) to be the amount that is actually observed; a sketch of the proof that the net force of gravity (or any inverse-square force) within a spherical shell is zero; modern definitions of measures of distance and time; using calculus to minimize physical quantities; how the principle of least action produces Newton's laws of motion; discussions of various concepts of energy and Joule's discussion of its conservation; resonance; theories of light; and statistics about women in the sciences.

So there's a lot in this book. How is one to evaluate it, and who is the intended audience? Certainly anyone interested in Newtonian science and its progress in the eighteenth and nineteenth centuries and the role of women in science in the same period will want to give it a try. A woman science student looking for predecessors would be an ideal audience, and somebody with such interests who wants a good popular account of the elementary topics of mechanics could learn a lot from the appendices and in-text explanations: my favorite of these is the quantitative account of how, as Newton says he once mused while watching an apple fall, the force of gravity would act if it were extended as far as the moon.

However, the historical background is unevenly sketched, with nuances missed and sources sometimes haphazardly chosen. For example, although of course this book is not intended as the definitive account of the history of the time periods covered, the French Revolution was far more than the Terror, and the relationship between mechanics, chemistry, light, electricity, and magnetism has a much richer history than this book allows. Newton did say, concerning the cause of gravity, that he "did not feign hypotheses," but he certainly made hypotheses, though his British contemporaries often dogmatically denied it. It is hard to accept Arianrhod's explanation of Newton's antipathy for Hooke (who misunderstood what Newton experimentally showed about the composition of white light and who wanted credit for the inverse-square law whose properties he could not mathematically demonstrate) as "Newton never seemed to outgrow the insecurity of his abandoned childhood" (p. 140).

Arianrhod frequently looks at eighteenth-century ideas, such as those of energy or space, and says, in effect, "Yes, this is like, or unlike, what Einstein proposed" or "They didn't get modern results, but that's because they had other goals or lacked the right equipment." I find this ahistorical and not always adding insight. For example, after stating that "only in nuclear reactions [can] energy be converted into a detectable gain in 'rest' mass," Arianrhod says, "No wonder Voltaire could not come to a conclusive result in his experiments!" (p. 205). In a similar example, Arianrhod writes, "Émilie did not articulate such a modern position [as Einsteinian relativity]—partly because she wanted a philosophy that took account of the history of humanity as well as that of impassive celestial spheres" (p. 112).

The scholarly apparatus is both deficient and annoying, surprising for a book from the Oxford University Press. It's all right to have endnotes instead of footnotes, but instead of normal endnotes, where a number or asterisk in the text signals a reference, in this book you need to flip to the back (and you'd better know the number of the chapter you are in, since no page numbers are cited in the endnotes) and then find, instead of the page referred to, a topic heading that may or may not be what you're looking for. In one frustrating example, on p. 79 Arianrhod writes that *Elements of Newton's Philosophy* was influential in popularizing the theory of gravity on the Continent. She supports this conclusion with this statement: "'All Paris studies and learns Newton', wrote an enthusiastic reviewer." If you want the eighteenth-century source of that eighteenth-century quotation about "all Paris", what you'll find, buried in an endnote on p. 296 headed "On Voltaire's Academy memberships", is the phrase "'All Paris studies Newton': quoted in Johnson and Chandrasekhar, Part II, p. 537"—a reference to a journal article published in 1990. Furthermore, some controversial statements made in the text have no supporting endnote at all.

So what do we have? An attractive idea; very interesting material; appendices that can teach a student some important ideas in physics, calculus, and astronomy; and a most readable account of the lives of two quite different pioneering women in science, all in under three hundred pages of text. But Judith Zinsser's recent biography of Du Châtelet, Kathryn Neely's of Somerville, Londa Schiebinger's book on women in science, Mary Terrall's biography of Maupertuis in the context of the science of his day, and I. Bernard Cohen's *The Newtonian Revolution* would provide a better resource for those interested in the topics covered here. I enjoyed reading *Seduced by Logic*; I just wish its organization were tighter and its scholarship more robust and more helpfully documented.

WHAT IS...

a Frame?

Christopher Heil

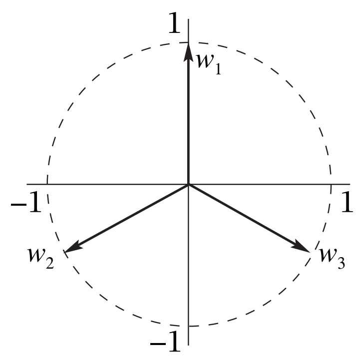

Figure 1. The *Mercedes frame* $\{w_1, w_2, w_3\}$.

A frame is a set of vectors in a Hilbert space that provides robust, basis-like representations even though the frame may be "redundant" or "overcomplete". In finite dimensions a frame is simply a spanning set, but this statement belies both the many practical applications of frames and the deep mathematical problems that remain unsolved. In infinite dimensions there are many shades of gray to the meanings of "spanning" and "independence", and some of the most important frames are overcomplete even though every finite subset is linearly independent. Though we do not have space to discuss them, applications drive much of the interest in frames. A short and incomplete list of areas in which frames play an important role includes analog-to-digital conversion and Sigma-Delta quantization, compressed sensing, phaseless reconstruction, reactive sensing, transmission with erasures (e.g., over the Internet), and classification and analysis of large data sets such as those obtained using LIDAR (a remote sensing method) or HSI (hyperspectral imagery).

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Frames were introduced by Duffin and Schaeffer in a 1952 paper in the *Transactions of the AMS*. In that article (which is a model of clarity and well worth reading today), they declare a set of vectors $\mathcal{F} = \{f_n\}_{n\in J}$, J a countable index set, to be a *frame* for a Hilbert space H if there exist constants $A, B > 0$ such that

$$A\,\|f\|^2 \le \sum_{n\in J} |\langle f, f_n\rangle|^2 \le B\,\|f\|^2, \quad f \in H.$$

Sadly, Duffin and Schaeffer both passed away before anyone thought to ask why they called such a system a "frame". Is it because $A\,\|f\|^2$ and $B\,\|f\|^2$ "frame" the sum between them? We will never know. In any case, a frame is *tight* if we can take $A = B$, and it is *Parseval* if we can take $A = B = 1$.

Every orthonormal basis is a Parseval frame, but a Parseval frame need not be orthogonal or a basis. The *Mercedes frame* $\{w_1, w_2, w_3\}$, pictured in Figure 1, is a simple example of a tight frame (with $A = B = 3/2$). Rescaling, $\{u_1, u_2, u_3\}$, $u_i = cw_i$, $c = (2/3)^{1/2}$ is a Parseval frame for $\mathbb{R}^2$, and hence every vector $v \in \mathbb{R}^2$ satisfies

$$v = (v\cdot u_1)\,u_1 + (v\cdot u_2)\,u_2 + (v\cdot u_3)\,u_3.$$

The coefficients in this linear combination are not unique, because $\{u_1, u_2, u_3\}$ is dependent, yet this is actually an advantage in many situations. However, even in finite dimensions we usually require much larger sets of vectors that form a frame, often for a very high-dimensional space. Do there exist unit vectors $v_1, \dots, v_{97} \in \mathbb{R}^{43}$ that form a tight frame for $\mathbb{R}^{43}$? This is a problem about equidistributing points on the sphere, but not with respect to the usual notions of distribution. A collection of unit vectors that forms a tight frame for $\mathbb{R}^d$ or $\mathbb{C}^d$ is called a *finite unit norm tight frame*, or *FUNTF*. Benedetto and Fickus characterized FUNTFs in terms of the minima of a certain potential energy function on the sphere. An active area of research is to construct finite uniform norm tight frames that are *equiangular* or as close to equiangular as possible. Such frames would be important in applications such as signal processing, radar, and communications engineering.

If $\mathcal{F} = \{f_n\}_{n\in J}$ is a frame for a Hilbert space H, then $Sf = \sum_{n\in J} \langle f, f_n\rangle f_n$ is a continuous linear bijection of H onto itself. The *canonical dual frame* $\tilde{\mathcal{F}} = \{\tilde{f}_n\}_{n\in J}$, $\tilde{f}_n = S^{-1} f_n$, satisfies

$$f = \sum_{n\in J} \langle f, \tilde{f}_n\rangle f_n, \quad f \in H. \tag{1}$$

If the frame is tight, then $\tilde{f}_n = \frac{1}{A} f_n$. In general, the *frame coefficients* $\langle f, \tilde{f}_n\rangle$ need not be the only scalars c_n that satisfy $f = \sum c_n f_n$, but the *frame representation* in equation (1) enjoys useful "stability" properties. For example, the series converges *unconditionally*, i.e., regardless of the ordering of the index set J, and among all choices of c_n for a given f, the sequence of frame coefficients has minimal ℓ^2-norm (but the sequence that has minimal ℓ^1-norm is often sought for sparsity reasons). The representations in (1) are unique for every f if and only if $\mathcal{F}$ is a *Riesz basis* (the image of an orthonormal basis under a continuous linear bijection $A\colon H \to H$). No proper subset of a Riesz basis can be a frame, yet if a frame is not a Riesz basis, then there exist proper subsets that are frames.

Why do we need frames that are not orthonormal bases or Riesz bases? The *Classical Sampling Theorem* (also known as the *Shannon* or *Nyquist-Shannon Sampling Theorem*) is a cornerstone of information theory and signal processing. The Sampling Theorem is equivalent to the statement that the sequence $\mathcal{E}_b = \{e^{2\pi i b n x}\}_{n\in\mathbb{Z}}$ is a tight frame for $L^2[0,1]$ for each $0 < b \le 1$. Taking $b = 1$, we obtain an orthonormal basis. However, if $b < 1$, then $\mathcal{E}_b$ is not a Riesz basis for $L^2[0,1]$, and hence frame coefficients are not unique (even so, every finite subset of $\mathcal{E}_b$ is linearly independent). If $b = 1/N$, then $\mathcal{E}_{1/N}$ is a union of N orthonormal bases, but in general $\mathcal{E}_b$ cannot be written as a union of orthonormal bases. The Sampling Theorem underlies the encoding of bandlimited signals in digital form: we must have $b \le 1$ in order to have a hope of reconstructing the original signal from its encoding. Taking $b < 1$ corresponds to "oversampling" the signal or to using a frame that is not a Riesz basis. The "8 times oversampling" note that appears on the labels of compact discs is closely related. Oversampling aids in both noise reduction and error correction.

Many seemingly simple questions about frames lead to deep mathematical problems. For example, it is natural to ask if we can explicitly characterize the meaning of redundancy, especially for infinite frames. In general, a frame cannot be written as a union of orthonormal sequences, but can every frame $\mathcal{F} = \{f_n\}_{n\in J}$ be written as the union of finitely many nonredundant subsequences $\mathcal{E}_1, \dots, \mathcal{E}_N$? Here, a subsequence is *nonredundant* if it is a Riesz basis not for the entire space H but for the closure of its linear span. We call such a set a *Riesz sequence*. (In finite dimensions, this would simply be a linearly independent set.) Excluding the trivial case $\|f_n\| \to 0$ suggests the following conjecture.

The Feichtinger Conjecture. *If $\mathcal{F} = \{f_n\}_{n\in J}$ is a frame for a Hilbert space H and $\inf \|f_n\| > 0$, then there exist finitely many Riesz sequences $\mathcal{E}_1, \dots, \mathcal{E}_N$ whose union is $\mathcal{F}$.*

Casazza and Tremain have shown that the Feichtinger Conjecture is equivalent to the following *Kadison-Singer*, or *Paving*, Conjecture, which has been called the deepest open problem in operator theory today. (They also demonstrated that the Paving and Feichtinger Conjectures are equivalent to a number of other open problems from mathematics and engineering.)

Paving Conjecture. *For each $\varepsilon > 0$ there exists an integer $M > 0$ such that for every integer $n > 0$ and every $n \times n$ matrix S that has zero diagonal, there exists a partition $\{\sigma_1, \dots, \sigma_M\}$ of $\{1, \dots, n\}$ such that,*

$$\|P_{\sigma_j} S P_{\sigma_j}\| \le \varepsilon \|S\|, \quad j = 1, \dots, M,$$

where P_I denotes the orthogonal projection onto $\mathrm{span}\{e_i\}_{i\in I}$ and $\|\cdot\|$ denotes operator norm.

Duffin and Schaeffer were specifically interested in frames of the form $\mathcal{E} = \{e^{2\pi i\lambda_n x}\}_{n\in\mathbb{N}}$ for $L^2[0,1]$, where $\{\lambda_n\}_{n\in\mathbb{N}}$ is an arbitrary countable subset of $\mathbb{R}$ or $\mathbb{C}$. Such *nonharmonic Fourier frames* yield "nonuniform" sampling theorems for bandlimited signals. Although frame theory was largely overlooked for many years after Duffin and Schaeffer, nonuniform sampling is today a major topic, both for bandlimited and nonbandlimited signals; e.g., it arises in magnetic resonance imaging (MRI).

In 1986 Daubechies, Grossmann, and Meyer brought frames back into the limelight with their work on *Gabor frames* and *wavelet frames* for $L^2(\mathbb{R})$. A (lattice) Gabor frame is a frame of the form $\mathcal{G}(g,a,b) = \{e^{2\pi i b n x} g(x - ak)\}_{k,n\in\mathbb{Z}}$, where $g \in L^2(\mathbb{R})$ and a, $b > 0$ are fixed (of course, g, a, and b must be carefully chosen in order for $\mathcal{G}(g,a,b)$ to actually form a frame). Thus a Gabor frame is produced by applying a discrete set of translation and modulation operators to g, and as a consequence there are underlying connections to representation theory, the Heisenberg group, and the uncertainty principle. Indeed, the *Balian-Low Theorem* states that, if a Gabor frame is a Riesz basis for $L^2(\mathbb{R})$, then the Heisenberg product $\left(\int_{-\infty}^{\infty} |x\, g(x)|^2\, dx\right)\left(\int_{-\infty}^{\infty} |\xi\, \hat{g}(\xi)|^2\, d\xi\right)$ must be infinite. Consequently, Gabor frames that are Riesz bases have limited interest. On the other hand, Feichtinger and Gröchenig proved that, once we find a reasonable function g that generates a Gabor frame $\mathcal{G}(g, a, b)$ for $L^2(\mathbb{R})$, then this frame provides stable basis-like representations not merely for square-integrable functions but also for functions in the entire family of Banach spaces $M_w^{p,q}(\mathbb{R})$ known as the *modulation spaces*. Thus, from a simple Hilbert space frame criterion we obtain representations valid across a wide range of function spaces. Similar representations hold for "irregular" Gabor frames of the form $\{e^{2\pi i b_k x} g(x - a_k)\}_{k\in\mathbb{N}}$, though the proofs in this setting are far more difficult. Recent advances in this area have come from profound new versions of Wiener's Lemma in noncommutative Banach algebras.

A wavelet frame is generated by the actions of translation and dilation. Specifically, if $\psi \in L^2(\mathbb{R})$ and a, $b > 0$ are fixed and if $\mathcal{W}(\psi, a, b) = \{a^{n/2}\psi(a^n x - bk)\}_{k,n\in\mathbb{Z}}$ is a frame for $L^2(\mathbb{R})$, then we call it a wavelet frame. In contrast to Gabor frames, it is possible to find very nice functions ψ such that $\mathcal{W}(\psi, a, b)$ is a Riesz basis or even an orthonormal basis for $L^2(\mathbb{R})$. This discovery by Meyer, Mallat, and Daubechies was the beginning of the "wavelet revolution". A wavelet frame or orthonormal basis generated by a "reasonably nice" function ψ will provide frame expansions not only for $L^2(\mathbb{R})$ but also for an entire suite of Banach spaces, including Sobolev spaces, Besov spaces, and Triebel–Lizorkin spaces. Wavelet frames have important applications today, as do various hybrid systems and generalizations such as curvelets and shearlets, which are especially important for analysis in higher dimensions (consider image or video processing). Even larger redundant "dictionaries", often so overcomplete that they are not even frames, are the basis for the theory and application of compressed sensing and *sparse representations*.

We cannot resist mentioning one last open problem. It is not difficult to show that any finite subset of the nonharmonic systems $\{e^{2\pi i\lambda_n x}\}_{n\in\mathbb{N}}$ studied by Duffin and Schaeffer is linearly independent. For *lattice* Gabor systems $\mathcal{G}(g, a, b) = \{e^{2\pi i bnx} g(x - ak)\}_{k,n\in\mathbb{Z}}$, it is likewise known that every finite subset is linearly independent, even if the system is not a frame. However, the answer is not known for irregular Gabor systems. As of this writing, the validity of the following conjecture is open.

Linear Independence of Time-Frequency Translates Conjecture. *If $g \in L^2(\mathbb{R})$ is not the zero function and $\{(a_k, b_k)\}_{k=1}^N$ is a set of finitely many distinct points in $\mathbb{R}^2$, then*

$$\{e^{2\pi i b_k x} g(x - a_k)\}_{k=1}^N$$

is linearly independent.

This conjecture is also known as the *HRT Conjecture*. It is known to be true for many special cases but not in general. For example, it is true if $N = 1$, 2, or 3. It is not known for $N = 4$, even if we impose the further condition that g is infinitely differentiable. In fact, even the following is open.

HRT Subconjecture. *If g is infinitely differentiable and $0 < \int_{-\infty}^{\infty} |g(x)|^2\, dx < \infty$, then*

$$\{g(x),\ g(x-1),\ e^{2\pi i x} g(x),\ e^{2\pi i\sqrt{2}x} g(x - \sqrt{2})\}$$

is linearly independent.

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Stay or Leave: What Factors Are Necessary to Persist in Mathematics Doctoral Programs in the U.S.? Perspectives from International Students

Dung Tran

Introduction

The mathematical community has recently become concerned about enrolling and keeping more students in doctoral programs. In particular, the attrition rate of students in Ph.D. programs in mathematics is alarmingly high and continues to increase. A. H. Herzig stated, "Despite the growing of scientific and quantitative needs of the twenty-first century, relatively small numbers of U.S. students develop and maintain an interest in studying science and mathematics" [6, p. 171]. In institutions of higher education in the United States, doctoral candidates in mathematics typically include American and international students with diverse backgrounds. The graduate students who had completed their college education at U.S. institutions often felt they were at a disadvantage compared to international students whose undergraduate training in mathematics was more advanced [5]. Given the increasing number of international students enrolled in doctoral programs, a companion question is, "What do international students in a Ph.D. program in mathematics experience?"

Foreign-born scientists and engineers are important for the security of the United States. This feeling was voiced by the president of the National Academy of Engineering: "Foreign-born scientists and engineers have come to the United States, stayed in large numbers, and *we are more prosperous and more secure, in large part, because of them!*" [9, p. 1]. In fact, in 2008 approximately 46.7 percent of students earning a Ph.D. in mathematics were international [7]. Exploring international students' perspectives about success in mathematics can facilitate the recruitment of international students for mathematics programs, as well as provide faculty members and administrators information that will be useful in establishing programs that provide a positive and supporting environment for international students.

This case study was done to gain a better understanding of the perspectives of international students pursuing a Ph.D. in mathematics and to learn why international students endure, persist, and successfully complete intensive doctoral programs. Furthermore, examining the academic life of doctoral students in mathematics may provide insight into the characteristics needed to succeed in the program.

Methods

The case study involved two Ph.D. students at a Midwestern university. Data collected included interviews, field notes, and related documents such as statements of purpose in their portfolios and writings regarding their beliefs about mathematics. As a native of Vietnam, I have also served as a lecturer in a mathematics department at a university in that country. Hence my beliefs about mathematics and mathematics careers were similar to those of the participants. Furthermore, being a part of the Vietnamese culture and studying at the same university with them for three years helped shape more valid interpretations. This study in no way seeks to be a generalization for all international students but instead aims to provide in-depth perspectives of Vietnamese students through this typical case.

In mathematics, we use an arbitrary case to draw an inference for all. However, such inferences cannot be made for social phenomena. Instead, people can start with typical cases or extreme outlier cases to gain in-depth information related to a phenomenon. While students from each country have their own unique cultural roots, looking specifically at Vietnamese students' experiences in the doctoral program may provide a new and useful perspective that will provide

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more knowledge about international students engaged in the programs.

The two participating students come from Vietnam; both are male, twenty-eight years of age, and from working class families. For the remainder of this paper the two students will be referred to as Dan and Victor. They are currently full-time Ph.D. students in the mathematics department of a research-intensive Midwestern university. During the 2011–2012 school year, this school's mathematics department consisted of thirty-six tenure-track faculty members, twenty nontenure-track faculty members, nine postdoctoral fellows, and seventy-seven master's and Ph.D. students. Over the last five years, thirty-six Ph.D. students have graduated (see Table 1).

School Year	Number of Ph.D. students graduating
2007–2008	9
2008–2009	8
2009–2010	8
2010–2011	9
Fall–2011	2

Table 1. Number of Ph.D. students graduating in five recent years.

Qualifying exams, including analysis and algebra tests, occur twice during the school year, once in January and once in July. Ph.D. students can take the exam more than once if they do not pass the exam the first time.

Both students participated in multiple Vietnamese competitions for talented students in mathematics in secondary school. They were also in the Honors Program in Vietnam, a program that recognizes talented high school students in specific subject areas. Students in the program devoted approximately fifteen hours per week to studying mathematics and to preparing for Vietnamese national competitions for talented students. They spent only one year finishing a three-year curriculum for high school students and used the remaining time to study advanced mathematics through special mentoring.

Dan and Victor finished their undergraduate program in mathematics and mathematics education, respectively, in Vietnam. After finishing their undergraduate degrees, they were selected to be lecturers for the mathematics departments where they studied, a common occurrence in most universities in Vietnam for students who excel in their studies. Dan was awarded his master's degree in mathematics from an institution in France. He took coursework in Vietnam with primarily French professors and then completed his thesis, written in English, in France. Victor completed one year of his master's degree at the university where he taught and then transferred to the Institution of Mathematics, the best academic program in mathematics in Vietnam, for another year. He decided to come to the United States after being admitted into the program without finishing his master's degree.

Dan and Victor both had the goal of going abroad, in particular to the United States, to complete their Ph.D. degrees in mathematics because of the reputation that the United States has for a "very good educational system," "good academia," or "top professors in the field." In addition, it is difficult to study mathematics in Vietnam because there is a lack of funding for research and there is not a strong community of mathematicians to help students accomplish their goals. At the time of this study Dan was in his third year of the Ph.D. program and Victor was in his fourth year of the program. They both received university fellowships for their first year in the program and assistantships from the university for the following years.

Stay or Leave: What Are the Factors?

Love for Mathematics

Dan and Victor shared the same belief that one needs to have talent to succeed in a Ph.D. program in mathematics. Learning mathematics was the way Victor used to show his "competitive intellect"; he participated in the Competition for Talented Students in Mathematics when he was a student in secondary school. Dan felt he possessed the talent to be successful in mathematics as well: "It seemed like I have a little talent in math." This belief tended to remain as they learned more about mathematics. "When I read more about math and learned math, I see that to succeed in mathematics, you need some kind of talents, specially the way you think," said Victor. They both mentioned that "potentials" in the field and "confidence" are prerequisites to studying mathematics. Furthermore, they both believed that the talent one has in mathematics was inherent and that this talent cannot be initiated within their programs. Although they admitted hard work is really necessary for success in mathematics programs, it is not "sufficient". Dan stated:

> After all, learning math is innate; I mean it is not trained, through your process of learning, the talent will be discovered. I am not sure if we can train someone to study math, or help a kid orient to study math in the future.

Their love of mathematics is an important part of their lives. In one of Victor's essay writings about mathematics, he compared mathematics to a beautiful charming girl he fell in love with. He started to regard mathematics as his immortal love in which he could find "absolute silence in his soul, the moment of aspiration, and the highly delighted moment." Dan and Victor had the same attitude towards mathematics, but the ways in which they became interested in mathematics were different. Victor's interest came from his reading about mathematicians who were very peculiar in how they devoted their entire lives to the study of mathematics even if they were in danger or had to make many sacrifices to continue studying math. With Dan, he came to be inspired towards mathematics with the Competition for Talented Students in Mathematics where he could prove that his success was innate for mathematics. In addition, Dan became interested in mathematics when he solved a multitude of problems in the *Journal of Mathematics and Youth*, a very famous journal for elementary mathematics in Vietnam containing highly challenging problems, and later inspired by his professors when he studied mathematics in his program.

They also regarded mathematics as their career, their "most important" life path. They chose to become professors in mathematics where they could teach and do mathematics as authentic mathematicians, and this was also the reason they chose to enter their Ph.D. programs. As Victor said:

> Well, it turns out that being a mathematician is so far away from being rich and famous. If one considers success as being rich and famous, one might not choose to be a mathematician. For me, I just love math so much so that I would be happy if I could do math and earn a living by doing math. I don't have a desire to be rich or famous.

Similarly, Dan wrote in his Statement of Purpose when applying for his Ph.D. program, "I can fulfill my lifelong dream of becoming a mathematician." Also his experiences in research made him "strongly believe that I will perform well in your [the] Ph.D. program and become a competitive mathematician."

Early Readiness for Milestones

Both students specified their subfields, analysis for Dan and algebraic geometry for Victor, during their programs at their undergraduate and master's institutions in Vietnam, allowing them to easily determine what courses to take during their first semester in the doctoral program. They also took two courses to prepare for the qualifying exams at the end of the first semester, including basic algebra and basic analysis. These two courses are designed for Ph.D. students, but both of them regard the courses as preparation "for master's students to pass the qualifying exam as well as for Ph.D. students to review basic knowledge in mathematics."

Dan's and Victor's scores were the highest among all students taking the qualifying exams; Dan received the highest score in the analysis test and Victor in the algebra test, coinciding with their subfields. The time they devoted to preparing for the exams ranged from one to three weeks after finishing the first semester in the Ph.D. program. However, they agreed that to succeed one should "accumulate knowledge on the way of learning," as it is not possible to wait until the exam and then prepare for several weeks. They used the short time during winter break to review and to practice "mathematics solving skills" and "techniques" for the problems related to the exams.

Highly determined, they continued to choose their coursework related to their research interests, which became "deeper and more specialized", and some courses of their "particular concern". The courses prepared as background and helped Dan and Victor know more about mathematics so that they could "communicate with others in conferences or outside of their subfield." Their perceptions about coursework changed during the program. For Victor, "The more I take classes, the worse I feel. Gradually, I tend to read books by myself." He described his ideal mathematics teaching style in a Ph.D. program as one in which the professor should be the person who guides the discussion and the students must "discover the idea" after they prepare and read the materials before class sessions. Dan, in contrast, expressed that, "Yes, I learn a lot of interesting knowledge from the classes," and he said they really helped him to "build up background" and prepared him for "doing research in the future."

Along with taking courses after the qualifying exam, they began focusing more on their research goals after the first semester, which they were familiar with from their undergraduate and master's programs. They started early working with their professors on the problems of interest. In the fourth year, Victor earned an award from the department for being the best student in research.

Close Relationship with Advisor

When choosing to apply to the university, they sought to find advisors who were among the best professors in their research fields of interest. With respect for his advisor, Victor valued his advisor's opinion and said, "Yes, before choosing courses, I always ask him first. His advice has significant impact on my choices. I think about 60 percent of my decisions have been influenced from him" even though Victor already knew what courses he should choose as part of his program to prepare for the qualifying exam, to support his research focus, or to learn more about his interests. Dan had a similar high regard for his advisor's opinion.

The role of advisor seems to be determinant in specifying a research focus. "For me, I specified my research trends when I chose my advisor. I mean, I knew I would do research related to his interest. Advisors often offer problems for their students to do," said Dan. At a very early stage in the program, they started research in their fields of interest. This academic activity helped the students have the feeling of doing mathematics as well as focusing on the problems they will complete for their dissertations.

The relationship with their advisors developed throughout the program, especially when they proved themselves. They both showed respect when talking about their advisors whether the relationship was in or outside of class. Victor said, "He's not only a good teacher in class but he's also very understanding and considerate outside the classroom." He described some "accidents" that helped him bond closer to his advisor:

> Well, we had a long journey before we could really understand each other well and know how the other thinks. For example, we were really extremely serious in a discussion in which we had different ideas of proving a lemma. That would have been worse but in the end we just realized that we were too serious and we both laughed.

The close relationship Victor had with his advisor made him confident to talk about his advisor's beliefs about mathematics and strengthened his passion for math.

Very early in his program, Dan carefully said about this relationship, "Good, most of the professors here are very nice. Whenever I have difficulty, they are eager to help." He said, "But if I am lazy, I don't want to meet with my advisor. For instance, when I have no result to report to him, I don't want to meet him." His advisor's working style somehow affects Dan's behavior; "They are very passionate to solve the problem thoroughly. When the problem results are not finished, they often suggest students to continue to solve." Establishing a good rapport with his advisor later in the program, Dan felt more comfortable sharing his ideas and sought help from his advisor.

Cultural Advantages

Dan and Victor began to be interested in mathematics when they were young and participated in competitions for those gifted in mathematics. They devoted a great deal of time, even double or triple the time other students devoted, to solving mathematical problems and to working on deeper and more general topics in the program, as well as to preparing for the exams. At an early age, they "liked mathematics and they liked the competitions" because they believed "the competitions also measured one's ability."

Both chose mathematics for their undergraduate program in Vietnam where they took courses focused on advanced mathematics, which provided them an appreciation for learning mathematics. They felt familiar with the content in their classes in the Ph.D. program because they had a chance to learn some of it at their undergraduate and master's institutions. In particular, when talking about the courses he took to prepare for the qualifying exam, Victor said, "Actually, two courses that I took… some like… the knowledge I have already built up for me in Vietnam." Consistent with what Victor said, Dan asserted, "Yes, my background in Vietnam was really helpful. I just had to review to prepare for the exam." This first orientation in mathematics helped the students specify their goal of mathematics very early. More importantly, they completed a thesis when they graduated from their undergraduate institutions based on original research in mathematics related to the problem their advisors were concerned with in their subfield.

Even though they admitted that sometimes they had difficulties speaking English at the very start of their program, it was not really a barrier for them to study mathematics. Sometimes they mentioned it was "difficult to get involved" or "to make friends" with students from different fields of study, but it didn't really matter. Both admitted that Vietnamese had advantages when learning mathematics, which helped them to get involved with the community very early. Victor thought, "Asians are smart, that is one of the advantages." Dan said,

> When I study in Vietnam, I have effort. This motivation is really helpful when I study here. When I have difficulty, I try to solve. I am not sure that is the case for U.S. students; maybe they do not try as hard as Vietnamese.

They thought that Vietnam and Asian countries focus on "test-oriented studying and are very competitive, so students try their best when working" to be successful—sink or swim. They shared the same thought that many students in Vietnam would like to study the formal sciences, which may not be practical at the time; in particular, they dealt a lot with pure mathematics with abstract levels early in their undergraduate programs. One thing to notice is that every student in Vietnam takes calculus in high school, so in their Honors Program, they studied much more advanced mathematics.

Their rich background in mathematics, their comfort with the program, their success in the program, and their desire to have a career as a mathematician caused both students to never consider leaving their Ph.D. program.

Discussion

The community of mathematicians sets expectations and students who are able or willing to adapt themselves to these U.S. cultural practices tend to be successful [6]. Mathematics is believed to be a discipline that is objective and emotion-free [1]; however these two Vietnamese students showed a different opinion. More specifically, both Victor and Dan were enthusiastic about mathematics and loved mathematics, and they felt mathematics could be subjective from the lens through which people look.

Students who enter graduate school participate in two distinct sequential communities of practice. In the first three years of study, students primarily participate in courses leading up to qualifying exams. Once they complete these requirements, they can begin looking for a research area/emphasis and learn to do research. V. Tinto stated that the first stage is far different from the activities of practicing mathematicians [8]. Proving themselves and examining their ability to be ready for the second stage in the program, both students built up more meaningful integration and relationships with advisors and other members in the community.

Mathematics is generally regarded as an objective field of knowledge in which mathematicians work to discover truths about the nature of the world [4]. This presumed objectivity of mathematics leads to a cultural blindness to personal issues in which students who do not correspond to the cultural norm (male, white, childless, self-assured) are at a disadvantage [3]. However, success in mathematics can be achieved by all; regardless of race or ethnicity. Dan and Victor asserted that they had an advantage when studying mathematics. Their culture encouraged patience and perseverance in solving math problems, which makes them confident both in coursework and independent research in mathematics.

Mathematics is not fragmented, and most mathematicians are not obsessive about their own little corner in isolation or worried about how their work connects to mathematics in the same area or outside their area in the "real" world. Mathematics is really a "big picture" field of study, and the Vietnamese students are on their way to exploring the picture with persistence, readiness, and a willingness to consider mathematics as a lifetime career.

Students participate in research and related activities and then overcome obstacles in order to integrate into the research community to practice as a full participant. Features of the individuals, relationships developed at the institution, and programs are correlated with doctoral student persistence; the quality of experience in graduate school is a function of how well integrated the student is in the academic communities of his own department. The results of this study also provide suggestions for students pursuing a Ph.D. degree in mathematics and for the community of mathematicians to successfully recruit native and international students.

How students prepare for a Ph.D. program in mathematics. Carefully considering an individual's interest in mathematics is one of the crucial points for determining if a student is appropriate for the program. One's interest may vary from time to time at the secondary school level and during undergraduate study, but a commitment to working hard when confronted with unfamiliar mathematics, exhibiting exceptional persistence, having confidence, and expecting to complete complex mathematics tasks are important for long-term success in mathematics [2]. Moreover, the willingness to adapt to the "competitive" academia at the first stage of the program sets the stage for self-proving and for building up meaningful integration into the environment later.

The qualifying exam often happens during the first years of the program, and students should be prepared for it. There is a big gap between undergraduate programs in mathematics and Ph.D. programs. The first year in the Ph.D. program may be overwhelming if students do not have a good background in mathematics. This is not the time to take courses to supplement basic knowledge for the exam or to transfer into the program [5]. Students should be prepared for the exam by equipping themselves with the knowledge before enrolling in the program. Students may consider taking a master's program before applying for a Ph.D. when the undergraduate program does not incorporate advanced mathematics. This transition step helps examine the student's interest in mathematics again and prepares students for their research experience.

Building up a good relationship with advisors and faculty members is essential for persistence in the program, but students need to be ready to prove themselves first. Students' interaction with faculty members during the first year of the program mostly occurs while listening to lectures in classes [5], [6], [8]. One should accept the role as a graduate student because treatment as "junior colleagues" is rare. Be focused, and be ready to feel isolated as you face the early challenges of the program.

What role do faculty members play supporting doctoral students? Some students select mathematics because of a genuine interest in mathematics. However, many people find that the reality of being enrolled in mathematics does not meet their expectations [6]. Transferring the beauty of mathematics to students through courses, office hours, or whenever interacting with them is helpful for them to keep their initial interest. Mathematics is a "big picture" field, but most students see one tiny piece of the picture, so that they do not see its beauty. Students need early moral support and encouragement to persist in the program.

The obstacles that students often encounter come from program structure or even from faculty members' beliefs about mathematics teaching and learning [5], [6]. Looking at students' mathematics backgrounds can serve as a predictor for their persistence in the program. Each student has his own learning trajectory, and receiving timely support from faculty members can help them succeed in the program. Recruiting international students who are ready to pursue a career in mathematics is of importance. Culture shock and language barriers are not big problems for students in mathematics. As Galileo stated, "The Universe is written in the language of mathematics" [4, p. 135].

Graduate students can be actively cultivated and provided with a nurturing environment that allows the largest possible number of them to be successful. Or they can be put in a demanding environment with little support so that whoever is not willing to adapt will not survive. The way Ph.D. students are educated in their programs may likely provide a model that they will emulate in their future careers so a self-perpetuating "domino effect" is created. The success of a student all depends on faculty members' beliefs about teaching and learning mathematics in the Ph.D. program.

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Lander Awarded Inaugural Breakthrough Prize

Eric S. Lander of the Massachusetts Institute of Technology and Harvard Medical School has been awarded an inaugural 2013 Breakthrough Prize, which carries a cash award of US$3,000,000.

He was honored "for the discovery of general principles for identifying human disease genes, and enabling their application to medicine through the creation and analysis of genetic, physical and sequence maps of the human genome." He was one of the principal leaders of the Human Genome Project and is currently president and founding director of the Eli and Edythe L. Broad Institute of Harvard and MIT, professor of biology at MIT, and professor of systems biology at Harvard Medical School.

Lander earned his B.A. in mathematics from Princeton University and his Ph.D. in mathematics from Oxford University, where he was a Rhodes Scholar. He wrote his doctoral thesis on algebraic coding theory and symmetric block designs. As a mathematician he studied combinatorics and applications of representation theory to coding theory. He later taught managerial economics at Harvard Business School.

He became interested in mathematical neurobiology and began by first studying cellular neurobiology and molecular biology. These studies finally led him to genetics. He joined the Whitehead Institute for Biomedical Research in 1986. In 1987 he received a MacArthur Fellowship. In 1990 he founded the Whitehead Institute/MIT Center for Genome Research (WICGR) and later the Broad Institute, which incorporated the laboratories of WICGR.

He has received numerous awards, including the Gairdner International Award, the Max Delbrück Medal, and the AAAS Award for Public Understanding of Science and Technology. He received the Albany Medical Center Prize in Medicine and Biomedical Research and the New York Academy of Medicine Medal for Distinguished Contributions in Biomedical Science. In 2009 President Barack Obama appointed him to cochair the President's Council of Advisors on Science and Technology. He is an elected member of the U.S. National Academy of Sciences, the U.S. Institute of Medicine, and the American Academy of Arts and Sciences, and is a member of the Mathematical Association of America.

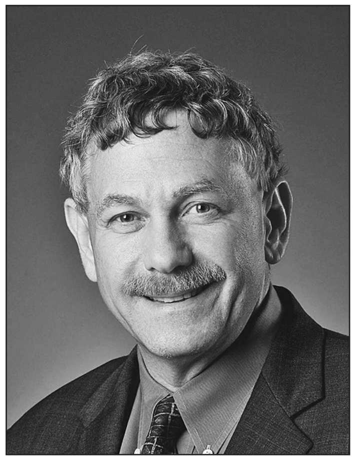
Photo by Len Rubenstein.

Eric S. Lander

The Breakthrough Prizes in Life Sciences were founded by Apple chairman Art Levinson; Google cofounder Sergey Brin; biotech analyst, biologist, and businesswoman Anne Wojcicki; Facebook founder Mark Zuckerberg and his wife, Priscilla Chan; and entrepreneur and investor Yuri Milner to recognize excellence in research aimed at curing intractable diseases and extending human life. The prize is administered by the Breakthrough Prize in Life Sciences Foundation, a not-for-profit corporation dedicated to advancing breakthrough research, celebrating scientists, and generating excitement about the pursuit of science as a career. The prizes are awarded annually for past achievements in the field of life sciences, with the aim of providing the recipients with more freedom and opportunity to pursue even greater future accomplishments.

—*Elaine Kehoe*

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Mazur and Golomb Awarded National Medal of Science

On December 21, 2012, President Obama announced the recipients of the National Medal of Science for 2011. Among the twelve honorees are two mathematicians: Barry Mazur of Harvard University and Solomon Golomb of the University of Southern California.

Barry Mazur

Barry Mazur was honored for "original and landmark contributions to differential topology, number theory, and arithmetic algebraic geometry, where, among other applications, his work was foundational to Wiles' proof of Fermat's last theorem and for his dedication to communicating subtle mathematical ideas to the broader public."

Photos: Ryan K. Morris/National Science & Technology Medals Foundation.

Barry Mazur and President Obama at National Medal ceremony, December 2012.

The *Notices* asked D. Kotschick of Ludwig-Maximilians-Universität München and R. L. Taylor of the Institute for Advanced Study to comment on the work of Mazur. They responded: "Barry Mazur is a mathematician of extraordinary breadth and originality. He started his career in topology, where he discovered what are now called Mazur manifolds. His achievements include a proof of the generalized Schoenflies theorem and a proof of the s-cobordism theorem. Mazur was the first to formalize certain arguments using infinite repetitions, which are designed to push difficulties off to infinity. This is now referred to as the 'Mazur swindle'.

"In the late 1960s Mazur's interests evolved toward number theory. Here he made a series of fundamental contributions, such as his work on Katz's conjecture, his classification of the possible rational torsion points on an elliptic curve, and his proof (with Wiles) of the main conjecture of Iwasawa theory. Mazur has repeatedly introduced new ideas and techniques into number theory that have changed the direction of the subject. With Swinnerton-Dyer he was the first to introduce p-adic L-functions for modular forms, a subject that has received enormous attention ever since. His 1977 Eisenstein ideal paper marked a turning point in the number theoretic applications of the detailed arithmetic algebraic geometry of modular curves. In the mid-1980s Mazur introduced the deformation theory of Galois representations, a simple, but extremely powerful, idea that transformed number theory. This proved to be key to Wiles' proof of Fermat's last theorem. A few years later, with Coleman, he introduced many new p-adic families of modular forms ('the eigencurve'), which continue to be a major topic of research. As important as Mazur's mathematical contributions are his remarkable contributions as a mentor. He has advised dozens of graduate students and postdocs, including many of the most successful number theorists of the last thirty-five years."

Barry Mazur was born in New York City and, under the direction of Ralph Fox, received his Ph.D. from Princeton University in 1959. At the time he received his degree, he had already proven the generalized Schoenflies conjecture in geometric topology. He was a research fellow at the Institute for Advanced Study from 1958 to 1959, and in 1959 he published his first four papers. He was a Junior Fellow at Harvard from 1959 to 1962. He became an assistant professor at Harvard in 1962 and is currently the Gerhard Gade University Professor and a Senior Fellow. His other honors include the Veblen Prize (1965), the Cole Prize (1982), the Chauvenet Prize (1994), and the Steele Prize (1999). He was elected a member of the National Academy of Sciences in 1982 and of the American Philosophical Society in 2001. He is the author of the book *Imagining Numbers (Particularly the Square Root of Minus Fifteen)* (Farrar, Straus and Giroux, 2003), and coauthor of *Universal Extensions and One Dimensional Crystalline Cohomology* with William Messing (Lecture Notes in Mathematics, Springer, 1974) and of *Kolyvagin Systems* with Karl Rubin (Memoirs of the AMS, 2004).

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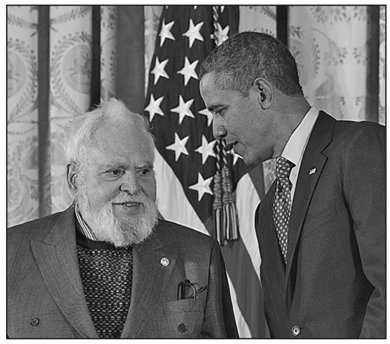
Solomon W. Golomb

Golomb was honored with the National Medal of Science for his "pioneering work in shift register sequences that changed the course of communications from analog to digital and for numerous innovations in reliable and secure space, radar, cellular, wireless and spread-spectrum communications."

The *Notices* asked Alfred W. Hales to comment on the work of Golomb. Hales is a professor emeritus at the University of California Los Angeles and is currently with the Center for Communications Research of the Institute for Defense Analyses. Hales responded: "For the past fifty-plus years, Solomon Golomb has been a world leader in the development and application of mathematics for communications and coding theory, especially digital and space communications. In his remarkable career, first at the Jet Propulsion Laboratory and then at the University of Southern California (in electrical engineering and mathematics), his research contributions have ranged over a wide spectrum of science and technology. Perhaps he is best known for his mathematical analysis of shift register sequences in his classic book with that title and in numerous journal publications—such sequences are ubiquitous in radar, space communications, cryptography, cell phones, etc. Other noteworthy contributions in this direction include Golomb (entropy) coding, Golomb rulers, and the Golomb construction for Costas arrays. For all this work the IEEE has honored him with both its Hamming Medal and the Shannon Award in Information Theory. Golomb's Harvard Ph.D. was in analytic number theory, and he has extensive (and seminal) publications in number theory, combinatorics, algebra, and various other fields (including even molecular genetics). He is also a noted expert in mathematical game theory (polyominoes were his invention), and he continues to publish a number of puzzle columns in various journals. In addition to his many research contributions, Golomb has had a great influence on future generations through his generous and insightful mentoring of young people—his students, postdocs, and many others."

Solomon Golomb was born in Baltimore, Maryland. He received his B.A. from Johns Hopkins University and his Ph.D. in mathematics from Harvard University in 1957 under the direction of David Widder. He is currently professor of electrical engineering at the University of Southern California and is best known to the general public and fans of mathematical games as the inventor of polyominoes, the inspiration for the computer game Tetris. While he was working toward his Ph.D. he held a Fulbright Fellowship at the University of Oslo. He worked at the Jet Propulsion Laboratory at the California Institute of Technology from 1956 to 1963, where he was a senior research mathematician and later supervisor of the research group and assistant chief of the Telecommunications Research Section. In the latter position he played a key role in formulating the design of deep-space communications for the subsequent lunar and planetary explorations. He joined the University of Southern California in 1963.



Solomon Golomb and President Obama.

In 1992 he received the medal of the U.S. National Security Agency for his research. He has also been the recipient of the Lomonosov Medal of the Russian Academy of Science and the Kapitsa Medal of the Russian Academy of Natural Sciences. His honors from the IEEE include the Shannon Award (1985) and the Richard W. Hamming Medal (2000) for his exceptional contributions to information sciences and systems. He was awarded the USC Presidential Medallion in 1985. He has been a major contributor in coding and information theory for more than forty years and is recognized for his ability to apply advanced mathematics to problems in digital communications. His books include *Shift Register Sequences* (Holden-Day, 1967), *Polyominoes* (Princeton University Press, 2nd ed., 1996), and *Signal Design for Good Correlation* (coauthored with Guang Gong, Cambridge University Press, 2005). He is a member of the National Academy of Engineering, the Institute of Electrical and Electronics Engineers (IEEE), the American Association for the Advancement of Science (AAAS), and a fellow of the AMS. He became a foreign member of the Russian Academy of Natural Science in 1994.

About the Medal

The National Medal of Science is the country's highest distinction for contributions to scientific research. According to a news release from the Office of Science and Technology Policy, "The National Medal of Science honors individuals for pioneering scientific research in a range of fields, including physical, biological, mathematical, social, behavioral, and engineering sciences, that enhances our understanding of the world and leads to innovations and technologies that give the United States its global economic edge." The National Science Foundation administers the award, which was established by Congress in 1959.

— Elaine Kehoe

Deligne Awarded 2013 Abel Prize

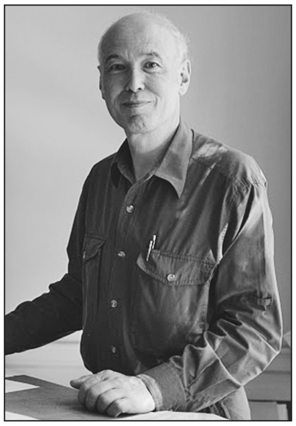


Photo: Cliff Moore.

Pierre Deligne

The Norwegian Academy of Science and Letters has awarded the Abel Prize for 2013 to PIERRE DELIGNE of the Institute for Advanced Study "for seminal contributions to algebraic geometry and for their transformative impact on number theory, representation theory, and related fields." The Abel Prize recognizes contributions of extraordinary depth and influence to the mathematical sciences and has been awarded annually since 2003. It carries a cash award of 6,000,000 Norwegian kroner (approximately US$1 million). Deligne received the Abel Prize in an award ceremony in Oslo, Norway, on May 21, 2013.

Citation

Geometric objects such as lines, circles, and spheres can be described by simple algebraic equations. The resulting fundamental connection between geometry and algebra led to the development of algebraic geometry, in which geometric methods are used to study solutions of polynomial equations and, conversely, algebraic techniques are applied to analyze geometric objects.

Over time, algebraic geometry has undergone several transformations and expansions and has become a central subject with deep connections to almost every area of mathematics. Pierre Deligne played a crucial role in many of these developments.

Deligne's best known achievement is his spectacular solution of the last and deepest of the Weil conjectures, namely the analogue of the Riemann hypothesis for algebraic varieties over a finite field. Weil envisioned that the proof of these conjectures would require methods from algebraic topology. In this spirit, Grothendieck and his school developed the theory of l-adic cohomology, which would then become a basic tool in Deligne's proof. Deligne's brilliant work is a real tour de force and sheds new light on the cohomology of algebraic varieties. The Weil conjectures have many important applications in number theory, including the solution of the Ramanujan-Petersson conjecture and the estimation of exponential sums.

In a series of papers, Deligne showed that the cohomology of singular, noncompact varieties possesses a mixed Hodge structure that generalized the classical Hodge theory. The theory of mixed Hodge structures is now a basic and powerful tool in algebraic geometry and has yielded a deeper understanding of cohomology. It was also used by Cattani, Deligne, and Kaplan to prove an algebraicity theorem that provides strong evidence for the Hodge conjecture.

With Beilinson, Bernstein, and Gabber, Deligne made definitive contributions to the theory of perverse sheaves. This theory plays an important role in the recent proof of the fundamental lemma by Ngo. It was also used by Deligne himself to greatly clarify the nature of the Riemann-Hilbert correspondence, which extends Hilbert's 21st problem to higher dimensions. Deligne and Lusztig used l-adic cohomology to construct linear representations for general finite groups of Lie type. With Mumford, Deligne introduced the notion of an algebraic stack to prove that the moduli space of stable curves is compact. These and many other contributions have had a profound impact on algebraic geometry and related fields.

Deligne's powerful concepts, ideas, results, and methods continue to influence the development of algebraic geometry, as well as mathematics as a whole.

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Biographical Sketch

Pierre Deligne was born in 1944 in Brussels, Belgium. He is professor emeritus in the School of Mathematics at the Institute for Advanced Study (IAS), Princeton, New Jersey.

When Deligne was around twelve years of age, he started to read his brother's university math books and to demand explanations. His interest prompted a high school math teacher, J. Nijs, to lend him several volumes of *Elements of Mathematics* by Nicolas Bourbaki, the pseudonymous grey eminence that called for a renovation of French mathematics. This was not the kind of reading matter that one would normally dream of offering a fourteen-year-old, but for Deligne it became a life-changing experience. From then on he never looked back.

Although his father wanted him to become an engineer and to pursue a career that would afford him a good living, Deligne knew early on that he should do what he loved, and what he loved was mathematics. He studied mathematics at the Université Libre de Bruxelles (University of Brussels) and received his Licence en mathématiques, the equivalent of a B.A., in 1966 and his Ph.D., Doctorat en mathématiques, in 1968. In 1972 Deligne received the doctorat d'Etatés Sciences Mathématiques from Université Paris-Sud 11.

Deligne went to the University of Brussels with the ambition of becoming a high school teacher and of pursuing mathematics as a hobby for his own personal enjoyment. There, as a student of Jacques Tits, Deligne was pleased to discover that, as he says, "One could earn one's living by playing, i.e., by doing research in mathematics."

After a year at École Normale Supérieure in Paris as auditeur libre, Deligne was concurrently a junior scientist at the Belgian National Fund for Scientific Research and a guest at the IHES. He was a visiting member at IHES from 1968 to 1970, at which time he was appointed its youngest permanent member.

Concurrently, he was a member (1972–1973, 1977) and visitor (1981) in the School of Mathematics at the IAS. He was appointed to a faculty position there in 1984.

In 1974 he received the François Deruyts Prize of the Belgium Royal Academy and the Henri Poincaré Medal from the French Academy of Sciences. He received the A. De Leeuw-Damry-Bourlart Prize in 1975 from the Belgian National Science Foundation. In 1978 he was awarded the Fields Medal. In 1988 he and A. Grothendieck received the Crafoord Prize of the Royal Swedish Academy of Sciences. In 2004 he received the Balzan Prize in Mathematics, which carries a cash award of 1 million Swiss francs. Because the Balzan Foundation requires that half of the sum be spent to support young researchers, Deligne chose to establish three-year research grants to support the most active young mathematicians working in Russia, Ukraine, and Belarus. In 2008 Deligne was awarded the Wolf Prize in Mathematics jointly with P. Griffiths and D. Mumford.

In 2006 Deligne was made a viscount by King Albert II of Belgium, and the Belgian postal service issued a postage stamp in honor of his achievements in fundamental mathematics.

He has been an honorary member of the Moscow Mathematical Society since 1995 and of the London Mathematical Society since 2003. He has been elected a foreign honorary member of the American Academy of Arts and Sciences (1978) and a foreign associate of the U.S. National Academy of Sciences (2007). In 2009 he became a member of the American Philosophical Society and a foreign member of the Royal Swedish Academy of Sciences.

About the Prize

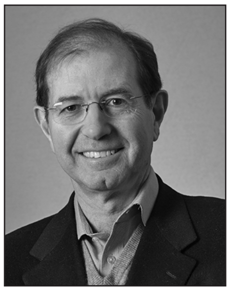
The Niels Henrik Abel Memorial Fund was established in 2002 to award the Abel Prize for outstanding scientific work in the field of mathematics. The prize is awarded by the Norwegian Academy of Science and Letters, and the choice of Abel Laureate is based on the recommendation of the Abel Committee, which consists of five internationally recognized mathematicians.

Previous recipients of the Abel Prize are: Jean-Pierre Serre (2003), Michael Atiyah and I. M. Singer (2004), Peter Lax (2005), Lennart Carleson (2006), S. R. S. Varadhan (2007), John G. Thompson and Jacques Tits (2008), Mikhail L. Gromov (2009), John Tate (2010), John Milnor (2011), and Endre Szemerédi (2012).

—From an announcement of the Norwegian Academy of Science and Letters

Goldwasser and Micali Awarded Turing Prize

Shafi Goldwasser



Silvio Micali

SHAFI GOLDWASSER of the Massachusetts Institute of Technology (MIT) and the Weizmann Institute of Science and SILVIO MICALI of MIT have received the 2012 A. M. Turing Award of the Association for Computing Machinery (ACM). The award, considered the "Nobel Prize in Computing", carries a cash award of US$250,000.

The prize citation reads in part: "Working together, [Goldwasser and Micali] pioneered the field of provable security, which laid the mathematical foundations that made modern cryptography possible. By formalizing the concept that cryptographic security had to be computational rather than absolute, they created mathematical structures that turned cryptography from an art into a science. Their work addresses important practical problems such as the protection of data from being viewed or modified, providing a secure means of communications and transactions over the Internet. Their advances led to the notion of interactive and probabilistic proofs and had a profound impact on computational complexity, an area that focuses on classifying computational problems according to their inherent difficulty."

Their 1983 paper "Probabilistic encryption" defined the security of encryption as a "game" involving adversaries; this definition has become a trademark of modern cryptography. Their simulation paradigm approach led to the construction of a secure encryption scheme. They observed that to satisfy their security definition, encryption schemes must be randomized rather than deterministic, with many possible encrypted texts corresponding to each message. This development revolutionized the study of cryptography and laid the foundation for the theory of cryptographic security that was developed throughout much of the 1980s.

Their introduction of the idea of zero-knowledge proofs provided the essential language for speaking about security of cryptographic protocols by controlling the leakage of knowledge.

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Shafi Goldwasser is the RSA Professor of Electrical Engineering and Computer Science at MIT, principal investigator at the MIT Computer Science and Artificial Intelligence Lab (CSAIL), and professor of computer science and applied mathematics at the Weizmann Institute of Science in Israel. She is the recipient of a National Science Foundation Presidential Young Investigator Award and of the ACM Grace Murray Hopper Award for outstanding young computer professional. She has twice won the Gödel Prize presented jointly by the ACM Special Interest Group on Algorithms and Computation Theory (SIGACT) and the European Association for Theoretical Computer Science (EATCS). She was elected to the American Academy of Arts and Sciences, the National Academy of Sciences, and the National Academy of Engineering. She was recognized by the ACM Council on Women in Computing (ACM-W) as the Athena Lecturer and received the IEEE Piore Award and the Franklin Institute's Benjamin Franklin Medal in Computer and Cognitive Science. She received her B.A. degree in mathematics from Carnegie Mellon University and her M.S. and Ph.D. degrees in computer science from the University of California Berkeley.

Silvio Micali, the Ford Professor of Engineering at MIT and a principal investigator at the MIT CSAIL, has received the Gödel Prize from ACM SIGACT and EATCS. A fellow of the American Academy of Arts and Sciences, the National Academy of Sciences, and the National Academy of Engineering, he is the recipient of the RSA Mathematics Award, the Berkeley Distinguished Alumnus of the Year Award, and the ISE (Information Security Executive) New England Rising Star Award. He is coeditor of a five-volume series of textbooks, *Advances in Computing Research*, and has published more than one hundred scientific papers. A graduate of Sapienza, University of Rome, with a degree in mathematics, he earned a Ph.D. degree in computer science from the University of California Berkeley.

The A. M. Turing Award was instituted in 1966 to honor the computer scientists and engineers who created the systems and underlying theoretical foundations that have propelled the information technology industry. Financial support for the Turing Award is provided by the Intel Corporation and Google Inc.

—From an ACM announcement

Teacher Training and Student Assessment: At Odds?

Michael Bardzell and Jennifer Bergner

Slipping standards for mathematics education in the United States have been a concern both at the state and national levels for many years. The role of the federal government and funding strategies to support education play a significant role in discussions on how to best address deficiencies in the American education system. There remain many diverse opinions on how to best improve student learning in mathematics. In [1] an argument is made that improving teacher quality is the key to better student learning and performance in mathematics and that this will necessitate further efforts in training and teacher support. How should taxpayer money be spent to improve teacher quality? There is a plethora of teacher professional development programs that focus on involving teachers in authentic mathematical experiences appropriate for their own classrooms. These programs share instructional materials and innovative approaches to classroom mathematics and engage teachers in standards-based mathematics instruction. Many such programs are funded by federal and state governments that put huge emphasis on standardized tests which assess how students implement basic mathematical algorithms instead of deeper conceptual understanding and more involved problem-solving skills. These professional development programs show how to make connections in mathematical knowledge by taking time to investigate, question, and conjecture. However, state tests point teachers in quite a different direction.

In recent years testing has been driven by No Child Left Behind (NCLB), although each state has its own set of standards. These high-stakes state tests focus on a small subset of mathematical skills which students should master. The questions are multiple choice or require short expository responses that do not reveal if a student has deep conceptual understanding of a topic. As student performance is used to measure how "successful" a school is, this encourages teaching of these concepts to be done in a linear and formulaic manner which does not emphasize connections between ideas. It also encourages teachers to turn the month before the state test into multiple cram sessions on how to do procedure X when key word/phrase Y is used in test questions. Ironically, much of the recently funded professional development has emphasized the importance of taking time to focus on mathematical content knowledge, problem solving, critical thinking skills, and a more integrated approach to mathematical learning with connections to other disciplines. But these

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programs have also deemphasized many rote procedures in K–12 mathematics.

We often hear from teachers that they would love to take the activities and approaches they see during their professional development programs into their classroom, but they are afraid to because the approach does not focus students on tested procedures and would distract them from the test items. We tell these educators that if their students can do more innovative and involved mathematics activities, then the rote type problems on standardized tests should be easier for them. But this is a tough sell to teachers who are under the gun with high-stakes tests that place so much importance on procedures. Teachers are told to implement inquiry-based learning approaches during their professional development, but the state tests send the message to teach isolated procedures.

Now the Common Core State Standards (CCSS) will define much of the K–12 educational climate for the foreseeable future (see [2] for one perspective). Although these standards were not written by the federal government, forty-five states have agreed to use the CCSS, making it a more nationalized effort than NCLB. CCSS describes eight standards for mathematical practice (see `www.corestandards.org`) and standards for mathematics content that are a "balanced combination of procedure and understanding." If test developers (like Smarter Balance and Partnership for Assessment of Readiness for College and Careers) write tests in alignment with the intent of CCSS, then the emphasis on rote memorization and isolated skills will be forced to change. Many school systems are already engaged in training for their teachers that involve the eight standards for mathematical practice. They are also in the process of redesigning curriculum guides to address the content standards. It is not yet clear what types of test questions will be written and how they will be evaluated. Will these new high-stakes tests measure a balance of procedure and understanding to test whether students can engage in a meaningful way with mathematics? Or will states once again push teachers towards isolated procedures and repeat the mistakes of NCLB? That remains to be seen.

So the question remains: what should professional development for K–12 teachers be in this current educational and fiscal climate? If test developers can find ways to create tests that better evaluate conceptual mathematical understanding, then CCSS-based professional development could be a step in the right direction. Teachers would engage in authentic mathematical experiences, share successful pedagogical approaches, and ultimately use these more innovative and creative techniques in the classroom. However, if test developers continue to write tests that focus too much on the successful completion of procedures, then such professional development programs will leave teachers facing their current pedagogical paradox. As Dr. William Schmidt claims, "What is clear in the research is that the Common Core State Standards for Mathematics are an important improvement over the state standards that they replaced and that, to see their full potential realized, they must be implemented well." He bases this claim on his research ([3]) which found that "States with past mathematics standards that were more similar to the CCSSM had statistically significantly higher NAEP (National Assessment of Educational Progress) 2009 performance."

In recent years, the "assessment" and "spending" arms of the federal and state governments have quite literally been working against each other. This has serious implications for our K–12 classrooms and the future of mathematics education. The debt ceiling crisis in Washington last year and the lead-up to the 2012 presidential election give us an indication of the tone and contention fiscal debates will have over the next several years. Our country has some tough decisions to make over our finances. But we also have many challenges regarding the current trajectory of the American K–12 education system, particularly with mathematics. Can we afford strong ongoing support of STEM education (mathematics in particular) and, in turn, meaningful teacher professional development? Can we afford not to support them? Either way, in-service teacher preparation will be important over the next decade. Whatever the future level of funding is for supporting initiatives, it is imperative that our teacher professional development and subsequent assessment efforts not be at odds. Sending teachers conflicting messages about how to run their classrooms is not only a misuse of taxpayer dollars, but it is harmful for the education of our students. While the levels of education funding will receive much of the spotlight over the next several years, we hope that the mathematical and education communities can work together and ensure that, whatever the funding, it is used in the most productive way to support our K–12 teachers and, ultimately, their students. The Common Core may provide an opportunity to take a step in the right direction if it can move us away from NCLB type assessments. In the future, we look forward to implementing meaningful teacher professional development that is consistent with both CCSS and student assessment.

References

[1] Irwin Kra, (Math) Teachers are the key, *Notices of the AMS*, Volume 59, Number 4, April 2012, 556–557.

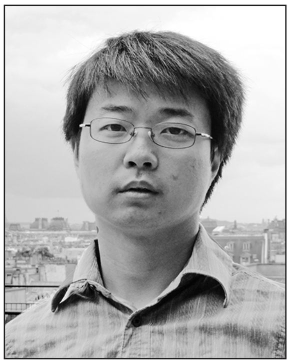
[2] Solomon Garfunkel, The Common Core State Standards—Education reform and us, *Notices of the AMS,* Volume 58, Number 6, June/July 2011, 820–821.

[3] Achieve, 2012, Common Core Math Standards implementation can lead to improved student achievement [Press conference]. Retrieved from `http://www.achieve.org/CCSS-schmidt-research`, video at `http://vimeo.com/41542448`.

Mathematics People

2013–2014 AMS Centennial Fellowship Awarded

The AMS has awarded its Centennial Fellowship for 2013–2014 to Xinwen Zhu of Northwestern University. The fellowship carries a stipend of US$82,000, an expense allowance of US$8,200, and a complimentary Society membership for one year.



Xinwen Zhu

Xinwen Zhu was born in China in 1982. He went to Peking University in China for undergraduate study and completed his Ph.D. degree at the University of California Berkeley in 2009 under the direction of Edward Frenkel. He was a Benjamin Peirce Lecturer at Harvard University from 2009 to 2012. He has been an assistant professor at Northwestern University since 2012.

Xinwen Zhu's research interests focus on geometric representation theory, in particular the geometric aspects of the Langlands program. He studies the geometry and topology of flag varieties of loop groups and applies techniques from the geometric Langlands program to arithmetic geometry.

He will use the Centennial Fellowship to visit Columbia University for several months during 2013–2014. During 2014–2015, he will use the fellowship to visit UC Berkeley and will participate in the program "Geometric Representation Theory" at the Mathematical Sciences Research Institute.

Please note: Information about the competition for the 2014–2015 AMS Centennial Fellowships will be published in the "Mathematics Opportunities" section of an upcoming issue of the *Notices*.

—Allyn Jackson

Chiang Receives Waterman Award

Mung Chiang of Princeton University has been named the recipient of the Alan T. Waterman Award of the National Science Foundation (NSF). Chiang is an electrical engineer who uses innovative mathematical analyses to design simpler and more powerful wireless networks. He is the founder of Princeton's EDGE Laboratory, which aims to connect network theory and real-world applications. He has also been a recipient of the U.S. Presidential Early Career Award for Scientists and Engineers (PECASE) and of the Office of Naval Research Young Investigator Award.

The Waterman Award is given annually to honor outstanding researchers under the age of thirty-five in any field of science or engineering supported by NSF. It carries an award of US$1 million spread over five years to further the recipient's research.

—From an NSF announcement

Tolsa Awarded Balaguer Prize

Xavier Tolsa of the Universitat Autònoma de Barcelona has been awarded the 2013 Ferran Sunyer i Balaguer Prize for his monograph *Analytic Capacity, the Cauchy Transform, and Nonhomogeneous Calderón-Zygmund Theory*. The monograph studies some of the striking advances that have occurred regarding analytic capacity and its relationship with rectifiability in the last two decades.

The Ferran Sunyer i Balaguer Foundation of the Institut d'Estudis Catalans (IEC) awards this international prize every year to honor the memory of Ferran Sunyer i Balaguer (1912–1967), a self-taught Catalan mathematician who gained international recognition for his research in mathematical analysis despite the serious physical disabilities with which he was born. The prize carries a cash award of 15,000 euros (approximately US$20,000); the winning monographs are published by Birkhäuser Verlag.

—From a Ferran Sunyer i Balaguer Foundation announcement

Raftery Awarded 2012 Parzen Prize

Adrian Raftery of the University of Washington has been awarded the 2012 Emanuel and Carol Parzen Prize for Statistical Innovation for "pioneering, influential, and outstanding research in statistical theory, including developing methods for Bayesian hypothesis testing, Bayesian model selection, Bayesian model averaging, probabilistic forecasting, model-based clustering and classification, inference from computer simulation models, time series, and image analysis" [and for] "leadership in applications of statistical methods to sociology, demography, environmental sciences, and health sciences."

Raftery received his Ph.D. in mathematical statistics in 1980 from the Université Pierre et Marie Curie and has been affiliated with the University of Washington since 1990. He is a founding director of the Center for Statistics and Social Sciences at the University of Washington.

He is a member of the U.S. National Academy of Sciences, a fellow of the American Academy of Arts and Sciences, a fellow of the American Statistical Association, a fellow of the Institute of Mathematical Statistics, and an elected member of the Sociological Research Association. His honors include the Population Association of America's Clifford C. Clogg Award, the American Sociological Association's Paul F. Lazarsfeld Award for Distinguished Contribution to Knowledge, and the Jerome Sacks Award for Outstanding Cross-Disciplinary Research from the National Institute of Statistical Sciences.

—Elaine Kehoe

Jimbo and Miwa Awarded Heineman Prize

The 2013 Dannie Heineman Prize in Mathematical Physics has been awarded to Michio Jimbo of Rikkyo University and Tetsuji Miwa of Kyoto University. Jimbo was honored "for profound developments in integrable systems and their correlation functions in statistical mechanics and quantum field theory, making use of quantum groups, algebraic analysis and deformation theory." Miwa was honored for "profound developments in integrable systems and their correlation functions in statistical mechanics and quantum field theory, making use of quantum groups, algebraic analysis and deformation theory."

The Heineman Prize is awarded annually in recognition of outstanding publications in the field of mathematical physics. The prize consists of US$10,000 and a certificate. It was established by the Heineman Foundation for Research, Educational, Charitable, and Scientific Purposes, Inc., and is administered jointly by the American Physical Society and the American Institute of Physics.

—From a Heineman Foundation announcement

Struwe Awarded Cantor Medal

Michael Struwe of Eidgenössische Technische Hochschule (ETH) Zürich has been awarded the 2012 Cantor Medal of the German Mathematical Society (DMV) "for his outstanding achievements in the field of geometric analysis, calculus of variations and nonlinear partial differential equations." He received his Ph.D. from the University of Bonn in 1980 and has been full professor at ETH since 1993. Among his honors are the Felix Hausdorff Prize (1984) and the Credit Suisse Award for the best teaching (2006). The Cantor Medal is awarded at most every two years and carries a cash award of 4,000 euros (approximately US$5,200).

—From a DMV announcement

Nemhauser and Wolsey Awarded von Neumann Prize

George L. Nemhauser of the Georgia Institute of Technology and Laurence A. Wolsey of the Université catholique de Louvain have been awarded the 2012 John von Neumann Theory Prize, the highest prize given in the field of operations research and management science, "for their outstanding and lasting contributions to integer optimization and example setting scholarship. Both individually and jointly, they have advanced significantly our understanding of discrete optimization both from theoretical and practical perspectives." The award, which is presented by the Institute for Operations Research and the Management Sciences (INFORMS), carries a cash prize of US$5,000.

—From an INFORMS announcement

Prizes of the Canadian Mathematical Society

The Canadian Mathematical Society has awarded a number of prizes for 2013.

Chantal David of Concordia University has been awarded the 2013 Krieger-Nelson Prize for her work in number theory. The prize recognizes female mathematicians who have made outstanding contributions in the area of mathematical research. According to the prize citation, her work focuses on understanding distribution questions associated to arithmetic objects such as elliptic curves, abelian varieties, and families of curves over finite fields.

Zinovy Reichstein of the University of British Columbia has been awarded the 2013 Jeffery-Williams Prize for Research Excellence for his contributions to the fields of algebra, algebraic geometry, and algebraic groups. The prize citation reads in part: "Reichstein's most notable research accomplishment is the discovery of an entirely new branch of study known as the essential dimension. Informally speaking, the essential dimension of an algebraic object is the minimal number of independent parameters one needs to define it. Essential dimension has proved to be a natural way to measure how complex an algebraic group is and, since its development, has been explored by mathematicians all over the world." The Jeffery-Williams Prize is awarded annually to an individual who has made outstanding mathematical research contributions.

Balázs Szegedy of the University of Toronto has been awarded the 2013 Coxeter-James Prize for young mathematicians who have made outstanding contributions to mathematical research. He was honored for his work in graph theory, analysis, and discrete mathematics. The prize citation reads in part: "Balázs Szegedy is interested in the asymptotic behaviour of very large systems such as the human brain as neural network, the Internet, and social networks. He also uses higher order Fourier analysis to deal with 'resonance patterns' found in chaotic waves. These generalize the Fourier transform that our inner ears are able to perform to listen to music." He has published and coauthored a number of papers in highly rated mathematics journals such as the *Journal of the AMS, Combinatorica*, and the *Journal of Combinatorial Theory*. He has been awarded the European Prize in Combinatorics (2009), a Sloan Fellowship (2009), and the Fulkerson Prize (2012).

—From a CMS announcement

Bondarenko Awarded Popov Prize

Andriy Bondarenko of the Kyiv National Taras Shevchenko University has been awarded the seventh Vasil Popov Prize for his outstanding contributions to approximation theory. He along with Radchenko and Viazovska solved the spherical t-design conjecture by Korevaar and Meyers. Bondarenko has also advanced powerful new ideas in other areas of approximation theory, in particular, in monotone rational approximation. The prize was awarded to Bondarenko at the 14th International Conference on Approximation Theory in San Antonio, Texas, where he gave a plenary lecture entitled "Fixed Point Theorems in Approximation Theory".

The Popov Prize honors the memory of Vasil A. Popov (1942–1990), the Bulgarian analyst best known for his work in nonlinear approximation. The prize is awarded every three years to a young mathematician who has made outstanding research contributions to approximation theory and/or related areas.

—From the Popov Prize Committee

Sloan Fellowships Awarded

The Alfred P. Sloan Foundation has announced the names of the recipients of the 2013 Sloan Research Fellowships. Each year the foundation awards fellowships in the fields of mathematics, chemistry, computational and evolutionary molecular biology, computer science, economics, neuroscience, physics, and ocean sciences. Grants of US$50,000 for a two-year period are administered by each fellow's institution. Once chosen, fellows are free to pursue whatever lines of inquiry most interest them, and they are permitted to employ fellowship funds in a wide variety of ways to further their research aims.

Following are the names and institutions of the 2013 awardees in mathematics: Zeev Dvir, Princeton University; Jacob Fox, Massachusetts Institute of Technology; Joshua E. Greene, Boston College; Adrian Ioana, University of California San Diego; Gautam Iyer, Carnegie Mellon University; Sarah C. Koch, Harvard University; Alex V. Kontorovich, Yale University; Swastik Kopparty, Rutgers, The State University of New Jersey; Jianfeng Lu, Duke University; Hoai-Minh Nguyen, University of Minnesota; Andrew Putman, Rice University; Pavlo Pylyavskyy, University of Minnesota; Yanir Rubinstein, University of Maryland, College Park; Sug Woo Shin, Massachusetts Institute of Technology; Jeffrey Streets, University of California Irvine; Arthur Szlam, The City College of the City University of New York; David Treumann, Boston College; Anna K. Wienhard, Princeton University; Robert Young, University of Toronto; and Wei Zhang, Columbia University.

—From a Sloan Foundation announcement

Hertz Fellowships Awarded

Three young mathematicians are among fifteen graduate students chosen to receive 2013 Fannie and John Hertz Foundation Fellowships. Zhou Fan of Harvard University and Cambridge University, Hilary Finucane of the Massachusetts Institute of Technology, and Eric Larson of Harvard University will receive support of more than US$250,000 each for up to five years of graduate work. Fellows have the freedom to innovate in their doctoral studies without university or research restrictions.

—From a Hertz Foundation announcement

Kouzniak Awarded 2013 PIMS Education Prize

Natalia Kouzniak of Simon Fraser University has been awarded the 2013 Education Prize of the Pacific Institute for the Mathematical Sciences. The prize recognizes individuals who have played a major role in encouraging activities that have enhanced public awareness and appreciation of mathematics, as well as those who foster communication among various groups concerned with mathematical education at all levels.

According to the prize citation, Kouzniak "has been an inspiration to her colleagues through her dedication to her students and tireless efforts for improving the instruction of mathematics and developing young people's interest in the subject." She has been involved in many outreach activities and has organized the annual Canadian Mathematical Society (CMS) Math Camps for high school students. She regularly visits area high school math classes along with some of her students as "math ambassadors" to talk about studying mathematics at the university level. In 2012 she was awarded the Simon Fraser University Excellence in Teaching Award.

-From a PIMS announcement

Harada Awarded Michler Prize

Megumi Harada of McMaster University has been awarded the 2013–2014 Ruth I. Michler Memorial Prize of the Association for Women in Mathematics (AWM). Harada was chosen for her "wide range of mathematical talents and her many connections with mathematics faculty at Cornell." Her research involves the interface of symplectic geometry, algebraic geometry, geometric representation theory, and algebraic combinatorics. In particular she studies classes of varieties such as toric varieties, Kac-Moody flag varieties G/P, and Hessenber varieties. At Cornell she plans to work with her long-term collaborators: Reyer Sjamar on divided difference operators in equivariant *K*-theory and a *K*-theoretic Martin theorem, and Tara Holm on the equivariant *K*-theory of orbifold toric varieties.

Harada received her Ph.D. in mathematics from the University of California Berkeley in 2003 under the direction of Allen Knutson, who is now a faculty member at Cornell. She held a postdoctoral research fellowship at the University of Toronto, as well as visiting positions at the Hausdorff Research Institute for Mathematics, the Mathematical Sciences Research Institute, and the Max Planck Institute for Gravitational Physics. She is currently an associate professor at McMaster.

The Ruth I. Michler Prize grants a midcareer woman in academia a residential fellowship in the Cornell University mathematics department without teaching obligations.

—From an AWM announcement

Cheney Awarded Kovalevsky Lectureship

Margaret Cheney of Colorado State University has been chosen as the AWM-SIAM Sonia Kovalevsky Lecturer for 2013 by the Association for Women in Mathematics (AWM). According to the citation, she was honored "in recognition of her broad line of research that is coupling disparate radar solutions in ways previously unrecognized. Her application of microlocal analysis to high-frequency radar scattering, a method largely unknown to the radar community, has proven to be especially relevant to the problems of radar target detection, tracking, and imaging. Using these tools, she has shown how the essential behavior of a wide variety of radar scattering scenarios can be isolated from secondary phenomena. Moreover, her unconventional approach has developed solutions to several long-standing problems in radar imaging that have heretofore defied complete analysis." Cheney will deliver the AWM-SIAM Kovalevsky Lecture at the 2013 meeting of the Society for Industrial and Applied Mathematics (SIAM) in San Diego, California. The Sonia Kovalevsky Lectureship honors significant contributions of women to applied or computational mathematics.

—From an AWM-SIAM announcement

Putnam Prizes Awarded

The winners of the seventy-third William Lowell Putnam Mathematical Competition have been announced. The Putnam Competition is administered by the Mathematical Association of America (MAA) and consists of an examination containing mathematical problems that are designed to test both originality and technical competence. Prizes are awarded to both individuals and teams.

The five highest ranking individuals, listed in alphabetical order, were: Benjamin P. Gunby (Massachusetts Institute of Technology), Eric K. Larson (Harvard University), Mitchell M. Lee (Massachusetts Institute of Technology), Zipei Nie (Massachusetts Institute of Technology), and Evan M. O'Dorney (Harvard University). Each received a cash award of US$2,500.

Institutions with at least three registered participants obtain a team ranking in the competition based on the rankings of three designated individual participants. The five top-ranked teams (with members listed in alphabetical order) were: first place, Harvard University (Eric K. Larson, Evan M. O'Dorney, Allen Yuan); second place, Massachusetts Institute of Technology (Benjamin P. Gunby, Brian C. Hamrick, Jonathan Schneider); third place, University of California Los Angeles (Xiangyi Huang, Tudor Padurariu, Dillon Zhi); fourth place, Stony Brook University (Thao T. Do, Dat Pham Nguyen, Kevin R. Sackel); and fifth place, Carnegie Mellon University (Michael Druggan, Albert Gu, Linus V. Hamilton). The first-place team receives an award of US$25,000, and each member of the team receives US$1,000. The awards for second place are US$20,000 and US$800; for third place, US$15,000 and US$600; for fourth place, US$10,000 and US$400; and for fifth place, US$5,000 and US$200.

—From an MAA announcement

Intel Science Talent Search Winners Announced

Three students who work in the mathematical sciences have received scholarship awards in the 2013 Intel Science Talent Search. Hannah Larson, eighteen, of South Eugene High School in Eugene, Oregon, was awarded fourth place and a US$40,000 scholarship for her project, "Classification of Some Fusion Categories of Rank Four". Samuel Zbarsky, a seventeen-year-old student at Montgomery Blair High School in Rockville, Maryland, was awarded seventh place and a US$25,000 scholarship for his project, "On Improved Bounds for Bounded Degree Spanning Trees for Points in Arbitrary Dimension". SAHANA VASUDEVAN, a sixteen-year-old homeschooled student at Gnyanam Academy in Palo Alto, California, received the tenth place award and a US$20,000 scholarship for her project, "Minimizing the Number of Carries in the Set of Coset Representatives of a Normal Subgroup".

—From an Intel Corporation announcement

NSF Graduate Research Fellowships

The National Science Foundation (NSF) has awarded a number of Graduate Research Fellowships for fiscal year 2013. Further awards may be announced later in the year. This program supports students pursuing doctoral study in all areas of science and engineering and provides a stipend of US$30,000 per year for a maximum of three years of full-time graduate study. Following are the names of the awardees in the mathematical sciences selected so far in 2013, followed by their undergraduate institutions (in parentheses) and the institutions at which they plan to pursue graduate work. TRICITY M. ANDREW (University of Tulsa), Harvard University; JOSEPH ARTHUR (North Carolina State University), Stanford University; DANIEL E. BLADO (California Institute of Technology), Massachusetts Institute of Technology; BENJAMIN BOND (Massachusetts Institute of Technology), University of California Berkeley; KOUSHIKI BOSE (Brown University), New York University; JENNIFER A. BRYSON (Texas A&M University), Stanford University; SAMUEL J. CAVAZOS (University of Texas, Pan American), Northwestern University; STEPHANIE F. CHAN (Massachusetts Institute of Technology), University of California Berkeley; GEOFFREY D. CLAPP (University of Maryland Baltimore County), University of Maryland College Park; STEVEN COLLAZOS (Binghamton University), University of Minnesota-Twin Cities; ALEXIS B. COOK (Duke University), University of Michigan Ann Arbor; MARTIN S. COPENHAVER (Georgia Institute of Technology), University of Maryland College Park; SAMUEL K. DASARATHA (Harvard University), Stanford University; JESSICA C. DE SILVA (California State University, Stanislaus), Stanford University; JESSIE A. DEERING (East Tennessee State University), University of California San Diego; COLLEEN DELANEY (California Institute of Technology), University of California Berkeley; BRANDON E. DUTRA (University of California Davis), University of California Davis; MIRIAM FARBER (Technion-Israel Institute of Technology), Princeton University; TONY FENG (Harvard University), Princeton University; KATELYN X. GAO (Massachusetts Institute of Technology), Stanford University; SHEILA GAYNOR (University of North Carolina at Chapel Hill), University of North Carolina at Chapel Hill; MARYCLARE C. GRIFFIN (University of Chicago), Carnegie Mellon University; GENO A. GUERRA (Arizona State University), University of California Berkeley, MAMIKON A. GULIAN (University of Maryland, Baltimore County), Princeton University; ALEXANDER GUTIERREZ (Arizona State University), University of Minnesota-Twin Cities; EWAIN N. GWYNNE (Northwestern University), University of California Berkeley; JEREMY HAHN (Massachusetts Institute of Technology), Harvard University; CARLOS X. HERNANDEZ (Columbia University), University of California San Diego; DANIEL J, HOFF (University of Minnesota-Twin Cities), University of California San Diego; JENNIFER M. IGLESIAS (Harvey Mudd College), Carnegie-Mellon University; ALEXANDER D. KAISER (University of California Berkeley), New York University; CASEY L. KELLEHER (California Polytechnic State University), University of California Irvine; JOHN Y.-J. KIM (Massachusetts Institute of Technology), Rutgers University; AMY M. K. KO (Amherst College), University of Washington; ERIC K. LARSON (Harvard University), Massachusetts Institute of Technology; ZANE K. LI (Princeton University), Harvard University; MARISSA K. LOVING (University of Hawaii at Hilo), University of Illinois at Urbana-Champaign; DANIELLE MADDIX (University of California Berkeley), University of California Berkeley; ADAM MARTINEZ (Arizona State University), Cornell University; DANIEL A. MONTEALEGRE (University of California Los Angeles), University of California Berkeley; MURPHYKATE L. MONTEE (University of Notre Dame), Princeton University; MARGARET E. NICHOLS (Oberlin College), University of Chicago; ELIZABETH O'REILLY (University of Pittsburgh), University of California Los Angeles; KYLE PERLINE (Clarkson University), Cornell University; LISA M. PICCIRILLO (Boston College), University of Texas at Austin; SAMUEL D. PIMENTEL (Stanford University), University of Pennsylvania; TYLER M. REESE (University of Connecticut), Cornell University; KELLY A. ROOKER (Bridgewater College), University of Tennessee Knoxville; DAVID B. RUSH (Massachusetts Institute of Technology), University of California Berkeley; WILL F. SAWIN (Yale University), Princeton University; DAVID A. SHERMAN (University of Michigan), Stanford University; LUIS SORDO VIEIRA (Wayne State University), University of Kentucky Research Foundation; KAITLIN M. SPEER (Baylor University), Northwestern University; JAN D. STEPINSKI (City College, City University of New York), Stanford University; BENJAMIN J. STETLER (Stanford University), Harvard University; CARSEN STRINGER (University of Pittsburgh), California Institute of Technology; RACHEL SUGGS (Brigham Young University), Brigham Young University; NIKET H. THAKKAR (University of Arizona), University of Washington; ASHLEIGH THOMAS (University of Pennsylvania), Stanford University; SARAH I. TREBAT-LEDER (Princeton University), Emory University; NICHOLAS G. TRIANTAFILLOU (University of Michigan), Princeton University; EMMANUEL TSUKERMAN (Stanford University), New York University; DANE VAN DOMELEN (Milwaukee School of Engineering), Emory University; ARTURO VARGAS (University of California Irvine), Rice University; ALISON I. WEBER (University of Chicago), University of Washington; ASHIA C. WILSON (Harvard University), University of California Berkeley; CHENGCHENG Y. YANG (Rice University), Rice University.

—From an NSF announcement

Guggenheim Fellowships Awarded

The John Simon Guggenheim Memorial Foundation has announced the names of 175 scholars, artists, and scientists who were selected as Guggenheim Fellows for 2013. Guggenheim Fellows are appointed on the basis of distinguished achievement in the past and exceptional promise for future accomplishment. Three scholars whose work involves the mathematical sciences have received fellowships for 2013. They are Peter Clote, Boston College; Samuel Kou, Harvard University; and Alexander Merkurjev, University of California Los Angeles.

—From a Guggenheim Foundation news release

SIAM Fellows Elected

The Society for Industrial and Applied Mathematics (SIAM) has elected thirty-three new fellows for 2013. Their names and institutions follow.

Randolph E. Bank, University of California San Diego; Kaushik Bhattacharya, California Institute of Technology; Jerry L. Bona, University of Illinois at Chicago; Oscar Bruno, California Institute of Technology; John A. Burns, Virginia Polytechnic Institute and State University; Raymond Honfu Chan, Chinese University of Hong Kong; Andrew R. Conn, IBM T. J. Watson Research Center; Benoit Couet, Schlumberger-Doll Research Center; Timothy A. Davis, University of Florida; Qiang Du, Penn State University; Michael C. Ferris, University of Wisconsin-Madison; Christodoulos A. Floudas, Princeton University; Michel X. Goemans, Massachusetts Institute of Technology; Andrew V. Goldberg, Microsoft Research; Alan Hastings, University of California Davis; Sze-Bi Hsu, National Tsing Hua University; Shi Jin, Shanghai Jiao Tong University and University of Wisconsin-Madison; David Kinderlehrer, Carnegie Mellon University; Edgar Knobloch, University of California Berkeley; C. David Levermore, University of Maryland, College Park; Marc Mangel, University of California Santa Cruz; Hans G. Othmer, University of Minnesota; Haesun Park, Georgia Institute of Technology; Robert J. Plemmons, Wake Forest University; John Rinzel, New York University; Björn Sandstede, Brown University; Guillermo Sapiro, Duke University; Michael A. Saunders, Stanford University; Larry L. Schumaker, Vanderbilt University; Horst D. Simon, Lawrence Berkeley National Laboratory; Peter R. Turner, Clarkson University; Pauline van den Driessche, University of Victoria; James A. Yorke, University of Maryland, College Park.

—From a SIAM announcement

Marshall Sherfield Scholarship Winners Announced

Three young scholars whose work involves the mathematical sciences have been awarded Marshall Sherfield Scholarships to study in the United Kingdom. Aditya Balasubramanian (Harvard University) will study for the M.Sc. in econometrics and mathematical economics at the London School of Economics. William Berdanier (University of Texas at Austin) will pursue Part III of the Mathematical Tripos at Cambridge University. Spencer Smith (University of Michigan) will study economics at the University of Oxford.

—From a Marshall Scholarship announcement

Corrections

The "Mathematics People" section of the May 2013 issue of *Notices* carried an item entitled "Miná Receives CMS Teaching Award". This should have read "Minác Receives CMS Teaching Award". The Canadian Mathematical Society's Excellence in Teaching Award recipient is Ján Minác of the University of Ontario.

Also in the May issue, the bibliographic information for Ingrid Daubechies ("Daubechies and Mumford Receive BBVA Foundation Award") stated that Daubechies was awarded the Ruth Little Satter Prize in 1997. In fact the award is the Ruth Lyttle Satter Prize.

—Sandy Frost

Mathematics Opportunities

NSF CAREER Awards

The National Science Foundation (NSF) solicits proposals for the Faculty Early Career Development (CAREER) Awards. These awards support junior faculty members who exemplify the role of teacher-scholars through outstanding research, excellent education, and the integration of education and research within the context of the mission of their organizations. In addition, award recipients are eligible to be selected for Presidential Early Career Awards for Scientists and Engineers (PECASE). The deadline for submission of proposals in the mathematical sciences is **July 24, 2013**. For more information, see `http://www.nsf.gov/pubs/2011/nsf11690/nsf11690.htm`.

—From an NSF announcement

Call for Nominations for Parzen Prize

To promote the dissemination of statistical innovation, the Emanuel and Carol Parzen Prize for Statistical Innovation is awarded in even-numbered years to North American statisticians who have made outstanding and influential contributions by developing innovative statistical methods. Candidates must have received the Ph.D. degree more than twenty-five years before the nomination. The prize consists of an honorarium of US$1,000 and travel expenses to College Station, Texas, to present a lecture at the prize ceremony. Nominations for the 2013 Parzen Prize should be submitted by **October 1, 2013**, to Thomas Wehrly, Department of Statistics, 3143 TAMU, Texas A&M University, College Station, Texas 77843-3143. For more information see the website `http://www.stat.tamu.edu/awards-and-prize-details.php?prizeid=7`.

—From a Texas A&M announcement

Call for Nominations for Sloan Fellowships

Nominations of candidates for Sloan Research Fellowships, sponsored by the Alfred P. Sloan Foundation, are due by **September 16, 2013**. A candidate must be a member of the regular faculty at a college or university in the United States or Canada and must have received the Ph.D. or equivalent within the six years prior to the nomination. For information, write to: Sloan Research Fellowships, Alfred P. Sloan Foundation, 630 Fifth Avenue, Suite 2550, New York, New York 10111-0242 or consult the foundation's website: `http://www.sloan.org/fellowships`.

—From a Sloan Foundation announcement

Call for Nominations for 2014 Balaguer Prize

The Ferran Sunyer i Balaguer Foundation invites nominations for the 2014 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$19,600) and publication of the winning monograph in Birkhäuser Verlag's series Progress in Mathematics. The deadline for nominations is **December 2, 2013**. For more information see `http://ffsb.iec.cat`.

—Ferran Sunyer i Balaguer Foundation announcement

Call for Nominations for 2013 SASTRA Ramanujan Prize

The Shanmugha Arts, Science, Technology, Research Academy (SASTRA) is seeking nominations for the 2013 SASTRA Ramanujan Prize. The prize is given annually to a mathematician not over the age of thirty-two for outstanding contributions in an area of mathematics influenced by the late Indian mathematical genius Srinivasa Ramanujan. The prize carries a cash award of US$10,000 and an invitation to give a talk at the SASTRA conference in December 2013. The deadline for nominations is **July 31, 2013**. For more information see the website `http://www.math.ufl.edu/sastra-prize/nominations-2013.html`.

—Krishna Alladi, University of Florida

Call for Nominations for Heineman Prize

The American Physical Society (APS) and the American Institute of Physics (AIP) are seeking nominations for the 2014 Dannie Heineman Prize for Mathematical Physics. The prize recognizes outstanding publications in the field of mathematical physics. The prize carries a cash award of US$10,000, an award certificate, and travel expenses to the meeting at which the prize is given. The deadline for nominations for the 2014 prize is **July 1, 2013**. For more information, see the APS website at `http://www.aps.org/programs/honors/prizes/heineman.cfm`.

—From an APS announcement

Fulbright Postdoctoral Fellowships in Israel

The United States-Israel Educational Foundation (USIEF), the Fulbright commission for Israel, will award eight fellowships to U.S. postdoctoral researchers in support of work to be carried out at Israeli universities during the course of the 2014-2015 and 2015-2016 academic years. The fellowships will support study for at least two academic years with an award of US$20,000 per academic year. The deadline for applications is **August 1, 2013**. For more information, see the website `http://j.mp/AMS_Fulbright`.

—From a USIEF announcement

Call for Proposals for 2014 NSF-CBMS Regional Conferences

The NSF-CBMS Regional Research Conferences in the Mathematical Sciences is a series of five-day conferences, each of which features a distinguished lecturer delivering ten lectures on a topic of important current research in one sharply focused area of the mathematical sciences. The lecturer subsequently prepares an expository monograph based upon these lectures which is normally published as a part of a regional conference series. CBMS refers to the Conference Board of the Mathematical Sciences, which publicizes the conferences and administers the resulting publications. Support is provided for about thirty participants at each conference. Proposals should address the unique characteristics of the NSF-CBMS conferences, outlined in the program description.

Proposals may be submitted only by the following: universities and two- and four-year colleges (including community colleges) accredited in and having a campus located in the United States acting on behalf of their faculty members. The following organizations also are referred to as academic institutions: nonprofit, nonacademic organizations such as independent museums, observatories, research labs, professional societies, and similar organizations in the United States associated with educational or research activities.

The deadline for full proposals is **July 2, 2013**. For more information, see the NSF website at `http://www.nsf.gov/pubs/2013/nsf13550/nsf13550.htm`.

—From an NSF announcement

News from the Clay Mathematics Institute

The Clay Mathematics Institute (CMI) will hold the Clay Research Conference on October 2, 2013, at the Mathematical Institute of the University of Oxford, United Kingdom. The speakers are Peter Constantin (Princeton University), Lance Fortnow (Georgia Institute of Technology), Fernando Rodriguez Villegas (University of Texas at Austin), and Edward Witten (Institute for Advanced Study).

The recipient of the 2013 Clay Research Award will be announced at the conference. Presented annually, the Clay Research Award celebrates the outstanding achievements of the world's most gifted mathematicians.

The following workshops will be held throughout the week of the conference:

September 29–October 1, 2013: The Navier-Stokes Equations and Related Topics.

September 30–October 4, 2013: New Insights into Computational Intractability.

September 30–October 4, 2013: Number Theory and Physics.

September 30–October 4, 2013: Quantum Mathematics and Computation.

Registration for the conference is required and free. Participation in the workshops is by invitation; a limited number of additional places is available. Some financial assistance is available for Ph.D. students and early career researchers; some accommodations are available. For more information, email Naomi Kraker at `admin@claymath.org`. For full details, including the schedule, titles, and abstracts when they become available, see `www.claymath.org/CRC13/`.

These events are held in conjunction with the University of Oxford's Mathematical Institute's Opening Conference on October 3, 2013, celebrating the opening of the institute's new building. The speakers are Ingrid Daubechies (Duke University), Raymond Goldstein (University of Cambridge), and Sir Andrew Wiles (University of Oxford). For more information and to register, visit `www.maths.ox.ac.uk/opening`.

—CMI announcement

News from MSRI

With funding from the National Science Foundation (NSF) and the National Security Agency (NSA), the Mathematical Sciences Research Institute (MSRI) will hold six workshops in Optimal Transport: Geometry and Dynamics and Mathematical General Relativity during the fall of 2013. Established researchers, postdoctoral fellows, and graduate students are invited to apply for funding. It is the policy of MSRI to actively seek to achieve diversity in its 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. The workshops to be held are as follows:

August 22–23, 2013: Connections for Women Workshop on Optimal Transport: Geometry and Dynamics. Website: `http://www.msri.org/web/msri/scientific/workshops/programmatic-workshops/show/-/event/Wm9225`.

August 26–August 30, 2013: Introductory Workshop on Optimal Transport: Geometry and Dynamics. Website: `http://www.msri.org/web/msri/scientific/workshops/programmatic-workshops/show/-/event/Wm9226`.

September 3–4, 2013: Connections for Women: Mathematical General Relativity. Website: `http://www.msri.org/web/msri/scientific/workshops/programmatic-workshops/show/-/event/Wm9551`.

September 9–13, 2013: Introductory Workshop: Mathematical Relativity. Website: `http://www.msri.org/web/msri/scientific/workshops/programmatic-workshops/show/-/event/Wm9552`.

October 14–18, 2013: Fluid Mechanics, Hamiltonian Dynamics, and Numerical Aspects of Optimal Transportation. Website: `http://www.msri.org/web/msri/scientific/workshops/programmatic-workshops/show/-/event/Wm9227`.

November 18–22, 2013: Initial Data and Evolution Problems in General Relativity. Website: `http://www.msri.org/web/msri/scientific/workshops/programmatic-workshops/show/-/event/Wm9554`.

—MSRI announcement

Inside the AMS

AMS-AAAS Mass Media Fellow Chosen

Anna Haensch has been awarded the 2013 American Mathematical Society's Mass Media Fellowship. Anna will earn her Ph.D. in mathematics from Wesleyan University in May 2013 and will work at National Public Radio for ten weeks this summer.

The Mass Media Science and Engineering Fellowship program is organized by the American Association for the Advancement of Science (AAAS). It is a very competitive program designed to improve public understanding of science and technology by placing advanced science, mathematics, and engineering students in newsrooms nationwide. Fellows work with media professionals to improve their communication skills and increase their understanding of the editorial process by which events and ideas become news.

The program is available to college or university students (in their senior years or in any graduate or postgraduate level) in the natural, physical, health, engineering, computer, or social sciences or mathematics with outstanding written and oral communication skills and a strong interest in learning about the media. The program has supported more than five hundred fellows over thirty years.

For more information on the AAAS Mass Media Science and Engineering Fellowship Program, visit the website `http://www.aaas.org/programs/education/MassMedia/`.

—AMS Washington Office

Fan China Exchange Program Names Awardees

The Society's Fan China Exchange Program awards grants to support collaborations between Chinese and U.S. or Canadian researchers. Institutions in the United States or Canada apply for the funds to support a visitor from China or vice versa. This funding is made possible through a generous gift made to the AMS by Ky and Yu-Fen Fan in 1999. The awardees for 2013 follow.

Michigan State University received a grant of US$5,000 to support a visit from Yongxia Hua, Harbin Institute of Technology.

Wayne State University received a grant of US$5,000 to support a visit from Yu Qiao, Shaanxi Normal University.

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—MSRI announcement

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For more information on the AAAS Mass Media Science and Engineering Fellowship Program, visit the website `http://www.aaas.org/programs/education/MassMedia/`.

—AMS Washington Office

Fan China Exchange Program Names Awardees

The Society's Fan China Exchange Program awards grants to support collaborations between Chinese and U.S. or Canadian researchers. Institutions in the United States or Canada apply for the funds to support a visitor from China or vice versa. This funding is made possible through a generous gift made to the AMS by Ky and Yu-Fen Fan in 1999. The awardees for 2013 follow.

Michigan State University received a grant of US$5,000 to support a visit from Yongxia Hua, Harbin Institute of Technology.

Wayne State University received a grant of US$5,000 to support a visit from Yu Qiao, Shaanxi Normal University.

University of Central Florida received a grant of US$5,000 to support a visit from Xing Liang, University of Science and Technology of China.

The department of each visitor will receive a grant of US$1,000 after the visit.

For information about the Fan China Exchange Program, visit the website http://www.ams.org/programs/travel-grants/china-exchange/china-exchange or contact the AMS Membership and Programs Department, email: chinaexchange@ams.org, telephone 401-455-4170 (within the U.S. call 800-321-4267, ext. 4170).

—AMS Membership and Programs Department

Erdős Memorial Lecture

The Erdős Memorial Lecture is an annual invited address named for the prolific mathematician Paul Erdős (1913–1996). The lectures are supported by a fund created by Andrew Beal, a Dallas banker and mathematics enthusiast. The Beal Prize Fund, now US$100,000, is being held by the AMS until it is awarded for a correct solution to the Beal Conjecture (see www.math.unt.edu/~mauldin/beal.html). At Mr. Beal's request, the interest from the fund is used to support the Erdős Memorial Lecture.

The first Erdős Memorial Lecturer for 2013 was Endre Szemerédi of Rutgers University and the Rényi Institute of Mathematics, who gave a lecture in April 2013 titled "On Subset Sums" at the Spring Central Section Meeting at Iowa State University.

The second 2013 Erdős Memorial Lecturer will be Barry Mazur of Harvard University. He will deliver a lecture at the Fall Eastern Section Meeting at Temple University in October 2013.

—AMS announcement

From the AMS Public Awareness Office

e-Mentoring Network in the Mathematical Sciences. This new AMS blog is edited by Ricardo Cortez (Tulane University) and Dagan Karp (Harvey Mudd College). Its goals are to reach and engage as many readers as possible, especially those who may not have sufficient mentoring at their current institution, and to connect students and mentors. Contributing bloggers will be Erika Camacho (Arizona State University), Rebecca Garcia (Sam Houston State University), Edray Goins (Purdue University), Herbert Medina (Loyola Marymount University), Talithia Williams (Harvey Mudd College), and Robin Wilson (Cal Poly Pomona). Members of the mathematics community are invited to comment on the blogs. http://blogs.ams.org/mathmentoringnetwork/.

Erik Demaine Gives Arnold Ross Lecture at MoMath. Erik Demaine (MIT) delighted more than 150 New York-area high school students with his lecture "Algorithms Meet Art, Puzzles, and Magic" at the National Museum of Mathematics (MoMath) in New York in April. Demaine showed the students many connections between mathematics and art, puzzles, and magic. Both Glen Whitney, the museum's director who welcomed audience members, and David Pollack (Wesleyan University), 2012 chair of the Arnold Ross Lecture Series Committee, who introduced Demaine, are former participants in the Young Scholars Program. Following the lecture, eight of the students, six of whom were female, played Who Wants to Be a Mathematician. Eric Schneider, a senior at High Technology High School in New Jersey, was the big winner, winning US$3,000. His classmate, Cynthia Guo, who is a sophomore, finished second and won US$500. Read more about the lecture and game at www.ams.org/arl2013.

—Annette Emerson and Mike Breen
AMS Public Awareness Officers
paoffice@ams.org

An Avuncular Chat about Reviewing for *Mathematical Reviews*

Benjamin P. Richert and Norman Richert

The reviews in *Mathematical Reviews* are increasingly important in an age of growing chaos in electronic searching for information about mathematical research. The reviews are of two kinds: those that are written by one of the over 15,000 active reviewers around the world and those that consist of the author's summary or other text drawn from the original publication. All the reviews provide information to help guide the *Mathematical Reviews*/MathSciNet user to papers and books of interest, but the externally written reviews are especially valuable, because they are typically written by someone who is very familiar with the topic area of the paper. This column is an informal conversation between an MR staff member, Norm, and a reviewer, Ben, who, by an amazing coincidence, happens to be a nephew of Norm. In this conversation we will touch on the value of reviewers to MathSciNet and the value of reviewing to reviewers.

Norm: *How did you come to be a reviewer for MR?*

Ben: When I moved to Ann Arbor to start my postdoc I got the tour of *Math Reviews*' offices. I think it was there that you first explained the importance of MR and suggested that I should sign up. Most people probably aren't so lucky to get invited to review on site! I wasn't sure that I could do it and thus stalled a bit, but shortly thereafter an invitation to review showed up in my mailbox. I'm glad that I accepted.

Norm: *How does reviewing work, from the reviewer's point of view?*

Ben: After receiving a formal invitation by email, I indicated my areas of reviewing interest by using the Mathematics Subject Classification (MSC) and some keyword phrases. When my first paper arrived in the mail, I remember that I wandered across the hall and asked a colleague if he did reviews for MR. Yes, he did. And how, exactly, did he go about it? He pulled open a drawer and showed me a few of the papers he was working on. His approach was to summarize the main results and give some indication of the techniques used in the proofs. That seemed like pretty good advice, and I always start my reviews with that in mind. I also attempt to put the results in context.

Norm: *How is reviewing different from refereeing?*

Ben: When I review I don't ever nitpick details of the presentation or go looking for typos or mistakes. Of course, if I find an error, I point it out, but I view my job as descriptive and not evaluative.

Norm: *I keep telling reviewers how valuable reviewing is to the world mathematical community. How is it valuable to you?*

Ben: Quite valuable. Research is required at my institution, but teaching is our primary mission, and can tend to crowd out other activities. Since the papers I get from MR are usually close to my interests, reviewing has helped me stay current in my field. Reviewing is also valued by the university (as a service to the profession) and plays a role in tenure and promotion.

Norm: *Have you ever been sent a paper that you were unable to review and sent it back to us?*

Ben: No, the editors have done a pretty good job of matching me with papers. Only once have I been tempted, but the paper was interesting, so I went ahead and did it.

Norm: *Excellent! Sometimes an editor will send you a paper that is way outside your interests, or perhaps is by a colleague who is close enough that you feel uncomfortable reviewing it. Just send an email to* `mathrev@ams.org`*, and we will send it to someone else. In the*

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old days we would have asked you to return the paper to us, but that is no longer necessary. Books must be returned, but I don't believe we have sent you a book yet.

Ben: No, I haven't reviewed a book. Am I right that book reviews work differently than article reviews? Journal articles simply arrive periodically, but I was once asked specifically about reviewing a book. I had to turn down that opportunity because I was so busy at the time. How would I indicate that I would like to review books in the future? How would I go about changing the number of papers I get sent at any one time in case I get busy again?

Norm: *You guessed right: books are handled differently. Because replacement may be difficult, we always ask the reviewer first before we send a book. Unless you said, "Don't ever send me a book" in your response to our inquiry about reviewing a book, a book is still an option. Regarding the frequency of being sent papers, there is a limit number associated with your reviewer database record that is an upper bound on the number of review items you will have in your hands at any one time. You can write to* `mathrev@ams.org` *and request that number be smaller. Typical numbers are in the 1–6 range. In the future this limit number should be visible at the Reviewer Home* (`www.ams.org/mresubs`).

Ben: Do you read my reviews?

Norm: *I don't normally have the opportunity. I edit in number theory and your reviewing interest is in commutative algebra, which is handled by another editor. I saw one of your reviews once while substituting for the commutative algebra editor and enjoyed it very much. After you submit your review, a number of eyes see it. We still use* $\mathcal{AMS}$-TEX *in the MR Database, so sometimes there is some massaging related to the* LaTeX *to* TeX *conversion. A copyeditor works on it, addressing English language issues* (*not many in your case*) *and working on any references you included in your review. Then two editors see it, and finally another copyeditor does quality control work. It is a fairly involved process.*

Ben: Is there anything new I should know about?

Norm: *In early January of 2013 a new database underlying the sign-in you do at the Reviewer Home was put into place on the AMS site. The first time you sign in after this change, you will be instructed to create a username and password. The username is easy: it will be the email address associated with your AMS Web Account. Your old password will be blanked, and you will be asked to create a new one. I hear you groaning. Fortunately, this is a one-time procedure, and at least you will always know what your username is. Speaking of your tour of MR, we extend an invitation to anyone visiting Ann Arbor to stop by our offices, particularly in this year celebrating the 125th anniversary of the AMS.*

Ben: Thanks for the chat. I think I'll go work on a review.

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 `smf@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.

Information for *Notices* Authors

The *Notices* welcomes unsolicited articles for consideration for publication, as well as proposals for such articles. The following provides general guidelines for writing *Notices* articles and preparing them for submission. Contact information for *Notices* editors and staff may be found on the *Notices* website, `http://www.ams.org/notices`.

***Notices* readership**. The *Notices* publishes articles that have broad appeal for a diverse audience with many different types of readers: graduate students, academic mathematicians, industrial mathematicians, researchers in mathematically based fields, and amateur enthusiasts. The paper edition of the *Notices* is sent to the approximately 33,000 members of the AMS, most of whom are professional mathematicians; about 25,000 of them reside in North America. Because the *Notices* is accessible for free over the Internet, the number of readers is much larger than the

AMS membership. All readers may be assumed to be interested in mathematics research, but they are not all active researchers.

Notices Feature Articles

Topics. The *Notices* seeks exceptional articles that report on major new developments in mathematics or that describe episodes from mathematics history that have connection to current research in the field. We also welcome articles discussing aspects of the mathematics profession, such as grant programs, the job market, professional opportunities for mathematicians, publishing, electronic communications, etc. We are also interested in articles about mathematics education at all levels. We publish reviews of books, films, plays, software, and mathematical tools.

Reaching the audience. Our goal is to educate the readership about new developments in mathematics and in the mathematics profession, as well as other matters of interest to the working mathematician. Each article is expected to have a large target audience of readers, perhaps 5,000 of the 33,000 subscribers. Authors must therefore write their articles for nonexperts rather than for experts or would-be experts. In particular, the mathematics articles in the *Notices* are expository. A *Notices* article should have an introduction that anyone can understand, and almost all readers should be able to understand the key points of the article.

Structure of articles. Most feature articles, including those on mathematics, are expected to be of long-term value and should be written as such. Ideally each article should put its topic in a context, providing some history and other orientation for the reader, and, as necessary, relating the subject matter to things that readers are likely to understand. In most cases, articles should progress to dealing with contemporary matters, not giving only historical material. The articles that are received the best by readers tend to relate different areas of mathematics to each other.

By design the *Notices* is partly magazine and partly journal, and authors' expository styles should take this into account. For example, many readers want to understand the mathematics articles without undue effort and without consulting other sources.

Format and length. Mathematics feature articles in the *Notices* are normally six to nine pages, sometimes a little longer. Shorter articles are more likely to be read fully than are longer articles. The first page is 400 or 500 words, and subsequent pages are about 800 words. From this one should subtract an allowance for figures, photos, and other illustrations and an appropriate allowance for any displayed equations and bibliography. The *Notices* is especially interested in the creative use of graphics and color and encourages illustrations. Articles on professional topics are typically 3 to 5 pages, as are book reviews.

Editorial process. The *Notices* aims to publish exceptionally well-written articles that appeal to a broad audience of mathematicians. Highly technical, specialized articles with a great deal of notation, insider jargon, and a long list of references are not suitable for the *Notices*. Some articles will be rejected by the editors without any external review. Other articles will be carefully refereed, and then a detailed editorial process will be used to bring the article up to the *Notices* standard. There will be considerable give and take between the author(s) and the editor, and it may take several drafts to get the article right.

The "WHAT IS...?" Column

Nearly every issue of the *Notices* carries an installment of the "WHAT IS...?" column. The purpose of the column is to provide brief, nontechnical descriptions of mathematical objects in use in current research. The target audience for the columns is first-year graduate students.

Each "WHAT IS...?" column provides an expository description of a single mathematical object being used in contemporary research. Thus "WHAT IS *M*-Theory?" would be too broad, but "WHAT IS a Brane?" would be appropriate; ideally "WHAT IS a Brane?" would give a flavor of what *M*-theory is.

The writing should be nontechnical and informal. Narrative description conveying main ideas should be favored over notation-heavy precision.

Where to Find It

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

There is a limit of two *Notices* pages (1,400 words with no picture or 1,200 words with one picture). A list of "Further Reading" should contain no more than three references. Inquiries and comments about the "WHAT IS...?" column are welcome and may be sent to notices-whatis@ams.org.

Upcoming Deadlines

July 1, 2013: Nominations for Dannie Heineman Prize. See "Mathematics Opportunities" in this issue.

July 2, 2013: Proposals for NSF-CBMS Regional Conferences. See "Mathematics Opportunities" in this issue.

July 24, 2013: Proposals for NSF CAREER Awards. See "Mathematics Opportunities" in this issue.

July 31, 2013: Nominations for SASTRA Ramanujan Prize. See "Mathematics Opportunities" in this issue.

August 1, 2013: Applications for August review for National Academies Research Associateship Programs. See the website 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 13, 2013: Full proposals for NSF Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) program. See http://www.nsf.gov/pubs/2012/nsf12529/nsf12529.htm.

September 15, 2013: Applications for spring 2014 semester of Math in Moscow. See http://www.mccme.ru/mathinmoscow, or write to: Math in Moscow, P.O. Box 524, Wynnewood, PA 19096; fax: +7095-291-65-01; e-mail: mim@mccme.ru. Information and application forms for the AMS scholarships are available on the AMS website at http://www.ams.org/programs/travel-grants/mimoscow, or by writing to: Math in Moscow Program, Membership and Programs Department, American Mathematical Society, 201 Charles Street, Providence RI 02904-2294; email student-serv@ams.org.

September 16, 2013: Nominations for Sloan Fellowships. See "Mathematics Opportunities" in this issue.

September 30, 2013: Nominations for W. K. Clifford Prize. See http://www.wkcliffordprize.org.

October 1, 2013: Applications for AWM Travel Grants and Mathematics Education Research Travel Grants. See https://sites.google.com/site/awmmath/programs/travel-grants; or telephone: 703-934-0163; e-mail: awm@awm-math.org; or contact Association for Women in Mathematics, 11240 Waples Mill Road, Suite 200, Fairfax, VA 22030.

October 4, 2013: Letters of intent for NSF Program ADVANCE Institutional Transformation and Institutional Transformation Catalyst awards. See http://www.nsf.gov/pubs/2012/nsf12584/nsf12584.htm?WT.mc_id=USNSF_36&WT.mc_ev=click.

October 16, 2013: Proposals for National Science Foundation (NSF) Postdoctoral Research Fellowships. See http://www.nsf.gov/pubs/2012/nsf12496/nsf12496.htm.

October 1, 2013: Nominations for Parzen Prize. See "Mathematics Opportunities" in this issue.

November 1, 2013: Applications for November review for National Academies Research Associateship Programs. See the website 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.

November 12, 2013: Full proposals for NSF Program ADVANCE Institutional Transformation and Institutional Transformation Catalyst awards. See http://www.nsf.gov/pubs/2012/nsf12584/nsf12584.htm?WT.mc_id=USNSF_36&WT.mc_ev=click.

December 2, 2013: Nominations for Ferran Sunyer i Balaguer Prize. See "Mathematics Opportunities" in this issue.

Book List

The Book List highlights recent books that have mathematical themes and are aimed at a broad audience potentially including mathematicians, students, and the general public. 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.

Algorithmic Puzzles, by Anany Levitin and Maria Levitin. Oxford University Press, October 2011. ISBN-13: 978-01997-404-44.

American Mathematicians as Educators, 1893–1923: Historical Roots of the "Math Wars", by David Lindsay Roberts. Docent Press, July 2012, ISBN-13: 978-09837-004-49.

Assessing the Reliability of Complex Models: Mathematical and Statistical Foundations of Verification, Validation, and Uncertainty Quantification, by the National Research Council. National Academies Press, 2012. ISBN: 978-0-309-25634-6.

The Best Writing on Mathematics 2012, edited by Mircea Pitici. Princeton University Press, November 2012. ISBN-13: 978-06911-565-52.

The Big Questions: Mathematics, by Tony Crilly. Quercus, April 2011. ISBN-13: 978-18491-624-01. (Reviewed October 2012.)

**Charles S. Peirce on the Logic of Number, by Paul Shields.* Docent Press, October 2012. ISBN-13: 978-0-9837004-7-0.

**The Continuity Debate: Dedekind, Cantor, du Bois-Reymond, and Peirce on Continuity and Infinitesimals,* by Benjamin Lee Buckley. Docent Press, December 2012. ISBN-13: 978-0-9837004-8-7.

The Crossing of Heaven: Memoirs of a Mathematician, by Karl Gustafson. Springer, January 2012. ISBN-13: 978-36422-255-74.

Decoding the Heavens: A 2,000-Year-Old Computer—and the Century-Long Search to Discover its Secrets, by Jo Marchant. Da Capo Press, February 2009. ISBN-13: 978-03068-174-27. (Reviewed in this issue).

The Foundations of Geometry And Religion from an Abstract Standpoint, by Salilesh Mukhopadhyay. Outskirts Press, July 2012. ISBN-13: 978-1-4327-9424-8.

The Fractalist: Memoir of a Scientific Maverick, by Benoit Mandelbrot. Pantheon, October 2012. ISBN-13: 978-03073-773-57.

Fueling Innovation and Discovery: The Mathematical Sciences in the

21st Century, by the National Research Council. National Academies Press, 2012. ISBN-13: 978-0-309-25473-1.

Galileo's Muse: Renaissance Mathematics and the Arts, by Mark Austin-Peterson. Harvard University Press, October 2011. ISBN-13: 978-06740-597-26. (Reviewed November 2012.)

Game Theory and the Humanities: Bridging Two Worlds, by Steven J. Brams. MIT Press, September 2012. ISBN-13: 978-02625-182-53.

Games and Mathematics: Subtle Connections, by David Wells. Cambridge University Press, November 2012. ISBN-13: 978-11076-909-12.

Girls Get Curves: Geometry Takes Shape, by Danica McKellar. Plume, July 2013. ISBN-13: 978-04522-987-43.

**Google's PageRank and Beyond: The Science of Search Engine Rankings*, by Amy Langville and Carl Meyer. Princeton University Press, February 2012. ISBN-13: 978-06911-526-60.

**The Golden Ticket: P, NP, and the Search for the Impossible*, by Lance Fortnow. Princeton University Press, March 2013. ISBN-13: 978-06911-564-91.

Guesstimation 2.0: Solving Today's Problems on the Back of a Napkin, by Lawrence Weinstein. Princeton University Press, September 2012. ISBN-13: 978-06911-508-02.

Heavenly Mathematics: The Forgotten Art of Spherical Trigonometry, by Glen Van Brummelen. Princeton University Press, December 2012. ISBN-13: 978-06911-489-22.

Henri Poincaré: Impatient Genius, by Ferdinand Verhulst. Springer, August 2012. ISBN-13: 978-14614-240-62.

Henri Poincaré: A Scientific Biography by Jeremy Gray. Princeton University Press, November 2012. ISBN-13: 978-06911-527-14.

How to Study as a Mathematics Major, by Lara Alcock. Oxford University Press, March 2013. ISBN-13: 978-0199661312.

I Died for Beauty: Dorothy Wrinch and the Cultures of Science, by Marjorie Senechal. Oxford University Press, December 2012. ISBN-13:978-01997-325-93.

Ibn al-Haytham's Theory of Conics, Geometrical Constructions and Practical Geometry, by Roshdi Rashed. Routledge, February 2013. ISBN: 978-0-415-58215-5.

Infinity: New Research Frontiers, edited by Michael Heller and W. Hugh Woodin. Cambridge University Press, February 2011. ISBN-13: 978-11070-038-73.

The Infinity Puzzle: Quantum Field Theory and the Hunt for an Orderly Universe, by Frank Close. Basic Books, November 2011. ISBN-13: 978-04650-214-44. (Reviewed September 2012.)

In Pursuit of the Traveling Salesman: Mathematics at the Limits of Computation, by William J. Cook. Princeton University Press, December 2011. ISBN-13: 978-06911-527-07.

In Pursuit of the Unknown: 17 Equations That Changed the World, by Ian Stewart. Basic Books, March 2012. ISBN-13: 978-04650-297-30. (Reviewed December 2012.)

Introduction to Mathematical Thinking, by Keith Devlin. Keith Devlin, July 2012. ISBN-13: 978-06156-536-31.

**Invisible in the Storm: The Role of Mathematics in Understanding Weather*, by Ian Roulstone and John Norbury. Princeton University Press, February 2013. ISBN-13: 978-06911-527-21.

The Joy of x: A Guided Tour of Math, from One to Infinity, by Steven Strogatz. Eamon Dolan/Houghton Mifflin Harcourt, October 2012. ISBN-13: 978-05475-176-50.

Late Style: Yuri I. Manin Looking Back on a Life in Mathematics. A DVD documentary by Agnes Handwerk and Harrie Willems. Springer, March 2012. ISBN NTSC: 978-3-642-24482-7; ISBN PAL: 978-3-642-24522-0. (Reviewed January 2013.)

Lemmata: A Short Mathematical Thriller, by Sam Peng. CreateSpace, December 2011. ISBN-13: 978-14681-442-39.

Levels of Infinity: Selected Writings on Mathematics and Philosophy, by Hermann Weyl. Edited by Peter Pesic. Dover Publications, February 2013. ISBN-13: 978-0486489032.

The Logician and the Engineer: How George Boole and Claude Shannon Created the Information Age, by Paul J. Nahin, Princeton University Press, October 2012. ISBN-13: 978-06911-510-07.

Magical Mathematics: The Mathematical Ideas That Animate Great Magic Tricks, by Persi Diaconis and Ron Graham. Princeton University Press, November 2011. ISBN-13: 978-06911-516-49. (Reviewed August 2012.)

Manifold Mirrors: The Crossing Paths of the Arts and Mathematics, by Felipe Cucker. Cambridge University Press, April 2013. ISBN-13: 978-0521728768.

Math Girls, by Hiroshi Yuki (translated from the Japanese by Tony Gonzalez). Bento Books, November 2011. ISBN-13: 978-09839-513-15. (Reviewed August 2012.)

Math Goes to the Movies, by Burkard Polster and Marty Ross. Johns Hopkins University Press, July 2012. ISBN-13: 978-14214-048-44.

Math Is Murder, by Robert C. Brigham and James B. Reed. Universe, March 2012. ISBN-13: 978-14697-972-81.

Mathematical Excursions to the World's Great Buildings, by Alexander J. Hahn. Princeton University Press, July 2012. ISBN-13: 978-06911-452-04.

The Mathematical Writings of Évariste Galois, edited by Peter M. Neumann. European Mathematical Society, October 2011. ISBN-13: 978-3-03719-104-0. (Reviewed December 2012.)

A Mathematician Comes of Age, by Steven G. Krantz. Mathematical Association of America, December 2011. ISBN-13: 978-08838-557-82.

A Mathematician's Lament: How School Cheats Us Out of Our Most Fascinating and Imaginative Art Form, by Paul Lockhart. Bellvue Literary Press, April 2009. ISBN-13: 978-1-934137-17-8. (Reviewed April 2013.)

Mathematicians in Bologna 1861-1960, edited by Salvatore Coen. ISBN-13: 978-30348-022-60.

Mathematics in Popular Culture: Essays on Appearances in Film, Fiction, Games, Television and Other Media, edited by Jessica K. Sklar and Elizabeth S. Sklar. McFarland, February 2012. ISBN-13: 978-07864-497-81.

Mathematics in Victorian Britain, by Raymond Flood, Adrian Rice, and Robin Wilson. Oxford University Press, October 2011. ISBN-13: 978-019-960139-4.

Maverick Genius: The Pioneering Odyssey of Freeman Dyson, by Phillip F. Schewe. Thomas Dunne Books, February 2013. ISBN-13:*978-03126-423-58.*

Meaning in Mathematics, edited by John Polkinghorne. Oxford University Press, July 2011. ISBN-13: 978-01996-050-57. (Reviewed May 2013.)

Measurement, by Paul Lockhart. Belknap Press of Harvard University Press, September 2012. ISBN-13: 978-06740-575-55.

Nine Algorithms That Changed the Future: The Ingenious Ideas That Drive Today's Computers, by John MacCormick. Princeton University Press, December 2011. ISBN-13: 978-06911-471-47.

On the Formal Elements of the Absolute Algebra, by Ernst Schröder (translated and with additional material by Davide Bondoni; with German parallel text). LED Edizioni Universitarie, 2012. ISBN-13: 978-88-7916-516-7.

Paradoxes in Probability Theory, by William Eckhardt. Springer, September 2012. ISBN-13: 978-94007-513-92. (Reviewed March 2013.)

**Peirce's Logic of Continuity: A Conceptual and Mathematical Approach,* by Fernando Zalamea. Docent Press, December 2012. ISBN-13: 978-0-9837004-9-4.

Proving Darwin: Making Biology Mathematical, by Gregory Chaitin. Pantheon, May 2012. ISBN-13: 978-03754-231-47.

**Relations Between Logic and Mathematics in the Work of Benjamin and Charles S. Peirce,* by Allison Walsh. Docent Press, October 2012. ISBN-13: 978-0-9837004-6-3.

The Search for Certainty: A Journey through the History of Mathematics, 1800-2000, edited by Frank J. Swetz. Dover Publications, September 2012. ISBN-13: 978-04864-744-27.

Secrets of Triangles: A Mathematical Journey, by Alfred S. Posamentier and Ingmar Lehman. Prometheus Books, August 2012. ISBN-13: 978-16161-458-73.

Seduced by Logic: Emilie Du Châelet, Mary Somerville and the Newtonian Revolution, by Robyn Arianrhod. Oxford University Press, September 2012. ISBN-13: 978-01999-316-13. (Reviewed in this issue).

Selected Papers: Volume II: On Algebraic Geometry, including correspondence with Grothendieck, by David Mumford. Edited by Amnon Neeman, Ching-Li Chai, and Takahiro Shiota. Springer, July 2010. ISBN-13: 978-03877-249-11. (Reviewed February 2013.)

The Signal and the Noise: Why So Many Predictions Fail—but Some Don't, by Nate Silver. Penguin Press, September 2012. ISBN-13:*978-15942-041-11.*

Simon: The Genius in My Basement, by Alexander Masters. Delacorte Press, February 2012. ISBN-13: 978-03853-410-80.

Sources in the Development of Mathematics: Series and Products from the Fifteenth to the Twenty-first Century, by Ranjan Roy. Cambridge University Press, June 2011. ISBN-13: 978-05211-147-07.

A Strange Wilderness: The Lives of the Great Mathematicians, by Amir D. Aczel. Sterling, October 2011. ISBN-13: 978-14027-858-49.

Thinking Statistically, by Uri Bram. CreateSpace Independent Publishing Platform, January 2012. ISBN-13: 978-14699-123-32.

Transcending Tradition: Jewish Mathematicians in German Speaking Academic Culture, edited by Birgit Bergmann, Moritz Epple, and Ruti Ungar. Springer, January 2012. ISBN-13: 978-36422-246-38. (Reviewed February 2013.)

Turbulent Times in Mathematics: The Life of J. C. Fields and the History of the Fields Medal, by Elaine McKinnon Riehm and Frances Hoffman. AMS, November 2011. ISBN-13: 978-0-8218-6914-7.

Uneducated Guesses: Using Evidence to Uncover Misguided Education Policies, by Howard Wainer. Princeton University Press, August 2011. ISBN-13: 978-06911-492-88. (Reviewed June/July 2012.)

The Universe in Zero Words: The Story of Mathematics as Told through Equations, by Dana Mackenzie. Princeton University Press, April 2012. ISBN-13: 978-06911-528-20. (Reviewed in this issue.)

Thinking In Numbers: On Life, Love, Meaning, and Math, by Daniel Tammet. Little, Brown and Company, July 2013. ISBN-13: 978-03161-873-74.

Visions of Infinity: The Great Mathematical Problems, by Ian Stewart. Basic Books, March 2013. ISBN-13: 978-04650-224-03.

A Wealth of Numbers: An Anthology of 500 Years of Popular Mathematics Writing, edited by Benjamin Wardhaugh. Princeton University Press, April 2012. ISBN-13: 978-06911-477-58. (Reviewed March 2013.)

Who's #1?: The Science of Rating and Ranking, by Amy N. Langville and Carl D. Meyer. Princeton University Press, February 2012. ISBN-13: 978-06911-542-20. (Reviewed January 2013.)

old days we would have asked you to return the paper to us, but that is no longer necessary. Books must be returned, but I don't believe we have sent you a book yet.

Ben: No, I haven't reviewed a book. Am I right that book reviews work differently than article reviews? Journal articles simply arrive periodically, but I was once asked specifically about reviewing a book. I had to turn down that opportunity because I was so busy at the time. How would I indicate that I would like to review books in the future? How would I go about changing the number of papers I get sent at any one time in case I get busy again?

Norm: *You guessed right: books are handled differently. Because replacement may be difficult, we always ask the reviewer first before we send a book. Unless you said, "Don't ever send me a book" in your response to our inquiry about reviewing a book, a book is still an option. Regarding the frequency of being sent papers, there is a limit number associated with your reviewer database record that is an upper bound on the number of review items you will have in your hands at any one time. You can write to* `mathrev@ams.org` *and request that number be smaller. Typical numbers are in the 1–6 range. In the future this limit number should be visible at the Reviewer Home* (`www.ams.org/mresubs`).

Ben: Do you read my reviews?

Norm: *I don't normally have the opportunity. I edit in number theory and your reviewing interest is in commutative algebra, which is handled by another editor. I saw one of your reviews once while substituting for the commutative algebra editor and enjoyed it very much. After you submit your review, a number of eyes see it. We still use* $\mathcal{AMS}$-TeX *in the MR Database, so sometimes there is some massaging related to the* LaTeX *to* TeX *conversion. A copyeditor works on it, addressing English language issues* (*not many in your case*) *and working on any references you included in your review. Then two editors see it, and finally another copyeditor does quality control work. It is a fairly involved process.*

Ben: Is there anything new I should know about?

Norm: *In early January of 2013 a new database underlying the sign-in you do at the Reviewer Home was put into place on the AMS site. The first time you sign in after this change, you will be instructed to create a username and password. The username is easy: it will be the email address associated with your AMS Web Account. Your old password will be blanked, and you will be asked to create a new one. I hear you groaning. Fortunately, this is a one-time procedure, and at least you will always know what your username is. Speaking of your tour of MR, we extend an invitation to anyone visiting Ann Arbor to stop by our offices, particularly in this year celebrating the 125th anniversary of the AMS.*

Ben: Thanks for the chat. I think I'll go work on a review.

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 `smf@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.

Information for *Notices* Authors

The *Notices* welcomes unsolicited articles for consideration for publication, as well as proposals for such articles. The following provides general guidelines for writing *Notices* articles and preparing them for submission. Contact information for *Notices* editors and staff may be found on the *Notices* website, `http://www.ams.org/notices`.

***Notices* readership**. The *Notices* publishes articles that have broad appeal for a diverse audience with many different types of readers: graduate students, academic mathematicians, industrial mathematicians, researchers in mathematically based fields, and amateur enthusiasts. The paper edition of the *Notices* is sent to the approximately 33,000 members of the AMS, most of whom are professional mathematicians; about 25,000 of them reside in North America. Because the *Notices* is accessible for free over the Internet, the number of readers is much larger than the

AMS membership. All readers may be assumed to be interested in mathematics research, but they are not all active researchers.

Notices Feature Articles

Topics. The *Notices* seeks exceptional articles that report on major new developments in mathematics or that describe episodes from mathematics history that have connection to current research in the field. We also welcome articles discussing aspects of the mathematics profession, such as grant programs, the job market, professional opportunities for mathematicians, publishing, electronic communications, etc. We are also interested in articles about mathematics education at all levels. We publish reviews of books, films, plays, software, and mathematical tools.

Reaching the audience. Our goal is to educate the readership about new developments in mathematics and in the mathematics profession, as well as other matters of interest to the working mathematician. Each article is expected to have a large target audience of readers, perhaps 5,000 of the 33,000 subscribers. Authors must therefore write their articles for nonexperts rather than for experts or would-be experts. In particular, the mathematics articles in the *Notices* are expository. A *Notices* article should have an introduction that anyone can understand, and almost all readers should be able to understand the key points of the article.

Structure of articles. Most feature articles, including those on mathematics, are expected to be of long-term value and should be written as such. Ideally each article should put its topic in a context, providing some history and other orientation for the reader, and, as necessary, relating the subject matter to things that readers are likely to understand. In most cases, articles should progress to dealing with contemporary matters, not giving only historical material. The articles that are received the best by readers tend to relate different areas of mathematics to each other.

By design the *Notices* is partly magazine and partly journal, and authors' expository styles should take this into account. For example, many readers want to understand the mathematics articles without undue effort and without consulting other sources.

Format and length. Mathematics feature articles in the *Notices* are normally six to nine pages, sometimes a little longer. Shorter articles are more likely to be read fully than are longer articles. The first page is 400 or 500 words, and subsequent pages are about 800 words. From this one should subtract an allowance for figures, photos, and other illustrations and an appropriate allowance for any displayed equations and bibliography. The *Notices* is especially interested in the creative use of graphics and color and encourages illustrations. Articles on professional topics are typically 3 to 5 pages, as are book reviews.

Editorial process. The *Notices* aims to publish exceptionally well-written articles that appeal to a broad audience of mathematicians. Highly technical, specialized articles with a great deal of notation, insider jargon, and a long list of references are not suitable for the *Notices*. Some articles will be rejected by the editors without any external review. Other articles will be carefully refereed, and then a detailed editorial process will be used to bring the article up to the *Notices* standard. There will be considerable give and take between the author(s) and the editor, and it may take several drafts to get the article right.

The "WHAT IS...?" Column

Nearly every issue of the *Notices* carries an installment of the "WHAT IS...?" column. The purpose of the column is to provide brief, nontechnical descriptions of mathematical objects in use in current research. The target audience for the columns is first-year graduate students.

Each "WHAT IS...?" column provides an expository description of a single mathematical object being used in contemporary research. Thus "WHAT IS *M*-Theory?" would be too broad, but "WHAT IS a Brane?" would be appropriate; ideally "WHAT IS a Brane?" would give a flavor of what *M*-theory is.

The writing should be nontechnical and informal. Narrative description conveying main ideas should be favored over notation-heavy precision.

Where to Find It

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

AMS Bylaws—*January 2012, p. 73*

AMS Email Addresses—*February 2013, p. 249*

AMS Ethical Guidelines—*June/July 2006, p. 701*

AMS Officers 2012 and 2013 Updates—*May 2013, p. 646*

AMS Officers and Committee Members—*October 2012, p. 1290*

Contact Information for Mathematical Institutes—*August 2012, p. 979*

Conference Board of the Mathematical Sciences—*September 2012, p. 1128*

IMU Executive Committee—*December 2011, p. 1606*

Information for *Notices* Authors—*June/July 2013, p. 776*

Mathematics Research Institutes Contact Information—*August 2012, p. 979*

National Science Board—*January 2013, p. 109*

NRC Board on Mathematical Sciences and Their Applications—*March 2013, p. 350*

NSF Mathematical and Physical Sciences Advisory Committee—*February 2013, p. 252*

Program Officers for Federal Funding Agencies—*October 2012, p. 1284 (DoD, DoE); December 2012, p. 1585 (NSF Mathematics Education)*

Program Officers for NSF Division of Mathematical Sciences—*November 2012, p. 1469*

There is a limit of two *Notices* pages (1,400 words with no picture or 1,200 words with one picture). A list of "Further Reading" should contain no more than three references. Inquiries and comments about the "WHAT IS...?" column are welcome and may be sent to notices-whatis@ams.org.

Upcoming Deadlines

July 1, 2013: Nominations for Dannie Heineman Prize. See "Mathematics Opportunities" in this issue.

July 2, 2013: Proposals for NSF-CBMS Regional Conferences. See "Mathematics Opportunities" in this issue.

July 24, 2013: Proposals for NSF CAREER Awards. See "Mathematics Opportunities" in this issue.

July 31, 2013: Nominations for SASTRA Ramanujan Prize. See "Mathematics Opportunities" in this issue.

August 1, 2013: Applications for August review for National Academies Research Associateship Programs. See the website 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 13, 2013: Full proposals for NSF Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) program. See http://www.nsf.gov/pubs/2012/nsf12529/nsf12529.htm.

September 15, 2013: Applications for spring 2014 semester of Math in Moscow. See http://www.mccme.ru/mathinmoscow, or write to: Math in Moscow, P.O. Box 524, Wynnewood, PA 19096; fax: +7095-291-65-01; e-mail: mim@mccme.ru. Information and application forms for the AMS scholarships are available on the AMS website at http://www.ams.org/programs/travel-grants/mimoscow, or by writing to: Math in Moscow Program, Membership and Programs Department, American Mathematical Society, 201 Charles Street, Providence RI 02904-2294; email student-serv@ams.org.

September 16, 2013: Nominations for Sloan Fellowships. See "Mathematics Opportunities" in this issue.

September 30, 2013: Nominations for W. K. Clifford Prize. See http://www.wkcliffordprize.org.

October 1, 2013: Applications for AWM Travel Grants and Mathematics Education Research Travel Grants. See https://sites.google.com/site/awmmath/programs/travel-grants; or telephone: 703-934-0163; e-mail: awm@awm-math.org; or contact Association for Women in Mathematics, 11240 Waples Mill Road, Suite 200, Fairfax, VA 22030.

October 4, 2013: Letters of intent for NSF Program ADVANCE Institutional Transformation and Institutional Transformation Catalyst awards. See http://www.nsf.gov/pubs/2012/nsf12584/nsf12584.htm?WT.mc_id=USNSF_36&WT.mc_ev=click.

October 16, 2013: Proposals for National Science Foundation (NSF) Postdoctoral Research Fellowships. See http://www.nsf.gov/pubs/2012/nsf12496/nsf12496.htm.

October 1, 2013: Nominations for Parzen Prize. See "Mathematics Opportunities" in this issue.

November 1, 2013: Applications for November review for National Academies Research Associateship Programs. See the website 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.

November 12, 2013: Full proposals for NSF Program ADVANCE Institutional Transformation and Institutional Transformation Catalyst awards. See http://www.nsf.gov/pubs/2012/nsf12584/nsf12584.htm?WT.mc_id=USNSF_36&WT.mc_ev=click.

December 2, 2013: Nominations for Ferran Sunyer i Balaguer Prize. See "Mathematics Opportunities" in this issue.

Book List

The Book List highlights recent books that have mathematical themes and are aimed at a broad audience potentially including mathematicians, students, and the general public. 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.

Algorithmic Puzzles, by Anany Levitin and Maria Levitin. Oxford University Press, October 2011. ISBN-13: 978-01997-404-44.

American Mathematicians as Educators, 1893–1923: Historical Roots of the "Math Wars", by David Lindsay Roberts. Docent Press, July 2012, ISBN-13: 978-09837-004-49.

Assessing the Reliability of Complex Models: Mathematical and Statistical Foundations of Verification, Validation, and Uncertainty Quantification, by the National Research Council. National Academies Press, 2012. ISBN: 978-0-309-25634-6.

The Best Writing on Mathematics 2012, edited by Mircea Pitici. Princeton University Press, November 2012. ISBN-13: 978-06911-565-52.

The Big Questions: Mathematics, by Tony Crilly. Quercus, April 2011. ISBN-13: 978-18491-624-01. (Reviewed October 2012.)

**Charles S. Peirce on the Logic of Number, by Paul Shields.* Docent Press, October 2012. ISBN-13: 978-0-9837004-7-0.

**The Continuity Debate: Dedekind, Cantor, du Bois-Reymond, and Peirce on Continuity and Infinitesimals,* by Benjamin Lee Buckley. Docent Press, December 2012. ISBN-13: 978-0-9837004-8-7.

The Crossing of Heaven: Memoirs of a Mathematician, by Karl Gustafson. Springer, January 2012. ISBN-13: 978-36422-255-74.

Decoding the Heavens: A 2,000-Year-Old Computer—and the Century-Long Search to Discover its Secrets, by Jo Marchant. Da Capo Press, February 2009. ISBN-13: 978-03068-174-27. (Reviewed in this issue).

The Foundations of Geometry And Religion from an Abstract Standpoint, by Salilesh Mukhopadhyay. Outskirts Press, July 2012. ISBN-13: 978-1-4327-9424-8.

The Fractalist: Memoir of a Scientific Maverick, by Benoit Mandelbrot. Pantheon, October 2012. ISBN-13: 978-03073-773-57.

Fueling Innovation and Discovery: The Mathematical Sciences in the

21st Century, by the National Research Council. National Academies Press, 2012. ISBN-13: 978-0-309-25473-1.

Galileo's Muse: Renaissance Mathematics and the Arts, by Mark Austin-Peterson. Harvard University Press, October 2011. ISBN-13: 978-06740-597-26. (Reviewed November 2012.)

Game Theory and the Humanities: Bridging Two Worlds, by Steven J. Brams. MIT Press, September 2012. ISBN-13: 978-02625-182-53.

Games and Mathematics: Subtle Connections, by David Wells. Cambridge University Press, November 2012. ISBN-13: 978-11076-909-12.

Girls Get Curves: Geometry Takes Shape, by Danica McKellar. Plume, July 2013. ISBN-13: 978-04522-987-43.

**Google's PageRank and Beyond: The Science of Search Engine Rankings*, by Amy Langville and Carl Meyer. Princeton University Press, February 2012. ISBN-13: 978-06911-526-60.

**The Golden Ticket: P, NP, and the Search for the Impossible*, by Lance Fortnow. Princeton University Press, March 2013. ISBN-13: 978-06911-564-91.

Guesstimation 2.0: Solving Today's Problems on the Back of a Napkin, by Lawrence Weinstein. Princeton University Press, September 2012. ISBN-13: 978-06911-508-02.

Heavenly Mathematics: The Forgotten Art of Spherical Trigonometry, by Glen Van Brummelen. Princeton University Press, December 2012. ISBN-13: 978-06911-489-22.

Henri Poincaré: Impatient Genius, by Ferdinand Verhulst. Springer, August 2012. ISBN-13: 978-14614-240-62.

Henri Poincaré: A Scientific Biography by Jeremy Gray. Princeton University Press, November 2012. ISBN-13: 978-06911-527-14.

How to Study as a Mathematics Major, by Lara Alcock. Oxford University Press, March 2013. ISBN-13: 978-0199661312.

I Died for Beauty: Dorothy Wrinch and the Cultures of Science, by Marjorie Senechal. Oxford University Press, December 2012. ISBN-13:978-01997-325-93.

Ibn al-Haytham's Theory of Conics, Geometrical Constructions and Practical Geometry, by Roshdi Rashed. Routledge, February 2013. ISBN: 978-0-415-58215-5.

Infinity: New Research Frontiers, edited by Michael Heller and W. Hugh Woodin. Cambridge University Press, February 2011. ISBN-13: 978-11070-038-73.

The Infinity Puzzle: Quantum Field Theory and the Hunt for an Orderly Universe, by Frank Close. Basic Books, November 2011. ISBN-13: 978-04650-214-44. (Reviewed September 2012.)

In Pursuit of the Traveling Salesman: Mathematics at the Limits of Computation, by William J. Cook. Princeton University Press, December 2011. ISBN-13: 978-06911-527-07.

In Pursuit of the Unknown: 17 Equations That Changed the World, by Ian Stewart. Basic Books, March 2012. ISBN-13: 978-04650-297-30. (Reviewed December 2012.)

Introduction to Mathematical Thinking, by Keith Devlin. Keith Devlin, July 2012. ISBN-13: 978-06156-536-31.

**Invisible in the Storm: The Role of Mathematics in Understanding Weather*, by Ian Roulstone and John Norbury. Princeton University Press, February 2013. ISBN-13: 978-06911-527-21.

The Joy of x: A Guided Tour of Math, from One to Infinity, by Steven Strogatz. Eamon Dolan/Houghton Mifflin Harcourt, October 2012. ISBN-13: 978-05475-176-50.

Late Style: Yuri I. Manin Looking Back on a Life in Mathematics. A DVD documentary by Agnes Handwerk and Harrie Willems. Springer, March 2012. ISBN NTSC: 978-3-642-24482-7; ISBN PAL: 978-3-642-24522-0. (Reviewed January 2013.)

Lemmata: A Short Mathematical Thriller, by Sam Peng. CreateSpace, December 2011. ISBN-13: 978-14681-442-39.

Levels of Infinity: Selected Writings on Mathematics and Philosophy, by Hermann Weyl. Edited by Peter Pesic. Dover Publications, February 2013. ISBN-13: 978-0486489032.

The Logician and the Engineer: How George Boole and Claude Shannon Created the Information Age, by Paul J. Nahin, Princeton University Press, October 2012. ISBN-13: 978-06911-510-07.

Magical Mathematics: The Mathematical Ideas That Animate Great Magic Tricks, by Persi Diaconis and Ron Graham. Princeton University Press, November 2011. ISBN-13: 978-06911-516-49. (Reviewed August 2012.)

Manifold Mirrors: The Crossing Paths of the Arts and Mathematics, by Felipe Cucker. Cambridge University Press, April 2013. ISBN-13: 978-0521728768.

Math Girls, by Hiroshi Yuki (translated from the Japanese by Tony Gonzalez). Bento Books, November 2011. ISBN-13: 978-09839-513-15. (Reviewed August 2012.)

Math Goes to the Movies, by Burkard Polster and Marty Ross. Johns Hopkins University Press, July 2012. ISBN-13: 978-14214-048-44.

Math Is Murder, by Robert C. Brigham and James B. Reed. Universe, March 2012. ISBN-13: 978-14697-972-81.

Mathematical Excursions to the World's Great Buildings, by Alexander J. Hahn. Princeton University Press, July 2012. ISBN-13: 978-06911-452-04.

The Mathematical Writings of Évariste Galois, edited by Peter M. Neumann. European Mathematical Society, October 2011. ISBN-13: 978-3-03719-104-0. (Reviewed December 2012.)

A Mathematician Comes of Age, by Steven G. Krantz. Mathematical Association of America, December 2011. ISBN-13: 978-08838-557-82.

A Mathematician's Lament: How School Cheats Us Out of Our Most Fascinating and Imaginative Art Form, by Paul Lockhart. Bellvue Literary Press, April 2009. ISBN-13: 978-1-934137-17-8. (Reviewed April 2013.)

Mathematicians in Bologna 1861-1960, edited by Salvatore Coen. ISBN-13: 978-30348-022-60.

Mathematics in Popular Culture: Essays on Appearances in Film, Fiction, Games, Television and Other Media, edited by Jessica K. Sklar and Elizabeth S. Sklar. McFarland, February 2012. ISBN-13: 978-07864-497-81.

Mathematics in Victorian Britain, by Raymond Flood, Adrian Rice, and Robin Wilson. Oxford University Press, October 2011. ISBN-13: 978-019-960139-4.

Maverick Genius: The Pioneering Odyssey of Freeman Dyson, by Phillip F. Schewe. Thomas Dunne Books, February 2013. ISBN-13:*978-03126-423-58.*

Meaning in Mathematics, edited by John Polkinghorne. Oxford University Press, July 2011. ISBN-13: 978-01996-050-57. (Reviewed May 2013.)

Measurement, by Paul Lockhart. Belknap Press of Harvard University Press, September 2012. ISBN-13: 978-06740-575-55.

Nine Algorithms That Changed the Future: The Ingenious Ideas That Drive Today's Computers, by John MacCormick. Princeton University Press, December 2011. ISBN-13: 978-06911-471-47.

On the Formal Elements of the Absolute Algebra, by Ernst Schröder (translated and with additional material by Davide Bondoni; with German parallel text). LED Edizioni Universitarie, 2012. ISBN-13: 978-88-7916-516-7.

Paradoxes in Probability Theory, by William Eckhardt. Springer, September 2012. ISBN-13: 978-94007-513-92. (Reviewed March 2013.)

**Peirce's Logic of Continuity: A Conceptual and Mathematical Approach,* by Fernando Zalamea. Docent Press, December 2012. ISBN-13: 978-0-9837004-9-4.

Proving Darwin: Making Biology Mathematical, by Gregory Chaitin. Pantheon, May 2012. ISBN-13: 978-03754-231-47.

**Relations Between Logic and Mathematics in the Work of Benjamin and Charles S. Peirce,* by Allison Walsh. Docent Press, October 2012. ISBN-13: 978-0-9837004-6-3.

The Search for Certainty: A Journey through the History of Mathematics, 1800-2000, edited by Frank J. Swetz. Dover Publications, September 2012. ISBN-13: 978-04864-744-27.

Secrets of Triangles: A Mathematical Journey, by Alfred S. Posamentier and Ingmar Lehman. Prometheus Books, August 2012. ISBN-13: 978-16161-458-73.

Seduced by Logic: Emilie Du Châelet, Mary Somerville and the Newtonian Revolution, by Robyn Arianrhod. Oxford University Press, September 2012. ISBN-13: 978-01999-316-13. (Reviewed in this issue).

Selected Papers: Volume II: On Algebraic Geometry, including correspondence with Grothendieck, by David Mumford. Edited by Amnon Neeman, Ching-Li Chai, and Takahiro Shiota. Springer, July 2010. ISBN-13: 978-03877-249-11. (Reviewed February 2013.)

The Signal and the Noise: Why So Many Predictions Fail—but Some Don't, by Nate Silver. Penguin Press, September 2012. ISBN-13:*978-15942-041-11.*

Simon: The Genius in My Basement, by Alexander Masters. Delacorte Press, February 2012. ISBN-13: 978-03853-410-80.

Sources in the Development of Mathematics: Series and Products from the Fifteenth to the Twenty-first Century, by Ranjan Roy. Cambridge University Press, June 2011. ISBN-13: 978-05211-147-07.

A Strange Wilderness: The Lives of the Great Mathematicians, by Amir D. Aczel. Sterling, October 2011. ISBN-13: 978-14027-858-49.

Thinking Statistically, by Uri Bram. CreateSpace Independent Publishing Platform, January 2012. ISBN-13: 978-14699-123-32.

Transcending Tradition: Jewish Mathematicians in German Speaking Academic Culture, edited by Birgit Bergmann, Moritz Epple, and Ruti Ungar. Springer, January 2012. ISBN-13: 978-36422-246-38. (Reviewed February 2013.)

Turbulent Times in Mathematics: The Life of J. C. Fields and the History of the Fields Medal, by Elaine McKinnon Riehm and Frances Hoffman. AMS, November 2011. ISBN-13: 978-0-8218-6914-7.

Uneducated Guesses: Using Evidence to Uncover Misguided Education Policies, by Howard Wainer. Princeton University Press, August 2011. ISBN-13: 978-06911-492-88. (Reviewed June/July 2012.)

The Universe in Zero Words: The Story of Mathematics as Told through Equations, by Dana Mackenzie. Princeton University Press, April 2012. ISBN-13: 978-06911-528-20. (Reviewed in this issue.)

Thinking In Numbers: On Life, Love, Meaning, and Math, by Daniel Tammet. Little, Brown and Company, July 2013. ISBN-13: 978-03161-873-74.

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A Wealth of Numbers: An Anthology of 500 Years of Popular Mathematics Writing, edited by Benjamin Wardhaugh. Princeton University Press, April 2012. ISBN-13: 978-06911-477-58. (Reviewed March 2013.)

Who's #1?: The Science of Rating and Ranking, by Amy N. Langville and Carl D. Meyer. Princeton University Press, February 2012. ISBN-13: 978-06911-542-20. (Reviewed January 2013.)

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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/`.

June 2013

2–5 **International Conference on Applied Analysis and Mathematical Modelling (ICAAMM2013)**, Yildiz Technical University, Davut Pasa Campus, Istanbul, Turkey. (Mar. 2013, p. 351)

2–8 **8th Spring School on Analysis**, Paseky nad Jizerou, Czech Republic. (Jan. 2013, p. 114)

3–7 **GESTA 2013 (Topological, Symplectic and Contact Spring in Toulouse)**, Université Paul Sabatier, Toulouse, France. (Jan. 2013, p. 114)

* 3–7 **Issues in Solving the Boltzmann Equation for Aerospace Applications**, ICERM, Providence, Rhode Island.
Description: Being central to gas dynamics, the Boltzmann equation describes gas flows at the microscopic level in regimes from free molecular to continuum. Its descriptive power makes it indispensable for predicting non-continuum phenomena in gases when experimental data is limited or not available. The Boltzmann equation is used in a wide range of applications, from external aerodynamics and thruster plume flows to vacuum facilities and microscale devices. Accurate solution of the Boltzmann equation for modeling gas flows arising in aerospace applications continues to be a challenge. Existing numerical capabilities fall short of capturing the complexities of engineering design. Reasons for this range from the absence of mathematical models that capture the physics properly to higher dimensionality of kinetic models and the resulting high cost of computations to the failure of mathematical theories to handle complex geometries of real life applications.
Information: `http://icerm.brown.edu/tw13-1-isbeaa`.

3–7 **MEGA 2013: Effective Methods in Algebraic Geometry**, Goethe University, Frankfurt am Main, Germany. (Sept. 2012, p. 1172)

3–7 **PIMS/EQINOCS Automata Theory and Symbolic Dynamics Workshop**, University of British Columbia, Vancouver, BC, Canada. (Apr. 2013, p. 513)

3–7 **Workshop on Slow-Fast Dynamics: Theory, Numerics, Application to Life and Earth Sciences**, Centre de Recerca Matemàtica, Bellaterra, Barcelona. (May 2013, p. 651)

3–9 **Summer school on Finsler geometry with applications to low-dimensional geometry and topology**, Department of Mathematics, University of the Aegean, Karlovassi, Island of Samos, Greece. (Dec. 2012, p. 1593)

3–14 **Moduli Spaces and their Invariants in Mathematical Physics**, Centre de Recherches Mathématiques, Montréal, Canada. (Feb. 2013, p. 262)

3–28 **Focus Program on Noncommutative Geometry and Quantum Groups**, Fields Institute for Research in Mathematical Sciences, Toronto, Ontario, Canada. (Sept. 2012, p. 1172)

3–28 **Rational Points, Rational Curves and Entire Holomorphic Curves on Projective Varieties**, Centre de recherches mathématiques, Montréal, Canada. (Apr. 2013, p. 513)

3–July 12 **Nonlinear expectations, stochastic calculus under Knightian uncertainty, and related topics**, Institute for Mathematical Sciences, National University of Singapore, Singapore. (Oct. 2012, p. 1303)

4–14 **Conference on Nonlinear Mathematical Physics: Twenty Years of JNMP**, The Sophus Lie Conference Center, Nordfjordeid, Norway. (Sept. 2012, p. 1173)

* 5 **Dimacs/Ccicada Workshop on S&T Innovations in Hurricane Sandy Research**, DIMACS Center, CoRE Building, Rutgers University, Piscataway, New Jersey.

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/`.

Description: The workshop is expected to advance discovery while accelerating transferral of research results to practice. It will seek to address disaster planning, response and recovery, and will provide a platform for dialogue between individuals across DHS, NSF and academia. Finally, given the likely long-term consequences of Hurricane Sandy, the results of this work are expected to be of broad interest to government, industry, academia and the public at large. The operation of modern power grids presents challenges and opportunities that are best met with appropriate technical methodology; it is clear that future grids will rely, to a much greater degree than is common today, on extensive sensorization and algorithmic machinery to guide both strategic planning and real-time operation. Although there is significant sophistication already present today, substantial innovative work remains to fulfill the promise implicit in mathematical methodologies.
Organizers: David Mendonca, Rensselaer Polytechnic Institute, mendod@rpi.edu; Fred Roberts, Director of CCICADA, froberts@dimacs.rutgers.edu.
Information: http://dimacs.rutgers.edu/Workshops/Sandy/.

5–9 **4th Novi Sad Algebraic Conference–NSAC 2013**, Department of Mathematics and Informatics, Faculty of Science, University of Novi Sad, Novi Sad, Serbia. (Sept. 2012, p. 1173)

7–12 **XVth International Conference on Geometry, Integrability and Quantization**, Sts. Constantine and Elena Resort, near Varna, Bulgaria. (Mar. 2013, p. 358)

8–13 **39th International Conference "Applications of Mathematics in Engineering and Economics" — AMEE'13**, Technical University Leisure House, Sozopol, Bulgaria. (Mar. 2013, p. 358)

9–13 (NEW DATE) **Tenth edition of the Advanced Course in Operator Theory and Complex Analysis**, Sevilla, Spain. (Dec. 2012, p. 1594)

* 10 **PIMS Marsden Memorial Lecture**, Isaac Newton Institute of Mathematical Sciences, Cambridge, United Kingdom.
Description: Peter Constantin (Princeton University) will give a lecture entitled Nonlocal Evolution Equations, in which he will describe results concerning evolution equations involving nonlocal terms. Particular examples will include the Surface Quasi-Geostrophic equation (SQG) and it generalizations. He will discuss a nonlinear maximum principle for linear nonlocal operators and applications to questions of regularity of solutions, long time dymamics and absence of anomalous dissipation in 2D SQG.
Information: http://www.pims.math.ca/scientific-event/130610-pmml.

10–11 **Workshop on Emergence, Spread and Control of Infectious Diseases**, Centre de Recerca Matemàtica, Bellaterra, Barcelona. (May 2013, p. 651)

10–14 **AIM Workshop: Automorphic forms and harmonic analysis on covering groups**, American Institute of Mathematics, Palo Alto, California. (Nov. 2012, p. 1481)

10–14 **ApplMath13, 8th Conference on Applied Mathematics and Scientific Computing**, Sibenik, Croatia. (Sept. 2012, p. 1173)

10–14 **Computational Methods and Function Theory 2013**, Shantou University, Shantou, Guangdong, China. (Sept. 2012, p. 1173)

10–14 **Fourth International Conference on Geometry, Dynamics, Integrable Systems – GDIS 2013**, Udmurt State University, Izhevsk, Russia. (May 2013, p. 651)

* 10–14 **Mini-courses in Mathematical Analysis 2013**, University of Padova, Italy.
Description: Following a long standing tradition, the University of Padova is organizing the meeting "Mini-courses in Mathematical Analysis 2013". The meeting will take place at "Torre Archimede", a new building of the University of Padova in the city center. The program consists of four lecture courses delivered by invited speakers and a limited number of short communications. The meeting aims at introducing the participants to important current research fields in Mathematical Analysis. The meeting is particularly indicated not only to graduate students, postdocs and young researchers but also to well-established experts in Mathematical Analysis. In association with ISAAC - International Society for Analysis, its Applications and Computation.
Information: http://minicourses.dmsa.unipd.it/.

10–14 **Pde's, Dispersion, Scattering theory and Control theory**, University of Monastir, Monastir, Tunisia. (Dec. 2012, p. 1593)

10–20 **Recent Advances in Hodge Theory: Period Domains, Algebraic Cycles, and Arithmetic**, UBC Campus, Vancouver, B.C., Canada. (Dec. 2012, p. 1593)

11–13 **4th International Conference on Mathematical and Computational Applications**, Celal Bayar University, Applied Mathematics and Computation Center, Manisa, Turkey. (Dec. 2012, p. 1593)

11–14 **6th Chaotic Modeling and Simulation International Conference (CHAOS2013)**, Yeditepe University, Istanbul, Turkey. (Feb. 2013, p. 262)

11–14 **Continued Fractions, Interval Exchanges and Applications to Geometry**, Centro di Ricerca Matematica Ennio De Giorgi, Palazzo Puteano, Piazza dei Cavalieri 3, Pisa, Italy. (May 2013, p. 651)

13–15 **30th Annual Workshop in Geometric Topology**, Calvin College, Grand Rapids, Michigan. (May 2013, p. 651)

16–21 **BIOMATH: International Conference of Mathematical Methods and Models in Biosciences and Young Scientists School**, Bulgarian Academy of Sciences, Sofia, Bulgaria. (Mar. 2013, p. 359)

16–23 **51st International Symposium on Functional Equations**, Rzeszów, Poland. (Dec. 2012, p. 1594)

* 17–19 **Complex Analysis and Approximation**, National University of Ireland Maynooth, Maynooth, Ireland.
Description: This is a conference in honour of Anthony G. O'Farrell's retirement (2012). The expected areas of the talks are those close to Tony's research which has included complex analysis, extensions and approximation, complex dynamics, and algebraic structures in analysis and geometry.
Invited speakers: Patrick Ahern, Joaquim Bruna, Garth Dales, Seán Dineen, Joel Feinstein, Walter Hayman, Alex Izzo, Dmitry Khavinson, Roman Lávicka, Don Marshall, Ivan Netuka, Fernando Pérez-González, Alejandro Sanabria, Ian Short, Richard Timoney, Joan Verdera, David Walsh.
Organizers: Stephen Buckley, Detta Dickinson, Tom Dowling, and Richard Watson.
Information: http://www.maths.nuim.ie/13CAA/.

17–20 **7th Annual International Conference on Mathematics**, Athens Institute for Education and Research, Athens, Greece. (May 2013, p. 651)

17–20 **Young Researchers in Mathematics (YRM2013)**, Edinburgh, Scotland. (Apr. 2013, p. 513)

17–21 **AIM Workshop: Exponential random network models**, American Institute of Mathematics, Palo Alto, California. (Sept. 2012, p. 1173)

* 17–21 **BIOMAT 2013: Evolution and cooperation in social sciences and biomedicine**, Facultad de Ciencias, Universidad de Granada, Granada, Spain.
Description: Tomás Alarcón (Centre de Recerca Matematica, Barcelona, Spain): An introduction to stochastic methods in mathematical biology; Mario Primicerio (Dipartimento di Matematica "Ulisse Dini", Univ. degli Studi di Firenze, Italy), Mathematical models for social

changes and criminology; Koby Rubinstein (Dept. of Math., Technion Inst. of Tech., Israel), Mathematical challenges in medicine; Karl Sigmund (Faculty for Math., Univ. of Vienna, Austria), On the evolution of cooperation; Corina Tarnina (Princeton Univ.); Cooperation and the evolution of social behavior: From multicellularity to eusociality. We have organized, during the school, a meeting of "young researchers modelling biological processes." The call to participate in this meeting is now open.
Information: `http://www.ugr.es/local/kinetic/biomat/`.

17–21 **Conference on Variational Problems and Geometric PDE's**, Granada, Spain. (May 2013, p. 513)

17–21 **Fluid Mechanics and Singular Integrals**, Institute of Mathematics of the University of Seville (IMUS), Seville, Spain. (Mar. 2013, p. 358)

17–21 **NSF-CBMS Regional Research Conference in Mathematical Sciences: The Global Behavior of Solutions to Critical Nonlinear Wave Equations**, Kansas State University, Manhattan, Kansas. (Apr. 2013, p. 513)

17–21 **String-Math 2013**, SCGP, Stony Brook, New York. (Apr. 2013, p. 513)

17–21 **Summer school on Donaldson hypersurfaces (in Topological, Symplectic and Contact Spring in Toulouse)**, La Llagonne, France. (Jan. 2013, p. 115)

17–21 **XVII International Conference on Waves and Stability in Continuous Media**, Bellavista Hotel, Levico terme (TN), Italy. (Apr. 2013, p. 513)

17–23 **Numerical Computations: Theory and Algorithms (International conference and Summer School NUMTA2013)**, Eurolido Hotel, Falerna (CZ), Tyrrhenian Sea, Italy. (Feb. 2013, p. 262)

17–28 **Algebraic Graph Theory**, University of Wyoming, Laramie, Wyoming. (Jan. 2013, p. 115)

17–28 **Algebraic Topology**, Mathematical Sciences Research Institute, Berkeley, California. (Nov. 2012, p. 1481)

17–August 9 **SUMMERICERM: 2013 Undergraduate Summer Research Program Geometry and Dynamics**, ICERM, Providence, Rhode Island. (Jan. 2013, p. 115)

18–20 **The 9th East Asia SIAM (EASIAM) Conference & The 2nd Conference on Industrial and Applied Mathematics (CIAM)**, Bandung Institute of Technology, Bandung, Indonesia. (Feb. 2013, p. 262)

18–21 **Financial Engineering Summer School (FESS2013)**, Bolsa de Barcelona, Spain. (May 2013, p. 651)

19–21 **Nonlinear Elliptic and Parabolic Partial Differential Equations**, Dipartimento di Matematica, Politecnico di Milano, Italy. (Jan. 2013, p. 115)

19–22 **4th International conference "Nonlinear Dynamics-2013"**, Sevastopol, Ukraine. (Jan. 2013, p. 115)

20–21 **DIMACS Workshop on Big Data Integration**, DIMACS Center, CoRE Building, Rutgers University, Piscataway, New Jersey. (Mar. 2013, p. 359)

21–24 **"Experimental and Theoretical Methods in Algebra, Geometry and Topology". Held in the honor of Alexandru Dimca and Stefan Papadima on the occasion of their 60th birthday**, Mangalia (near Constanta), Romania. (Sept. 2012, p. 1173)

22–29 **Physics and Mathematics of Nonlinear Phenomena 2013**, Hotel Le Sirene, Gallipoli, South of Italy. (Oct. 2012, p. 1303)

23–30 **Bogolyubov readings DIF-2013. Differential equations, theory of functions and their applications**, Sevastopol Institute of Banking, Sevastopol, Ukraine. (May 2013, p. 651)

24–26 **Numerical Analysis and Scientific Comlputation with Applications (NASCA13)**, University of Littoral Cote d'Opale, Calais, France. (Jan. 2013, p. 115)

* 24–27 **IV Jaen Conference on Approximation Theory, Computer Aided Geometric Design, Numerical Methods and Applications**, Ubeda, Jaen, Spain.
Description: The conference is a new activity of the Jaen Approximation Project. Jaen Approximation Project has organized ten editions of the Ubeda Meeting on Approximation and three editions of the Jaen Conference on Approximation. It also issues the *Jaen Journal on Approximation* from 2009. The objective of these conferences is to provide a useful and nice forum for researchers in the subjects to meet and discuss. In this sense, the conference programs have been designed to keep joined the group during four/five days with a program full of scientific and social activities. The Conference will be devoted to some significant aspects on Approximation Theory, Computer Aided Geometric Design, Numerical Methods and the Applications of these fields in other areas. As usual, the Conference will take place in Ubeda, a World Heritage Site.
Information: `http://www.ujaen.es/revista/jja/jca/`.

24–28 **Constructive Mathematics: Foundations and Practice**, University of Niš (Faculty of Mechanical Engineering), Niš, Serbia. (Apr. 2013, p. 514)

24–28 **EACA'S Second International School on Computer Algebra and Applications**, Faculty of Sciences, University of Valladolid, Spain. (Feb. 2013, p. 262)

24–28 **Low-dimensional Topology and Geometry in Toulouse**, Université Paul Sabatier, Institut de Mathématiques de Toulouse, Toulouse, France. (Jan. 2013, p. 115)

24–28 **Riemann and Klein Surfaces, Symmetries and Moduli Spaces**, Linkoping University, Linkoping, Sweden. (Apr. 2013, p. 514)

24–28 **The Second Pacific Rim Mathematical Association Congress (PRIMA-2013)**, Shanghai Jiao Tong University, Shanghai, China. (May 2013, p. 651)

24–28 **Sz.-Nagy Centennial Conference**, Szeged, Hungary. (Apr. 2013, p. 514)

* 24–28 **2013 USENIX Federated Conferences Week (USENIX FWC'13)**, San Jose, California.
Description: Back for 2013, USENIX is combining conferences and workshops, both established and new, into one week chock full of research, training, and information. The USENIX Federated Conferences Week offers a unique opportunity to gain insight into a variety of hot topics, while the joint lunches, breaks, and evening events provide cross-topic networking possibilities. Your daily registration gets you into all the events happening that day. Events at FCW'13 include: USENIX ATC'13: 2013; USENIX Annual Technical Conference; ICAC'13: 10th International Conference on Autonomic Computing; HotPar'13: 5th USENIX Workshop on Hot Topics in Parallelism; UCMS'13: 2013 USENIX Configuration Management Summit; HotCloud'13: 5th USENIX Workshop on Hot Topics in Cloud Computing; WiAC'13:'13: 2013 USENIX Women in Advanced Computing Summit; HotStorage '13: 5th USENIX Workshop on Hot Topics in Storage and File Systems; HotSWUp'13: 5th Workshop on Hot Topics in Software Upgrades.
Information: `http://www.usenix.org/conference/fcw13`.

24–29 **5th Conference for Promoting the Application of Mathematics in Technical and Natural Sciences (AMiTaNS'13)**, Resort of Albena, Bulgaria. (Feb. 2013, p. 262)

* 24–July 5 **2013 AMSI Winter School**, The University of Queensland, Brisbane, Queensland, Australia.
Description: 2013 is the International Year of the Mathematics of Planet Earth, and the 8th annual AMSI Winter School will be on this

theme. The Winter School is aimed at post-graduate students and postdoctoral fellows in the mathematical sciences and cognate disciplines. The Winter School aims to enable participants to broaden and deepen their mathematical knowledge, and to build collaborative networks with other Ph.D. students and early career researchers. A series of mini-courses will be offered over the two-week long school. The courses in the first week will be more introductory in nature, and the courses in the second week will lead into current research problems. The courses cover a range of topics in the broad area of the mathematics of planet earth, and are offered by eminent national and international researchers. The Winter School is one of AMSI's flagship higher-education programs, which comprise vacation schools (Summer School, Winter School and BioInfoSummer), Vacation Research School.
Information: `http://www.smp.uq.edu.au/2013-amsi-winter-school`.

24–July 5 **Seminaire de Mathematiques Superieures 2013: Physics and Mathematics of Link Homology**, Montreal, Canada. (Dec. 2012, p. 1594)

25–28 **Advanced Course on Topics in Conformal Geometry and Geometry Analysis**, Centre de Recerca Matématica, Bellaterra, Barcelona. (May 2013, p. 652)

* 25–28 **Graph Operad Logic**, Tallinn University of Technology, Tallinn, Estonia.
Description: The main purpose of the meeting is to stimulate and promote interactions between the following three research areas: differential graphical calculus (DGC), operad algebra and logic as main ingredients of the applied category theory with wide application prospects everywhere in contemporary science, cognition and technology.
Information: `http://www.agmp.eu/gol13`.

26–29 **International Symposium on Symbolic and Algebraic Computation (ISSAC)**, Northeastern University, Boston, Massachussetts. (Nov. 2012, p. 1481)

27 **5th National Dyscalculia and Maths Learning Difficulties Conference, UK**, Cumberland Hotel, London, England. (Nov. 2012, p. 1481)

27–28 **A singular life – in honour of Eduard Looijenga**, Utrecht University, Utrecht, The Netherlands. (Apr. 2013, p. 514)

28–30 **First International Conference on Smarandache Multispace and Multistructure**, Academy of Mathematics and Systems, Chinese Academy of Sciences, Beijing 100190, People's Republic of China. (Sept. 2012, p. 1173)

30–July 5 **British Combinatorial Conference 2013**, Royal Holloway, University of London, Egham, United Kingdom. (Feb. 2013, p. 262)

30–July 20 **IAS/PCMI Summer 2013: Geometric Analysis**, Mathematical Sciences Research Institute, Berkeley, California. (Nov. 2012, p. 1481)

July 2013

1–4 **2nd IMA Conference on Dense Granular Flows**, Isaac Newton Institute of Mathematical Sciences, Cambridge, United Kingdom. (Oct. 2012, p. 1303)

1–5 **Conference on Geometrical Analysis**, Centre de Recerca Matemática, Bellaterra, Barcelona. (May 2013, p. 652)

1–5 **Erdös Centennial**, Budapest, Hungary. (Sept. 2012, p. 1173)

1–5 **International conference on Sampling Theory and Applications 2013**, Jacobs University, Bremen, Germany. (Sept. 2012, p. 1173)

* 1–5 **28th Journées Arithmétiques JA 2013**, University Joseph Fourier Grenoble I, Grenoble, France.
Description: The (JA) Journées Arithmétiques are International Conferences devoted to number theory and its interactions. An Int. Sci. Com. (chaired by David Masser in 2013) selects 12 prominent scientists of the moment to be the invited speakers. In 2013, the Prof. Em. Yuri Manin will give the "Public Lecture". The JA was held at Grenoble (France) in 1960 for the first time, under the impulsion of Claude Chabauty, in an attempt to structure the French activities in the domain of number theory and to give them a better visibility. The JA are organized each two years, in France, then in a nonFrench European university/city (2005: Marseilles, 2007: Edinburgh, 2009: St-Etienne, 2011:Vilnius). The number of participants exceeds 250.
Invited speakers: Drzmitry Badziahin, Francis Brown, Henri Cohen, Laurent Fargues, Charles Favre, Haruzo Hida, Mahesh Kakde, Alex Kontorovich, Kaisa Matomki, Rachel Pries, Tom Sanders, Umberto Zannier. J.-L. Verger-Gaugry (Inst. Fourier, CNRS, Presidt Loc. Org. Com).
Information: `http://www-fourier.ujf-grenoble.fr/ja2013/index-en.html`.

1–5 **The 6th Pacific RIM Conference on Mathematics 2013**, Sapporo Convention Center, Sapporo City, Japan. (Nov. 2012, p. 1481)

1–5 **7th International Summer School on Geometry, Mechanics and Control (ICMAT School)**, La Cristalera, Miraflores de la Sierra, Madrid, Spain. (Feb. 2013, p. 262)

1–5 **Oxford Conference on Challenges in Applied Mathematics (OCCAM)**, St Anne's College, Oxford, United Kingdom. (May 2013, p. 652)

1–5 **Preconditioning of Iterative Methods—Theory and Applications 2013 (PIM 2013)**, Faculty of Civil Engineering, Czech Technical University in Prague, Czech Republic. (Oct. 2012, p. 1303)

1–12 **Advanced School and Workshop on Matrix Geometries and Applications**, The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy.

1–12 **New Geometric Techniques in Number Theory**, Mathematical Sciences Research Institute, Berkeley, California. (Nov. 2012, p. 1481)

2–5 **The 4th International Conference on Matrix Analysis and Applications**, Konya, Turkey. (Nov. 2012, p. 1481)

3–5 **The 2013 International Conference of Applied and Engineering Mathematics**, Imperial College London, London, United Kingdom. (Nov. 2012, p. 1482)

3–6 **International Conference on Anatolian Communications in Nonlinear Analysis (ANCNA 2013)**, Abant Izzet Baysal University, Bolu, Turkey. (Feb. 2013, p. 263)

7–13 **Seventh Czech-Slovak International Symposium on Graph Theory, Combinatorics, Algorithms and Applications**, Košice, Slovakia. (Apr. 2013, p. 514)

8–10 **SIAM Conference on Control and Its Applications (CT13)**, Town and Country Resort and Convention Center, San Diego, California. (Sept. 2012, p. 1174)

8–12 **AIM Workshop: Generalizations of chip-firing and the critical group**, American Institute of Mathematics, Palo Alto, California. (Sept. 2012, p. 1174)

* 8–12 **Low-Dimensional Topology after Floer**, Le Centre de Recherches Mathématiques, Montreal, Quebec, Canada.
Description: The conference will focus on the current impact of Floer homology methods in low-dimensional topology. In recent years, the interactions between geometric, contact and symplectic topology and the many types of Floer homologies have proved very successful in solving outstanding questions in low-dimensional topology, and there are signs that more breakthroughs will occur in the near future. This event will bring together leading experts working in these related areas, but also a special emphasis will be put on the invitation of up-and-coming researchers and graduate students,

some of whom will have attended the SMS summer school on the mathematics and physics of knot homologies.
Information: http://www.crm.umontreal.ca/act/theme/theme_2012_2_en/floer12_e.php.

8–12 **Mathematics of Planet Earth Australia 2013**, RMIT, Melbourne, VIC, Australia. (May 2013, p. 652)

8–12 **Mathematics of Planet Earth 2013 - Pan-Canadian Thematic Program - Climate Change and the Ecology of Vector-borne Diseases**, Fields Institute, CDM, Toronto, Canada. (Sept. 2012, p. 1174)

8–12 **2013 SIAM Annual Meeting (AN13)**, Town and Country Resort & Convention Center, San Diego, California (Jan. 2013, p. 116)

8–12 **Topics in Numerical Analysis for Differential Equations**, Instituto de Ciencias Matemáticas-ICMAT, campus de Cantoblanco, Madrid, Spain. (Jan. 2013, p. 116)

* 8–17 **Summer School on Dynamical Systems**, Pomorski Park Naukowo-Technologiczny, Al. Zwyciestwa 96/98, 81-451 Gdynia, Poland.
Description: Baltycki Istytut Matematyki is organizing the Summer School on Dynamical Systems. This meeting is mostly intended for Ph.D. students and postdocs working on Dynamical Systems. It is a good opportunity to meet students with the same research interests.
Topics: Stability theory, chaotic dynamics, ergodic theory, billiards theory and more. About twelve lecturers well-known in the field will give a 6-hour mini-course each.
Information: http://sites.google.com/site/ssods2013.

8–26 **RTG Summer School on Microlocal Analysis and Inverse Problems**, University of Washington, Seattle. (Mar. 2013, p. 360)

* 9–10 **Random Perturbations and Statistical Properties of Dynamical Systems**, Max Planck Institute for Mathematics in the Sciences, Leipzig, Germany.
Description: The aim of the workshop is to bring together experts working on different aspects related to random perturbations and statistical properties of dynamical systems, as well as young researchers and Ph.D. students interested in the area. All the speakers are supposed to motivate their talks and embed them into a broad context, in order to make them accessible also to non-specialists. In addition, there will be a few survey lectures on recent advances and techniques used to describe from a statistical point of view randomly perturbed dynamics, and a few contributed talks by young researchers.
Topics: Random perturbations and physical measures of dynamical systems, large deviations and concentration inequalities, stochastic aspects of bifurcations, statistical and stochastic stability.
Information: http://www.mis.mpg.de/calendar/conferences/2013/randyn13/.

9–12 **Moduli-Operads-Deformations**, Buskerud University College, Kongsberg, Norway. (May 2013, p. 652)

9–13 **Satellite Summer School to the 7th International Conference on Levy Processes: Theory and Applications**, Mathematical Research and Conference Center of the Institute of Mathematics of the Polish Academy of Sciences, Bedlewo, Poland. (Mar. 2013, p. 360)

* 11–12 **Variational methods and partial differential equations workshop on the occasion of Michel Willem's 60th birthday**, Université Catholique de Louvain, Louvain-la-Neuve, Belgium.
Description: Workshop on variational methods, semilinear elliptic partial differential equations and critical point theory. It will be preceded by a mini-course for graduate students.
Information: http://sites.uclouvain.be/pde2013/.

14–19 **The Sixth International Congress of Chinese Mathematicians (ICCM)**, Opening ceremony on July 14 in the Big Hall of the Grand Hotel, Taipei, Taiwan. Lectures and invited talks from July 15–19 on the campus of National Taiwan University, Taipei, Taiwan. (Jan. 2013, p. 116)

* 15–18 **4th European Set Theory Conference**, Mon Sant Benet, Barcelona/Manresa, Catalonia, Spain.
Scientific program: Andrzej Mostowski Centenary. Invited lecture by Adam Krawczyk (Warsaw). Tutorial by Moti Gitik (Tel Aviv). Lecture by the winner of the Hausdorff Medal.
Plenary lectures: Laura Fontanella, Menachem Magidor, Michael Rathjen, John Steel, Philip Welch. 8 invited lectures. Contributed talks. Poster sessions. Round table on the future of set theory.
Registration fees: Regular 250; Shared room-200 euros. Junior people from Eastern Europe and less-developed countries may apply for a grant by sending a CV together with a recommendation letter from a senior set-theorist to 4thESTC@gmail.com.
Online registration: Is currently open at http://estcongress.org/.
Contributed talks: The deadline for submitting an abstract for a contributed 20- or 50-minute talk is April 15, 2013.
Information: http://estcongress.org/.

15–19 **Finite Dimensional Integrable Systems 2013**, CIRM, Marseille, France. (Dec. 2012, p. 1594)

15–19 **General Algebra and its Applications GAIA2013**, La Trobe University, City Campus, Melbourne, Victoria, Australia. (May 2013, p. 652)

15–19 **ICERM IdeaLab 2013: Weeklong Program for Postdoctoral Researchers**, ICERM, Providence, Rhode Island. (Jan. 2013, p. 116)

15–19 **7th International Conference on Lévy Processes: Theory and Applications**, University of Wroclaw and Wroclaw University of Technology, Wroclaw, Poland.

* 15–19 **School "Luis Santaló": Mathematics of Planet Earth: Scientific challenges in a sustainable planet**, Palacio de la Magdalena in Santander, Spain.
Programme: Jordi Bascompte (Integrative Ecology Group, Estación Biológica de Doñana, CSIC, Spain), The mathematics of biodiversity; Nicola Bellomo (Politecnico di Torino, Torino, Italy), Towards a theory of complex living beings; Joel Brown (UIC Biological Sciences, University of Illinois at Chicago), Evolutionary game theory: From life on earth to pest management and cancer; Juan Manuel García Ruiz (CSIC and University of Granada, Spain), Patterns on the rocks; Robert Gatenby (Moffitt Cancer Centre, Tampa, Florida), Living with your enemy; Jorge M. Pacheco (University of Minho, Portugal), Evolution of diversity and cooperation; Eitan Tadmor (Center for Scientific Computation and Mathematical Modelling, University of Maryland), Consensus and flocking in self-alignment dynamics.
Information: http://www.ugr.es/local/kinetic/santalo/.

15–19 **Symmetries of Discrete Systems and Processes**, Decin, Czech Republic, North Bohemia. (May 2013, p. 652)

15–19 **Women in Shape (WiSh): Modeling Boundaries of Objects in 2- and 3-Dimensions (in cooperation with AWM)**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California. (Mar. 2013, p. 360)

15–19 **Workshop on Interactions between Dynamical Systems and Partial Differential Equations (JISD2013)**, School of Mathematics and Statistics, Universitat Politècnica de Catalunya, Barcelona, Spain. (Feb. 2013, p. 263)

15–20 **Stochasticity in Biology: Is Nature Inherently Random?**, Montreal, Canada. (Dec. 2012, p. 1595)

* 15–27 **XVI Summer Diffiety School**, Pomorski Park Naukowo-Technologiczny, Gdynia, Poland.
Description: The aim of this permanent School is to introduce undergraduate and Ph.D. students in mathematics and physics as well as post-doctoral researchers in a recently emerged area of mathematics

and teoretical physics: Secondary calculus. A diffiety is a new geometrical object that properly formalizes the concept of the solution space of a given system of (nonlinear) PDEs, much as an algebraic variety does with respect to solutions of a given system of algebraic equations. Secondary calculus is a natural diffiety analogue of the standard calculus on smooth manifolds, and as such leads to a very rich general theory of nonlinear PDEs. Moreover, it appears to be a natural language for quantum physics, just as the standard calculus is the natural language for classical physics.
Scientific Director: Professor A. M. Vinogradov.
Organizing Committee: S. Bytsun, C. Kolodina, M. Sorokina, L. Vitagliano, N. Zinoviev.
Information: `http://sites.google.com/site/levicivitainstitute/xvi-summer-diffiety-school`.

15–August 2 **School and Workshop on Geometric Measure Theory and Optimal Transport**, International Centre for Theoretical Physics (ICTP), Trieste, Italy. (Apr. 2013, p. 514)

* 16 **Workshop on Time Delay Systems — Stability and Control in Applications**, ETH, Zurich, Switzerland.
Description: The workshop will be held preceding the European Control Conference (`http://www.ecc13.ch/`) that will be held in Zurich, Switzerland, July 17-19, 2013. Details of the Workshop can be found at `http://www.coe.neu.edu/~rifat`.
Lecturers: Fatihcan M. Atay, Germany; Dimitri Breda, Italy; Wim Michiels, Belgium; Silviu-Iulian Niculescu, France; Hitay Ozbay, Turkey; Rifat Sipahi, USA.
Information: `http://www.ecc13.ch/`.

* 18 **CRM-Fields-PIMS Prize Lecture**, Simon Fraser University, IRMACS Theatre, Vancouver BC, Canada.
Description: Professor Bruce Reed (McGill) has been awarded the 2013 CRM/Fields/PIMS Prize. The prize recognizes exceptional achievement in the area of mathematical sciences and is considered one of Canada's top honours in mathematics. The prize carries a monetary award of CAD $10,000 and the recipient presents lectures at each of the three awarding institutes.
Information: `http://www.pims.math.ca/scientific-event/130718-cfpplbr`.

* 18–19 **Model Theory and Applications to Geometry**, Center for Mathematics and Fundamental Applications (CMAF), Lisbon, Portugal.
Aim: Of this workshop is to give the opportunity to the participants, to hear more about the recent developments in model theory and its applications and connections to real geometry.
Invited speakers: Raf Cluckers (Univ. de Lille and KULeuven), Antongiulio Fornasiero (Seconda Univ. di Napoli), Isaac Goldbring (UIC), François Loeser (Univ. Pierre et Marie Curie), Chris Miller (Ohio State University), Giovanni Morando (Univ. di Padova), Jean-Philippe Rolin (Univ. de Bourgogne).
Organizers: Mario Edmundo, Marcello Mamino, Luca Prelli, Tamara Servi.
Registration: If you plan on attending this event, please contact: email: `tamara.servi@gmail.com`.
Information: `http://ptmat.fc.ul.pt/~tservi/`.

20–25 **European Meeting of Statisticians**, Eotvos Lorand University, Budapest, Hungary. (Sept. 2012, p. 1174)

* 21–26 **The 2013 Progress on Difference Equations**, Bialystok University of Technology, Bialystok, Poland.
Description: The workshop will be hosted by Bialystok Branch of the Polish Mathematical Society. This meeting continues in the line of other PODE workshops, the first two held in Laufen (Germany) PODE 2007, PODE 2008, followed by the workshops in Bedlewo (Poland) PODE 2009, Xanthi (Greece) PODE 2010, Dublin (Ireland) PODE 2011, and Richmond (Virginia, USA) PODE 2012. The workshop aim is to provide a forum for researchers in the area of difference equations (ordinary and partial), discrete dynamical systems, and their applications, to discuss and exchange their latest works. There will be organized a special session dedicated to fractional difference equations. The conference will consist of invited plenary talks and contributed presentations.
Information: `http://katmat.pb.bialystok.pl/pode13/`.

21–27 **Applied Topology - Bedlewo 2013**, Bedlewo, near Poznan, Poland. (Feb. 2013, p. 263)

22–25 **MIP2013: Mixed Integer Programming Workshop**, University of Wisconsin-Madison, Madison, Wisconsin. (Sept. 2012, p. 1174)

22–25 **Moscow International Conference "Israel Gelfand Centenary"**, Russian Academy of Science, Leninski Ave., Moscow, Russia. (May 2013, p. 652)

22–26 **Mathematics of Planet Earth 2013 - Pan-Canadian Thematic Program - Biodiversity in a Changing World**, CRM, Cambam, Montréal, Canada. (Sept. 2012, p. 1174)

22–26 **Planetary Motions, Satellite Dynamics, and Spaceship Orbits**, Centre de recherches mathématiques, Montréal, Canada. (Apr. 2013, p. 514)

22–26 **Positivity VII**, Leiden University, Leiden, The Netherlands. (Dec. 2012, p. 1595)

22–26 **Samuel Eilenberg Centenary Conference**, Warsaw, Poland. (Apr. 2013, p. 514)

* 22–26 **VII International Meeting on Lorentzian Geometry**, University of Sao Paulo, Sao Paulo, Brazil.
Description: The aim of the meeting is to gather together researchers working on Lorentzian Geometry, Pseudo-Riemannian Geometry, General Relativity and Mathematical Relativity.
Confirmed speakers: Albert Fathi, Lyon, France; Bennett Palmer, Idaho State University, USA; Giovanni Calvaruso, Lecce, Italy; Jorge Herbert de Lira, Fortaleza, Brazil; Jose Luis Flores, Málaga, Spain; José María Martín Senovilla, Bilbao, Spain; Laszlo Beno Szabados, Budapest, Hungary; Levi Lopes de Lima, Fortaleza, Brazil; Miguel Brozos-Vázquez, Universidade da Coruña, Spain; Miyuki Koiso, Kyushu University, Japan; Nicolas Ginoux, Regensburg, Germany. The event is open to speakers from several countries, giving them the opportunity to present their own recent research, and stimulating the interaction among them. The program will include an open problems session, where contribution of all participants is welcome to discuss problems in these areas of mathematics of growing interest.
Information: `http://www.ime.usp.br/~gelosp2013/`.

22–August 9 **Complex Geometry**, Institute for Mathematical Sciences, National University of Singapore, Singapore. (May 2013, p. 653)

23–26 **4th Canadian Conference on Nonlinear Solid Mechanics (CanCNSM2013)**, McGill University, Montreal, Quebec, Canada. (May 2013, p. 653)

* 29–30 **First International Conference on Mobile Computing, E-commerce and Information Security System 2013**, Singapore, Singapore.
Aim: To provide a platform to scholars, academicians, practitioners, and business managers to share their valuable knowledge and experience with each other in the context of changing global market. The objective of the conference is to bring people from academia and business world closer so that they can share the latest technology developments in the fields of computing, engineering, education, business, economics, organizational information security, social sciences, and technology as well as challenges of information security of these topics.
Information: `http://www.icmceiss.com`.

29–August 2 **36th Conference on Stochastic Processes and their Applications**, Boulder, Colorado. (Sept. 2012, p. 1174)

29–August 9 **Introduction to the Mathematics of Seismic Imaging**, Mathematical Sciences Research Institute, Berkeley, California. (Nov. 2012, p. 1482)

31–August 10 **Workshop and Conference on the Topology and Invariants of Smooth 4-Manifolds (First Announcement)**, University of Minnesota, Twin Cities, Minnesota. (Jan. 2013, p. 117)

August 2013

1–3 **15th IMS New Researchers Conference**, Centre de recherches mathématiques, Montréal, Canada. (Apr. 2013, p. 514)

3–11 **Groups St. Andrews 2013**, University of St. Andrews, St. Andrews, Fife, Scotland, UK. (Sept. 2012, p. 1174)

5–9 **1st Mathematical Congress of the Americas**, Guanajuato, Mexico. (Sept. 2012, p. 1174)

5–9 **AIM Workshop: Sections of convex bodies**, American Institute of Mathematics, Palo Alto, California. (Mar. 2013, p. 360)

* 5–9 **BLAST 2013**, Chapman University, Orange, California.
Description: BLAST is a conference focusing on B = Boolean Algebras, L = Lattices, Algebraic and Quantum Logic, A = Universal Algebra, S = Set Theory, T = Set-theoretic and Point-free Topology.
Invited Speakers: Bernhard Banaschewski (McMaster), William DeMeo (Univ. South Carolina), Francois Dorais (Dartmouth), Mai Gehrke (Paris 7, CNRS), Steven Givant (Mills College), Steve Jackson (Univ. North Texas), Michael Pinsker (Paris 7), Dima Sinapova (Univ. Illinois at Chicago), Sam van Gool (Radboud Univ., Nijmegen). Invited tutorials by Martin Escardo (Univ. Birmingham), Heinz-Peter Gumm (Univ. Marburg), Hilary Priestley (Oxford).
Information: http://www.chapman.edu/events/blast-2013/.

5–9 **Quantum/Affine Schubert Calculus**, University of Oregon, Eugene, Oregon. (Mar. 2013, p. 360)

5–9 **XXII Rolf Nevanlinna Colloquium**, Helsinki, Finland. (Aug. 2011, p. 1014)

* 5–16 **Hypergeometric Functions and Representation Theory**, Cimpa-Unesco-Mesr-Mineco-Mongolia Research School, National University of Mongolia, Ulaanbaatar, Mongolia.
Description: The research school will focus on theory of hypergeometric functions, representation theory and representation-theoretic approaches to hypergeometric functions. The school intends to promote young researchers in Mongolia and other countries. Graduate students and young researchers of Mongolia, from Asian countries and students from other countries like Europe, Japan and America are welcomed.
Information: http://www.cimpa-icpam.org/spip.php?article484.

5–16 **International Cimpa School: New Trends in Applied Harmonic Analysis Sparse Representations, Compressed Sensing and Multifractal Analysis**, Mar del Plata, Argentina. (May 2013, p. 653)

11–12 **A quasiconformal life: Celebration of the legacy and work of F. W. Gehring**, University of Helsinki, Helsinki, Finland. (Mar. 2013, p. 361)

11–17 **3rd Mile High Conference on Nonassociative Mathematics**, University of Denver, Denver, Colorado. (Dec. 2012, p. 1595)

12–15 **International Conference on Algebra in Honour of Patrick Smith and John Clark's 70th Birthdays**, Balikesir, Turkey. (Nov. 2012, p. 1482)

12–15 **12th International Workshop on Dynamical Systems and Applications**, Atilim University, Ankara, Turkey. (Mar. 2013, p. 361)

12–17 **18th International Summer School on Global Analysis and Applications**, Juraj Pales Institute, Bottova 15, Levoca, Slovakia. (May 2013, p. 653)

12–October 11 **Mathematical Horizons for Quantum Physics 2**, Institute for Mathematical Sciences, National University of Singapore, Singapore. (May 2013, p. 653)

12–16 **AIM Workshop: Computable stability theory**, American Institute of Mathematics, Palo Alto, California. (Dec. 2012, p. 1595)

12–16 **Random Trees**, Centre de Recherches Mathématiques, Montréal, Canada. (Dec. 2012, p. 1595)

12–16 **2nd Strathmore International Mathematics Conference (SIMC-2013)**, Strathmore University, Nairobi, Kenya. (Feb. 2013, p. 263)

18–24 **International Conference "Differential Equations. Function Spaces. Approximation Theory" dedicated to the 105th anniversary of the birthday of S.L. Sobolev**, Sobolev Institute of Mathematics, Novosibirsk, Russia. (Apr. 2013, p. 515)

19–23 **Differential Geometry and its Applications**, Masaryk University, Old campus, Brno, Czech Republic. (May 2013, p. 653)

19–23 **Fifth Montreal Problem Solving Workshop, A CRM-Mprime Event**, Centre de Recherches Mathématiques, Montréal, Canada. (Apr. 2013, p. 515)

19–23 **GAP XI Pittsburgh - Geometry and Physics "Seminaire Itinerant"**, University of Pittsburgh, Pittsburgh, Pennsylvania. (May 2013, p. 653)

19–September 13 **Infectious Disease Dynamics**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Dec. 2012, p. 1595)

19–December 20 **Mathematical General Relativity**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1174)

19–December 20 **Optimal Transport: Geometry and Dynamics**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1175)

* 21–23 **The 38th Sapporo Symposium on Partial Differential Equations**, Room 203, Faculty of Science Building #5, Hokkaido University, Sapporo, Hokkaido, Japan.
Description: The Sapporo Symposium on Partial Differential Equations has been held annually to present the latest developments on partial differential equations (PDE). The aim of the symposium is to help boost interaction and in-depth discussion among researchers working on different branches of PDE.
Organizers: H. Kubo (Hokkaido University), H. Takaoka (Hokkaido University).
Program Committee: H. Kubo (Hokkaido University), H. Takaoka (Hokkaido University), Y. Tonegawa (Hokkaido University), S. Jimbo (Hokkaido University), Y. Giga (The University of Tokyo), T. Ozawa (Waseda University), K. Tsutaya (Hirosaki University), T. Sakajo (Kyoto University).
Contact: email: cri@math.sci.hokudai.ac.jp.
Information: http://www.math.sci.hokudai.ac.jp/sympo/sapporo/program130821_en.html.

22–23 **Connections for Women on Optimal Transport: Geometry and Dynamics**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1175)

23–25 **14th International Pure Mathematics Conference 2013**, Islamabad, Pakistan. (May 2013, p. 653)

24–31 **Second International Conference "Mathematics in Armenia: Advances and Perspectives" dedicated to the 70th anniversary of foundation of Armenian National Academy of Sciences**, YSU Guesthouse, Tsaghkadzor, Armenia. (Mar. 2013, p. 361)

25–27 **The 7th Global Conference on Power Control and Optimization (PCO'2013)**, Prague, Czech Republic. (Feb. 2013, p. 263)

26–29 **2nd International Eurasian Conference on Mathematical Sciences and Applications**, Sarajevo, Bosnia and Herzegovina. (Feb. 2013, p. 263)

26–30 **AIM Workshop: Rigorous computation for infinite dimensional nonlinear dynamics**, American Institute of Mathematics, Palo Alto, California. (Apr. 2013, p. 515)

26–30 **Geometric Function Theory and Applications 2013**, Isik University, Campus of Sile, Istanbul, Turkey. (Jan. 2013, p. 116)

26–30 **International Conference AMMCS-2013 (Applied Mathematics, Modeling and Computational Science)**, Waterloo, Ontario, Canada. (Sept. 2012, p. 1175)

26–30 **Introductory Workshop on Optimal Transport: Geometry and Dynamics**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1175)

* 26–30 **Joint Events of Colloquium on Differential Geometry and its Applications and IX-th International Conference on Finsler Extensions of Relativity Theory**, Debrecen, Hungary.
Description: The Colloquium on Differential Geometry and its Applications will be held in Debrecen, Hungary, organized by the Department of Geometry, University of Debrecen, Hungary, in cooperation with the Debrecen Branch of the Hungarian Academy of Sciences and the Janos Bolyai Mathematical Society, as a joint event with the IX-th International Conference on Finsler Extensions of Relativity Theory (FERT 2013). During the Colloquium we celebrate the 90th birthday of Professor Lajos Tamassy, doyen of Hungarian differential geometry. The scientific program (26-30th August) is devoted to lectures given by the participants of CDG and FERT and invited lectures on various fields of differential geometry together with global analysis and applications to mathematical physics. Parallel sessions will run for CDG and FERT in the afternoons.
Information: `http://www.math.unideb.hu/diffgeo/`.

26–September 7 **DGS 2013 — International Conference and Advanced School Planet Earth, Dynamics, Games and Science**, Calouste Gulbenkian Foundation (FCL) and Escola Superior de Economia e Gestão, Universidade Técnica de Lisboa (ISEG-UTL), Lisbon, Portugal. (Mar. 2013, p. 361)

* 27–30 **The 44th Annual Iranian Mathematics Conference**, Ferdowsi University of Mashhad, Mashhad, Iran.
Description: The Annual Iranian Mathematics Conference has been held since 1970. The 11th, 22nd and 33rd annual Iranian mathematics conferences were held at Ferdowski University of Mashhad and now we are pleased to organize the 44th conference. The conference will provide a forum for mathematicians worldwide and scholar students to present their latest results about all aspects of pure and applied mathematics and a means to discuss their recent researches with each other. Interested scientists are warmly invited to propose their new ideas and recent researches for enhancing the scientific level of the conference. The language of the presentation may be English or Farsi. We look forward to meeting you in the second biggest city of Iran, Mashhad. For participating in the conference, the international mathematicians may contact the scientific chair, Prof. M. S. Moslehian, via `moslehian@member.ams.org` or `http://imc44@um.ac.ir`.
Information: `http://imc44.um.ac.ir/index.php?&newlang=eng`.

27–31 **The 9th William Rowan Hamilton Geometry and Topology Workshop, on Geometry and Groups after Thurston**, Hamilton Mathematics Institute, Trinity College, Dublin, Ireland. (Mar. 2013, p. 361)

27–December 20 **Mathematical Challenges in Quantum Information**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Dec. 2012, p. 1596)

28–September 2 **Gelfand Centennial Conference: A View of 21st Century Mathematics**, Massachusetts Institute of Technology, Cambridge, Massachusetts. (Jan. 2013, p. 116)

* 30–31 **8th International Symposium on Trustworthy Global Computing (TGC 2013)**, Fac. de Ciencias Económicas - UBA Av Córdoba Avenida Córdoba 2122 C1120AAQ, Buenos Aires, Argentina.
Description: The Symposium on Trustworthy Global Computing is an international annual venue dedicated to safe and reliable computation in the so-called global computers, i.e., those computational abstractions emerging in large-scale infrastructures such as service-oriented architectures, autonomic systems and cloud computing. The TGC series focuses on providing frameworks, tools, algorithms and protocols for designing open-ended, large-scaled applications and for reasoning about their behaviour and properties in a rigorous way. The related models of computation incorporate code and data mobility over distributed networks that connect heterogeneous devices and have dynamically changing topologies.
Information: `http://sysma.lab.imtlucca.it/tgc2013/`.

September 2013

1–5 **Motivic Galois Groups**, Alfréd Rényi Institute of Mathematics, Budapest, Hungary. (Mar. 2013, p. 362)

1–6 **Kangro-100, Methods of Analysis and Algebra, International Conference dedicated to the Centennial of Professor Gunnar Kangro**, University of Tartu, Tartu, Estonia. (Feb. 2013, p. 264)

* 1–7 **51st Summer School on Algebra and Ordered Sets**, Hotel Troyer, Trojanovice, Czech Republic.
Description: A traditional conference focused on general algebra and ordered sets. The scientific program consists of 20- or 30-minute talks by the participants, plus plenary lectures by invited speakers.
Information: `http://ameql.math.muni.cz/ssaos`.

1–August 31, 2014 **Call for Research Programmes 2013-2014**, Centre de Recerca Matemàtica, Bellaterra, Barcelona, Spain. (Sept. 2012, p. 1175)

* 1–November 30 **Research Programme on Geometry and Dynamics of Integrable Systems**, Centre de Recerca Matemàtica, Bellaterra, Barcelona.
Description: This research Programme wants to focus on the geometrical and the dynamical aspects in the study of integrable systems. We want to specially stress the following topics in the study of integrable systems: Connections of several aspects showing up in the geometry, topology and dynamics of integrable systems in symplectic manifolds such as singular aspects of integrable systems, symplectic topology of integrable systems, integrability criteria and obstructions to integrability, connection with geometric quantization and integrable systems in contact and Poisson manifolds; study of geodesic flows, their integrability and non-integrability: methods and examples; applications to mathematical physics and classical differential geometry.
Scientific Committee: Vladimir Matveev, Eva Miranda, Francisco Presas and Iskander Taimanov.
Information: `http://www.crm.cat/2013/RPIntegrable-Systems`.

1–December 20 **Research Program on Automorphisms of Free Groups: Algorithms, Geometry and Dynamics**, Centre de Recerca Matemàtica, Bellaterra, Barcelona, Spain. (Dec. 2012, p. 1596)

2–5 **XXII International Fall Workshop on Geometry and Physics**, University of Évora, Évora, Portugal. (Mar. 2013, p. 362)

* 2–6 **School and Workshop on Conformal Blocks, Vector Bundles on Curves and Moduli of Curves**, Mathematics Department, G. Castelnuovo Sapienza, Universita di Roma, Rome, Italy.
Aim: Of this school/workshop is to give an introduction to conformal blocks, their construction and use as research tools and objects in different branches of algebraic geometry and topology, in particular moduli spaces of algebraic curves and of vector bundles on curves. Four mini-courses of 5 hours each will be held.
Speakers: Prakash Belkale (Univ. North Carolina at Chapel Hill), Angela Gibney (Univ. of Georgia at Athens), Christian Pauly (Univ. de Nice Sophia-Antipolis), Aaron Pixton (Princeton University).
Funding: It is possible for Ph.D. students and young post-docs to apply for funding for lodging guaranteed by our sponsors. Subscribe to the conference on the registration page to apply.
Deadline: For applying for funding is May 31st, 2013.
Information: http://conformalmoduli.sciencesconf.org/.

3–4 **Connections for Women: Mathematical General Relativity**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1175)

3–6 **CAI 2013: 5th Conference on Algebraic Informatics**, ERISCS and IML, Aix-Marseille University, IGESA, Porquerolles Island, France. (Dec. 2012, p. 1596)

4–6 **Loday Memorial Conference**, Institut de Recherche Mathématique Avancée (IRMA), Strasbourg, France. (May 2013, p. 654)

* 4–6 **Semiclassical Origins of Density Functional Approximations**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: Density functional theory (DFT) has become an enormously successful tool for electronic structure calculations. Recent work has sought to re-examine the link between DFT, semiclassical approximations, and functional analysis. Numerical and heuristic results suggest a close (but subtle) underlying link. Understanding of these links, and using them to build new and more powerful approximations, could have tremendous impact in modern electronic structure calculations. The aim of this workshop is to reunite these disparate strands and begin a conversation among the different communities, including researchers from mathematics, physics, and theoretical chemistry. An application and registration form are available online.
Information: http://www.ipam.ucla.edu/programs/dft2013/.

* 6–12 **Conference on Integrability, Topological Obstructions to Integrability and Interplay with Geometry**, Centre de Recerca Matemàtica, Bellaterra, Barcelona, Spain.
Description: The main goal of this workshop is to gather specialists in different aspects, dynamical aspects and connection with other areas like mathematical physics.
List of speakers: Alain Albouy (CNRS), Sergey Bolotin (UW-Madison), Alexey V. Borisov (Udmurt State Univ.), Vincent Colin (Univ. de Nantes), Lucia Di Vizio (Univ. de Versailles-St. Quentin), Christian Duval (Centre National de la Recherche Scientifique Marseille, France), Rui Loja Fernandes (Univ of Illinois at Urbana-Champaign), Valerij Vasilievich Kozlov (Russian Academy of Sciences), Boris Kruglikov (Univ. of Tromso), Ivan Sergeevich Mamaev (Institute of Computer Science), Valentin Ovsienko (Univ. Claude Bernard-Lyon), Daniel Peralta (ICMAT), Jean-Pierre Ramis (Univ. Paul Sabatier), Tudor Ratiu (EPFL), Dmitry Treschev (Steklov Mathematical Institute) and Jacques-Arthur Weil (Univ. de Limoges).
Information: http://www.crm.cat/2013/CIntegrability.

8–14 **Combinatorial Methods in Topology and Algebra**, Il Palazzone, Cortona, Italy. (Feb. 2013, p. 264)

9–11 **Aachen Conference on Computational Engineering Science (AC.CES)**, AC.CES takes place at RWTH Aachen University (SuperC building), Germany. (May 2013, p. 654)

9–11 **S.Co. 2013 - Complex Data Modeling and Computationally Intensive Statistical Methods for Estimation and Prediction**, Politecnico di Milano, Milano, Italy. (Apr. 2013, p. 515)

* 9–11 **Seventh International Workshop Meshfree Methods for Partial Differential Equations**, Universität Bonn, Germany.
Organizers: Ivo Babuska (University of Texas, Austin, USA), Ted Belytschko (Northwestern University, USA), Jiun-Shyan Chen (University of California, USA), Michael Griebel (Universität Bonn, Germany), Wing Kam Liu (Northwestern University, USA), Marc Alexander Schweitzer (Universität Bonn, Germany), Harry Yserentant (Technische Universitaet Berlin, Germany).
Contact: http://wissrech.ins.uni-bonn.de/meshfree; email: meshfree@ins.uni-bonn.de.
Deadlines and Important Dates: Online Regisration Open: May 1, 2013. 2013 Abstract Submission: June 15, 2013. Notification of Acceptance: July 15, 2013.
Information: http://wissrech.ins.uni-bonn.de/meshfree.

* 9–13 **AIM Workshop: Definability and decidability problems in number theory**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to studying definability and decidability questions in number theory, more specifically over rational numbers and their algebraic extensions, as well as over rings of functions of natural interest.
Information: http://aimath.org/ARCC/workshops/definabilityinnt.html.

9–13 **European Conference on Combinatorics, Graph Theory and Applications - Eurocomb 2013**, National Research Council of Italy (CNR), Pisa, Italy. (Mar. 2013, p. 362)

9–13 **Introductory Workshop: Mathematical General Relativity**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1175)

* 9–14 **Advanced Course on Geometry and Dynamics of Integrable Systems**, Centre de Recerca Matemàtica, Bellaterra, Barcelona, Spain.
Objectives: This advanced course aims at describing different aspects in the study of integrable systems from a geometrical, algebraic and dynamical point of view.
Organizing and scientific committee: Vladimir Matveev (Jena), Eva Miranda (UPC), Francisco Presas (ICMAT) and Iskander Taimanov (Novosibirsk).
Speakers at Minicourses: There are 4 sessions in each group. Alexey Bolsinov (Louborough), "singularities of bi-Hamiltonian systems and stability analysis"; Juan Jose Morales-Ruiz (UPM), "integrable systems and differential galois theory"; Nguyen Tien Zung (Toulouse), "geometry of integrable non-Hamiltonian systems"
Information: http://www.crm.cat/2013/ACIntegrable-Systems.

9–December 6 **ICERM Semester Program on "Low-Dimensional Topology, Geometry, and Dynamics"**, Institute for Computational and Experimental Research in Mathematics (ICERM), Providence, Rhode Island. (Sept. 2012, p. 1176)

* 11–13 **BioDynamics 2013**, Bristol, United Kingdom.
Description: Rhythms in biological systems – the theme for our first in a series of annual international workshops designed to bring together biologists, mathematicians, clinicians, physicists, and computer scientists who are interested in dynamical systems in the biological and medical sciences. These workshops will provide a unique forum for multidisciplinary interactions, which we hope will lead to rewarding collaborations between theoretical, experimental, and clinical scientists.
Confirmed keynote speakers: Professor Russell Foster, University of Oxford, UK; Dr. Michael Hastings, MRC Laboratory of Molecular Biology, Cambridge, UK; Professor David Hazlerigg, University of Aberdeen, UK; Professor Allan Herbison, University of Otago Centre for

Neuroendocrinology, New Zealand; Professor Kevin O'Byrne, King's College, London, UK; Professor David Rand, University of Warwick, UK; Professor James Sneyd, University of Auckland, New Zealand.
Information: http://www.bio-dynamics2013.org.

11–13 **14th IMA Conference on Mathematics of Surfaces**, University of Birmingham, United Kingdom. (Sept. 2012, p. 1176)

11–14 **The Sixth International Workshop on Differential Equations and Applications**, Izmir University of Economics, Izmir, Turkey. (Apr. 2013, p. 515)

12–14 **The Algerian-Turkish International Days on Mathematics 2013**, Fatih University, Istanbul, Turkey. (May 2013, p. 654)

15–20 **ICERM Workshop: Exotic Geometric Structures**, ICERM, Providence, Rhode Island. (Jan. 2013, p. 116)

16–20 **Mathematics for an Evolving Biodiversity**, Centre de Recherches Mathématiques, Montréal, Canada. (Dec. 2012, p. 1596)

16–20 **MatTriad'2013 - Conference on Matrix Aanalysis and its Applications**, Herceg-Novi, Montenegro. (Dec. 2012, p. 1596)

16–October 11 **Mathematics and Physics of the Holographic Principle**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Dec. 2012, p. 1596)

* 19–22 **Conference on Applied and Industrial Mathematics - CAIM 2013**, Faculty of Mathematics and Computer Science, University of Bucharest, Romania.
Description: Caim 2013 provides a forum for the review of the recent trends in applied mathematics: mathematical modeling, studies of models coming from industry, biology, economy, etc., either from a qualitative or from a numerical point of view. Since theoretical studies find sooner or later their applicability, the conference has also sections for more theoretical branches of mathematics like algebra or geometry. Computer science communications are welcome.
Information: http://www.romai.ro/conferintele_romai/caim2013_en.html.

21–23 **The First International Conference on New Horizons in Basic and Applied Science Session "Aspects of Mathematics and its Applications"**, Hurghada, Egypt. (May 2013, p. 654)

21–27 **"Wavelets and Related Multiscale Methods" within ICNAAM2013: 11th International Conference of Numerical Analysis & Applied Mathematics**, Rodos Palace Hotel, Rhodes, Greece. (Apr. 2013, p. 515)

* 22–26 **18th Annual cum 3rd International Conference of Gwalior Academy of Mathematical Sciences (GAMS)**, Department of Mathematics Maulana Azad National Institute of Technology, Bhopal, India 462051.
Description: The academic program of the conference will consist of keynote, plenary and invited talks, and paper presentations in mathematical biology, statistics, air pollution, differential equations, special functions and other allied topics.
Theme: Mathematical, Computational and Integrative Sciences.
Call for Papers: Original research papers on recent developments in Mathematical and Computational Sciences are invited for presentation in the conference. Intended participants are invited to send the abstracts (not exceeding 250 words) on or before May 31, 2013. After receiving the acceptance the authors will have to submit full-length papers no later than June 30, 2013. The author will have to follow "Instructions to Authors" as given in the website http://www.gamsinfo.com for the GAMS Journal. All abstracts should be submitted online to the Organizing Secretary.
Important dates: Deadline for Submission of Abstract: May 31, 2013. Notification of Acceptance: June 15, 2013. Early bird Registration: June 15, 2013. Full length Paper Submission: June 30, 2013.
Information: http://www.gamsinfo.com and http://www.manit.ac.in.

23–27 **Mathematics of Sequence Evolution: Biological Models and Applications**, Centre de Recherches Mathématiques, Montréal, Canada. (Dec. 2012, p. 1596)

* 23–27 **Solar Cells**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: This is the first workshop in the long program "Materials for a Sustainable Energy Future." The workshop will include a poster session; a request for posters will be sent to registered participants in advance of the workshop.
Organizing committee: Claudia Draxl (Humboldt-Universitt), Jeff Neaton (Lawrence Berkeley Laboratory), and Keith Promislow (Michigan State University, Mathematics).
Registration: An application and a registration form is available online.
Application deadline: July 29, 2013.
Information: http://www.ipam.ucla.edu/programs/msews1/.

* 23–28 **International conference "Complex Analysis and Related Topics"**, Lviv Ivan Franko National University, Lviv, Ukraine.
Description: The following topics will be presented on the conference: - complex analysis of one variable; - complex analysis of several variables; - complex approximation.
Information: http://analysis13.mathlviv.org.ua.

* 27–28 **The twelfth annual Prairie Analysis Seminar**, Kansas State University, Manhattan, Kansas.
Description: The conference features Gui-Qiang Chen, University of Oxford, who will give two one-hour talks, and Mikhail Feldman, University of Wisconsin, Augusto Ponce, Université Catholique de Louvain, and Mónica Torres, Purdue University, who will each give a one-hour talk. There is time scheduled for contributed talks; all participants, especially mathematicians early in their careers, are encouraged to contribute a 20-minute talk. The conference is supported by the NSF and funding is available with priority given to students, postdocs and those early in their careers.
Organizers: Marianne Korten, Charles Moore, Kansas State University; Estela Gavosto, Rodolfo Torres, University of Kansas
Information: http://www.math.ksu.edu/pas/2013/PrairieAnalysisSeminar/2013.html.

28–29 **Mathematics of Planet Earth 2013 - Pan-Canadian Thematic Program - Mathematical Modeling of Indigenous Population Health**, BIRS, Banff, Canada. (Sept. 2012, p. 1176)

October 2013

5–6 **2013 Fall Southeastern Section Meeting**, University of Louisville, Louisville, Kentucky. (Sept. 2012, p. 1176)

7–11 **Coalescent Theory: New Developments and Applications**, Centre de Recherches Mathématiques, Montréal, Canada. (Dec. 2012, p. 1596)

* 7–11 **Differential Geometry and Global Analysis**, Leipzig University, Department of Mathematics, Leipzig, Germany.
Description: International conference, topics include (Pseudo-) Riemannian and conformal geometry, geometry of metric spaces, geometry of differential operators, geometric variational problems, Hamiltonian systems, symplectic geometry and topology.
Information: http://www.math.uni-leipzig.de/~rademacher/dgga13.html.

10–12 **International Conference on Statistical Distributions and Applications**, Mt. Pleasant, Michigan. (Mar. 2013, p. 362)

* 11–13 **International Symposium on Biomathematics and Ecology: Education and Research**, Marymount University, Arlington, Virginia.
Description: This is the sixth annual meeting which traditionally covers a wide spectrum of topics in biomathematics, biology, exology, biostatistics focused on both education and research.
Information: http://www.biomath.ilstu.edu/beer.

12–13 **2013 Eastern Sectional Meeting**, Temple University, Philadelphia, Pennsylvania. (Sept. 2012, p. 1176)

14–18 **Fluid Mechanics, Hamiltonian Dynamics, and Numerical Aspects of Optimal Transportation**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1176)

* 14–18 **Fuels from Sunlight**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: This workshop seeks to enhance the quality of research on chemical energy conversion and open new directions. We invite colleagues from materials science, physics, chemistry, chemical engineering, applied mathematics and statistics, and computer science.
Organizing Committee: Rupert Klein (Freie Universitt Berlin), Jens Norskov (Stanford University), and Matthias Scheffler (Fritz-Haber-Institut der Max-Planck-Gesellschaft).
Registration: An application and a registration form are available online.
Application deadline: August 19, 2013.
Information: `http://www.ipam.ucla.edu/programs/msews2/`.

* 14–18 **Topological and Combinatorial Problems in One-dimensional Complex Dynamics**, Centro di Ricerca Matematica "Ennio De Giorgi", Piazza dei Cavalieri 3, Pisa, Italy.
Description: One dimensional complex dynamics involves the usage of many different tools taken from other areas of mathematics. We would like to focus on the interaction of holomorphic dynamics with topology on one side, and with combinatorics on the other side. The goal of this workshop is to investigate these two themes from the threefold view-point of local dynamics, dynamics of transcendental maps, and dynamics of rational maps, emphasizing the similarities between these problems in the three settings. This will outline a fairly complete summary of the current topological and combinatorial methods available in the three areas, with the hope of suggesting new applications. Emphasis will be on open problems and interrelations between the two major themes of the workshop. A side goal is to encourage the participation of graduate students and recent Ph.D.'s in the field.
Registration: On-line registration required. No attendance fee. Support for selected young participants available.
Deadline: Application: June 23, 2013.
Information: `http://www.crm.sns.it/event/271/`.

15–19 **VII Moscow International Conference on Operations Research (ORM2013)**, Dorodnicyn Computing Center of RAS (CC of RAS) and Lomonosov Moscow State University (MSU), Moscow, Russian Federation. (Jan. 2013, p. 117)

18–20 **2013 Fall Central Section Meeting**, Washington University, St. Louis, Missouri. (Sept. 2012, p. 1176)

* 19–20 **The 23rd annual Route 81 Conference on Commutative Algebra and Algebraic Geometry**, Syracuse University, Syracuse, New York.
Description: The Route 81 Conference on Commutative Algebra and Algebraic Geometry rotates between the campuses of Cornell University (Ithaca), Queen's University (Kingston), and Syracuse University (Syracuse), along the Route 81 corridor in New York State. This year's conference will feature 6-10 talks of approximately one hour. Persons interested in giving a talk are invited to submit a title and abstract to one of the organizers. There is no formal registration process, but it would be helpful if you would let the organizers know if you plan to attend.
Information: `http://www.commalg.org/Rte81-2013/`.

21–25 **ICERM Workshop: Topology, Geometry and Group Theory, Informed by Experiment**, ICERM, Providence, Rhode Island. (Jan. 2013, p. 117)

21–25 **Mathematics of Planet Earth 2013 - Pan-Canadian Thematic Program - Sustainability of Aquatic Ecosystem Networks**, AARMS, Fredericton, New Brunswick, Canada. (Sept. 2012, p. 1176)

21–December 20 **Mathematics for the Fluid Earth**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Dec. 2012, p. 1597)

23–25 **International Conference in Modeling Health Advances ICMHA 2013**, Berkeley, California. (Mar. 2013, p. 363)

24 **3rd IMA Mathematics in Defence**, QinetiQ, Malvern, United Kingdom. (May 2013, p. 654)

28–31 **Groups, Group Rings, and Related Topics GGRRT 2013**, United Arab Emirates University, Al Ain, United Arab Emirates. (May 2013, p. 654)

28–November 9 **Lévy Processes and Self-similarity 2013**, Tunis, Tunisia. (Feb. 2013, p. 264)

November 2013

2–3 **2013 Western Fall Section Meeting**, University of California Riverside, Riverside, California. (Sept. 2012, p. 1176)

* 4–8 **Batteries and Fuel Cells**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: An energy economy fueled by renewable resources will require significant improvement in existing materials for energy conversion and storage. It is the goal of this workshop to bring together mathematicians, physicists, computer scientists, materials scientists and engineers who work in the area of batteries and fuel cells to spark collaborations across disciplines and seed new interdisciplinary research directions. This workshop will include a poster session; a request for posters will be sent to registered participants in advance of the workshop. An application and registration form are available online.
Application deadline: September 9, 2013.
Information: `http://www.ipam.ucla.edu/programs/msews3/`.

4–8 **Biodiversity and Environment: Viability and Dynamic Games Perspectives**, Centre de Recherches Mathématiques, Montréal, Canada. (Dec. 2012, p. 1596)

09–16 (NEW DATE) **International Conference on Fractals and Wavelets**, Rajagiri School of Engineering & Technology Kakkanad Cochin, Kerala, India. (Feb. 2013, p. 264)

10–15 **Mathematics of Planet Earth 2013 - Pan-Canadian Thematic Program - Current Challenges for Mathematical Modelling of Cyclic Populations**, BIRS, Banff, Canada. (Sept. 2012, p. 1176)

11–14 **SIAM Conference on Geometric and Physical Modeling (GD/SPM13)**, The Curtis, A DoubleTree by Hilton Hotel, Denver, Colorado. (May 2013, p. 654)

11–15 **Mal'tsev Meeting 13**, Sobolev Institute of Mathematics SB RAS, Novosibirsk, Russia. (May 2013, p. 654)

12–14 **2013 IEEE International Conference on Technologies for Homeland Security (IEEE HST.13)**, The Westin, Waltham, Boston, 70 Third Avenue, Waltham, Massachusetts 02451. (Apr. 2013, p. 515)

12–14 **The Second International Conference on Informatics Engineering & Information Science (ICIEIS2013)**, University Technology Malaysia (UTM), Kuala Lumpur, Malaysia. (Dec. 2012, p. 1597)

* 13–15 **School on Quantum Ergodicity and Harmonic Analysis (Part III)**, Philipps University, Marburg, Germany.
Description: This school is aimed at doctoral students and also welcomes more experienced researchers. Its third part will consist of four lecture series: N. Anantharaman: Entropy and the localization of eigenfunctions; J. Hilgert: Introduction to quantum ergodicity and related topics; S. Nonnenmacher: Resonances in chaotic scattering:

a semiclassical gap in terms of topological pressure; R. Schubert: On the rate of quantum ergodicity. This activity is a continuation of events held in Göttingen in January 2013 and in Marburg in September 2012. It can be attended without earlier participation.
Support: Finanical support can be provided.
Information: `http://www.uni-math.gwdg.de/QEMarburg2013`.

* 15 (NEW DATE) **Information, Instability and Fragility in Networks: Methods and Applications**, University of Colorado, Boulder, Colorado.
Description: The recent financial crisis raised the specter of cascading disruptions across financial institutions, due to their growing interconnectedness and the speed at which disruptions may propagate across them. Quantitative "Connectionist" research in the physical sciences, engineering and information theory has modeled analogous phenomena, using techniques that are less familiar to economists, financial researchers and regulators and social scientists in general. This conference will bring the seemingly disparate researchers together, in order to share ideas and jump start future collaborations. Early researchers coped with the limited micro-level data about large networks by adopting information-theoretic estimation techniques (e.g., the maximum entropy method). The conference is especially interested in papers employing information-theoretic, Bayesian techniques for additional purposes.
Information: `http://www.american.edu/cas/economics/info-metrics/workshop/conference-2013-fall.cfm`.

* 18–22 **Energy Conservation and Waste Heat Recovery**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: A most effective, though still underestimated, issue in dealing with the energy requirements of modern societies concerns the conservation of energy. It is the goal of this workshop to bring together mathematicians, physicists, computer scientists, materials scientists and engineers who work in the area of energy conservation and waste heat recovery. An application and registration form is available online.
Organizing Committee: Giulia Galli (University of California, Davis), Richard James (University of Minnesota, Twin Cities), Jennifer Lukes (University of Pennsylvania), and Matthias Scheffler (Fritz-Haber-Institut der Max-Planck-Gesellschaft).
Information: `http://www.ipam.ucla.edu/programs/msews4/`.

18–22 **Evolution Problems in General Relativity**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1176)

18–22 **ICERM Workshop: Geometric Structures in Low-Dimensional Dynamics**, ICERM, Providence, Rhode Island. (Jan. 2013, p. 117)

19–21 **Gulf International Conference on Applied Mathematics (GICAM13)**, Mubarak Al-Abdullah Al-Jaber Area, Kuwait. (Feb. 2013, p. 264)

* 24–29 **II International Conference on Applied Mathematics and Informatics - ICAMI 2013**, San Andres Island, Colombia.
Description: This conference is organized every three years (starting from 2010) in the region of Latin America and the Caribbean as an official event of the REALMA Network (Réseau Europa–Amérique Latine en Maths Appliques, `http://www.realma.org/`) and targets to involve local researchers who have fewer opportunities to attend similar conferences held in Europe and USA.
Main streams: Applied analysis and geometry; applied probability, statistics, and stochastic processes; continuous and discrete dynamic systems; game theory and other economics applications; mathematical epidemiology and biosciences; mathematical geosciences; numerical methods and software tools; operations research, optimization methods and applications; partial differential equations and applications; robotics and mechanical engineering; uncertainty quantification (UQ) and visualization in scientific computing.
Deadline: For abstract submission: June 20, 2013.
Information: `http://matematicas.univalle.edu.co/icami/2013/`.

* 24–29 **Multi-scale and Multi-field Representations of Condensed Matter Behavior**, Centro di Ricerca Matematica "Ennio De Giorgi", Piazza dei Cavalieri 3, Pisa, Italy.
Description: The School will introduce and discuss recent trends in the theoretical and computational approaches for the modelling of condensed matter. There will be special emphasis on describing the various ways events at finer scales in both space and time affect the macroscopic behaviour of matter at the macroscopic scales. Topics in continuum mechanics, theory of PDEs, stochastic calculus, and scientific computing will be addressed. The School will be a unique interdisciplinary opportunity to foster interactions among scholars coming from different scientific environments. The list of lecturers is available on the website.
Registration: Is free but participants are requested to register on the website. Some funds will be made available to offer financial support to a number of selected young researchers and students for their participation in the School. Applications can be made online through the website.
Deadlines: For applications for financial support: October 31, 2013. Registration: November 18, 2013.
Information: `http://www.crm.sns.it/event/280/`.

26–28 **International Conference on Pure and Applied Mathematics, ICPAM-LAE 2013**, Png University of Technology, Lae, Morobe Province, Papua New Guinea. (Sept. 2012, p. 1176)

December 2013

* 7–8 **Infinite-Dimensional Geometry**, University of California, Berkeley (740 Evans Hall), California.
Description: The purpose of this workshop is to gather researchers working in various areas of geometry in infinite dimensions in order to facilitate collaborations and sharing of ideas.
Topics: Represented include optimal transport and geometries on densities, metrics on shape spaces, Euler-Arnold equations on diffeomorphism groups, the universal Teichmuller space, geometry of random Riemann surfaces, metrics on spaces of metrics, and related areas.
Funded: By an NSF grant.
Information: `http://www.msri.org/web/msri/scientific/workshops/all-workshops/show/-/event/Wm10168`.

7–11 **"ATCM+TIME 2013": A joint session of 18th Asian Technology Conference in Mathematics and 6th Technology & Innovations in Mathematics Education**, Department of Mathematics, Indian Institute of Technology, Powai, Mumbai 400076, India. (Mar. 2013, p. 363)

* 16–18 **International Conference on Role of Statistics in the Advancement of Science and Technology**, Department of Statistics, University of Pune, Pune, Maharashtra, India.
Description: The Department of Statistics, University of Pune is organizing "Diamond Jubilee Year & International Year of Statistics Conference" to commemorate 60 years of establishment.
Aim: To explore the role of statistics in the advancement of science and technology.
Topics: Statistical inference, inference in stochastic processes, statistical computing, biostatistics, reliability, survival analysis, industrial statistics, actuarial, financial statistics, data mining, probability theory, decision theory, design of experiments, distribution theory, econometrics, multivariate analysis, neural networks, nonparametric inference, operations research, queuing theory, simulation methods, statistical genetics, statistical quality control, survey sampling, time series analysis, etc.

Information: http://stats.unipune.ac.in/Conf13.html.

* 16–19 **International Conference on Advances in Applied Mathematics**, Hammamet, Tunisia.
Description: The Tunisian Association of Applied Mathematics and Industrial organizes its first conference in Applied Mathematics "ICAAM 2023". The purpose of this conference is to highlight some of the major theoretical advances and applications in the fields of: Spectral theory, operator theory, optimization, numerical analysis, partial differential equations, ordinary differential equations, control theory, dynamical systems, nonlinear systems and matrix, probability and statistics.
Information: http://sites.google.com/site/icaam2013/.

16–20 **Fundamental Groups in Arithmetic and Algebraic Geometry**, Centro di Ricerca Matematica Ennio De Giorgi, Pisa, Italy. (Mar. 2013, p. 363)

* 16–20 **The XXIVth Edition of the International Workshop on Operator Theory and its Applications (IWOTA)**, Indian Institute of Sciences, Bangalore, India.
Description: As usual there will be special sessions at IWOTA 2013. Proposals should be submitted to iwota2013@gmail.com and should contain a brief description of the session and a preliminary list of speakers and tentative lecture titles. We plan to have at least eight special sessions and each session will have between six to eight hours of time.
Information: The webpage will soon have information about registration, registration fee, hotel booking etc. There is a rudimentary website at the address http://math.iisc.ernet.in/~iwota2013.

* 17–20 **Marrakesh International Conference on Probability and Statistics (MICPS-2013)**, Marrakesh, Morocco.
Organizing Committee: M. Eddahbi, K. Es-Sebaiy, I. Ouassou, Y. Ouknine and M. Rachdi.
Registration and submission: For all the actions related to the MICPS-2013 (abstract submission, registration, conference fee, etc) please check the conference website.
Accommodation/Transportation: Special prices have been arranged with some hotels for MICPS 2013 participants.
Information: http://www.ensa.ac.ma/micps2013/; email: k.essebaiy@uca.ma.

18–20 **6th Indian International Conference on Artificial Intelligence**, Tumkur (near Bangalore), India. (May 2013, p. 655)

* 18–21 **HiPC 2013: 20th IEEE International Conference on High Performance Computing**, Hyderabad, India.
Description: You are invited to submit original unpublished research work that demonstrates current research in all areas of high performance computing including design and analysis of parallel and distributed systems, embedded systems, and their applications in scientific, engineering, and commercial areas. All accepted papers will be published in printed conference books/proceedings (ISBN) or on a CD. In addition, please assist in printing the CFP and displaying it on your organization's message boards. The details of CFP (call for papers) can be found at http://www.hipc.org/hipc2013/papers.php. In addition to technical sessions consisting of contributed papers, the conference will include invited presentations, a student research symposium, tutorials, and vendor presentations in the industry, user and research symposium. Further details about call for student research symposium, workshops, tutorials, and exhibits, as well as submission guidelines are available at the conference website.
General Co-Chairs: Badrinath Ramamurthy, HP, India; Rama Govindaraju, Google, California, USA.
Vice-General Chair: Jigar Halani, Wipro, India.
Deadline: Paper submission: May 16, 2013.
Information: http://www.hipc.org.

* 21–22 **The International Congress on Science and Technology**, Allahabad, U.P., India.
Description: The ICST-2013 is organized by the CWS, a non-profit society for the scientists and the technocrats and will take place in Allahabad, U.P., INDIA, from Dec. 21-22, 2013. The conference has the focus on the current trends on frontier topics of the science and technology (Applied Engineering) subjects. The ICST conferences serve as good platforms for our members and the entire science and technological community to meet with each other and to exchange ideas.
Information: http://sites.google.com/site/intcongressonsciandtech/.

* 21–23 **7th International Conference of IMBIC on "Mathematical Sciences for Advancement of Science and Technology" (MSAST 2013)**, Hotel Indismart, Kolkata, India.
Description: The main objective of the conference is to bring specialized topics in mathematics, statistics, computer science, information technology, bioinformatics and closely related interdisciplinary areas to the forefront. Original full papers are invited. All papers are to be screened and accepted papers will be published in the *Proceedings of IMBIC*, Volume 2 (2013), having ISBN 978-81-925832-1-1, except for a few full scientific papers of high quality, which may be published in the highly acclaimed series of monographs of IMBIC in Volume 2 (2014).
Contact: All correspondence in respect to the conference is to be addressed to Dr. Avishek Adhikari, Convenor MSAST 2013 & Secretary, IMBIC; email: msast.paper@gmail.com; http://www.isical.ac.in/~avishek_r/.
Information: http://www.indismart.in/kol-index.php; http://www.imbic.org/forthcoming.html.

28–30 **3rd International Conference on Mathematics & Information Science (ICMIS 2013)**, Luxor, Egypt. (Oct. 2012, p. 1303)

January 2014

5–7 **ACM-SIAM Symposium on Discrete Algorithms (SODA14), being held with Analytic Algorithmics and Combinatorics (ANALCO14) and Algorithm Engineering and Experiments (ALENEX14)**, Hilton Portland & Executive Tower, Portland, Oregon. (Dec. 2012, p. 1597)

* 6–10 **Mathematics of Social Learning**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: The goal of this workshop is to bring together mathematicians, physicists, and social, information, and computer scientists to explore the dynamics of social learning and cultural evolution. Of particular interest will be ways of using data from social media and online experiments to address questions of interest.
Deadline: An application and registration form is available online. Application deadline: November 11, 2013.
Information: http://www.ipam.ucla.edu/programs/sl2014/.

6–July 4 **Free Boundary Problems and Related Topics**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Dec. 2012, p. 1597)

* 15–18 **Joint Mathematics Meetings**, Baltimore, Maryland.
Information: http://www.ams.org/meetings/national/national.

* 16–18 **Mathematical Challenges in Ophthalmology**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: Ophthalmology has become increasingly subspecialized and technologically advanced, making it impossible to be an expert in every area and highlighting the need for multi-disciplinary collaborations with engineers and mathematicians. The goal of this workshop is to encourage communication between engineers, mathematicians, scientists, and clinicians to improve patient care

and scientific advancement. The integration of new imaging technology allows visualization down to the cellular level, but objectivity of evaluation and automated analysis still need more refinement. The incorporation of intraoperative imaging technology would be the beginning of a new surgical era in ophthalmology. Robotics in ophthalmic surgery is also on the horizon. It would reduce human error, improve precision, and increase surgical capabilities. An application and registration form are available online.
Information: http://www.ipam.ucla.edu/programs/mco2014/.

* 20–23 **International Conference on Recent Advances in Mathematics (ICRAM 2014)**, Department of Mathematics, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur Maharashtra State, India.
Description: The conference schedule includes plenary talks, invited talks on current areas of research followed by a large number of paper and poster presentations.
Aim: The main aim of the conference is to promote, encourage, discuss the latest developments and research in the field of Mathematics and its applications and bring together researchers in the different fields. The conference is broad-based on (i) pure mathematics, algebra, algebraic geometry, mathematical analysis, number theory, numerical analysis & scientific computing, topology and differential equation, operations research and statistics (iii) mathematical physics, general relativity and cosmology, high energy physics, quantum mechanics.
Information: http://www.icram2014.com.

* 20–24 **An international symposium on orthogonality and quadrature (ORTHOQUAD 2014)**, Puerto de la Cruz, Tenerife, Canary Islands, Spain.
Description: This is an international conference in memory of Prof. Dr. Pablo González Vera, Professor of Applied Mathematics at the University of La Laguna (Canary Islands), who passed away on July 11, 2012. Professor González Vera was a recognized specialist in approximation theory, orthogonal polynomials and quadrature formulae, and was author of more than one hundred fifty papers published in prestigious international journals in the area of applied mathematics. He also wrote several books, among which specially stands "Orthogonal Rational Functions", published by Cambridge University Press, and written in collaboration with Adhemar Bultheel (KU Leuven, Belgium), Erik Hendriksen (Netherlands) and Olav Njastad (Univ. of Trondheim). In this sense, the main topics of the conference will be orthogonality and quadrature, but other topics in approximation theory, special functions and related issues are also within the scope of the conference.
Information: http://gama.uc3m.es/pablo/.

* 20–24 **ICERM Topical Workshop: From the Clinic to Partial Differential Equations and Back: Emerging challenges for Cardiovascular Mathematics**, ICERM, Providence, Rhode Island.
Description: Mathematical models have been giving remarkable contributions in advancing knowledge and supporting decisions in several branches of medicine. The goal of this workshop is to foster collaboration between mathematicians and medical doctors on modeling cardiovascular system. It will organized into two lines: "Core topics" are up-to-date research areas in mathematics and scientific computing that still present several open exciting challenges, which can require developing new numerical models, computational approaches and validation techniques; "New challenges" are a set of cardiovascular (in broad sense) problems and diseases that have not been attacked extensively with numerical tools. The workshop will be based on round-table discussions in smaller groups and lectures.
Information: http://icerm.brown.edu/tw14-1-pdecm.

20–May 23 **Algebraic Topology Program**, Mathematical Sciences Research Institute, Berkeley, California. (Nov. 2012, p. 1482)

20–May 23 **Model Theory and Number Theory**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1177)

23–24 **Connections for Women: Algebraic Topology**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1177)

27–31 **Introductory Workshop: Algebraic Topology**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1177)

* 27–31 **Rough Paths: Theory and Applications**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: The theory of rough paths has established itself as a powerful tool to analyze a variety of stochastic systems that are too "rough" for their solutions to exist in the class of functions that can be handled by classical analytical methods. The power of the theory resides in its ability to cleanly separate the probabilistic components from their purely analytic aspects. Recently, the theory has seen an explosion of new results that caused its scope to expand considerably. This workshop will bring together experts in the theory of rough paths with researchers working in related areas of mathematics (probability, PDEs/SDEs, analysis, etc) and sciences in general. An application and registration form are available online.
Information: http://www.ipam.ucla.edu/programs/rp2014/.

February 2014

3–7 **Introductory Workshop: Model Theory, Arithmetic Geometry and Number Theory**, Mathematical Sciences Research Institute, Berkeley, California. (Nov. 2012, p. 1482)

3–May 9 **ICERM Semester Program on "Network Science and Graph Algorithms"**, ICERM, Providence, Rhode Island. (Jan. 2013, p. 117)

10–11 **Connections for Women: Model Theory and its interactions with number theory and arithmetic geometry**, Mathematical Sciences Research Institute, Berkeley, California. (Sept. 2012, p. 1177)

* 10–14 **ICERM Workshop: Semidefinite Programming and Graph Algorithms**, ICERM, Providence, Rhode Island.
Description: Semidefinite programming is playing an ever increasing role in many areas of computer science and mathematics, including complexity theory, approximation algorithms for hard graph problems, discrete geometry, machine learning, and extremal combinatorics. This workshop will bring together researchers from these different fields. The goal is to explore connections, learn and share techniques, and build bridges.
Information: http://icerm.brown.edu/sp-s14-w1.

* 10–14 **Translating Cancer Data and Models to Clinical Practice**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: This workshop will emphasize an integrated approach to understanding cancer initiation, progression, metastasis, and treatment. Proposed participants will include a number of clinicians and experimentalists whose approach and research may complement and motivate new mathematical and physical modeling, as well as empirical or clinical investigations. Our ultimate goals will be to critically examine and discuss approaches for improving clinical .standards of care. and to foster new investigative directions in applied cancer research that involve the right level of detail in emerging mathematical and physical approaches. An application and registration form are available online.
Information: http://www.ipam.ucla.edu/programs/cdm2014/.

* 24–28 **Stochastic Gradient Methods**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: This workshop will address various topics in the theory, implementation, and practice of SG methods, possibly including the following: applications to nonconvex problems and regularized objectives; parallel implementations; hybridization of SG methods with other optimization techniques; and use of SG methods in deep

learning, latent variable models, and other settings. An application and registration form are available online.
Information: `http://www.ipam.ucla.edu/programs/sgm2014/`.

March 2014

* 3–7 **AIM Workshop: Postcritically finite maps in complex and arithmetic dynamics**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to questions relating to postcritically finite (PCF) rational maps.
Information: `http://www.aimath.org/ARCC/workshops/finitedynamics.html`.

* 4–7 **11th German Probability and Statistics Days 2014 - Ulmer Stochastik-Tage**, University Ulm, Ulm, Germany.
Description: The venue is at the University of Ulm. In the tradition of the previous conferences, this meeting provides an international forum for presentation and discussion of new results in the area of probability and statistics.
Speakers: The plenary speakers of the conference will be: Jianqing Fan (Princeton), Geoffrey Grimmett (Cambridge), Jean-Franis Le Gall (Paris), Alexandre Tsybakov (Paris). Contributed talks will be given in 17 sections devoted to specific topics; the highlight of each section will be one invited main talk. Over the last years, the "Stochastik-Tage" organized biannually have been attracting an increasing number of participants from abroad.
Language: English.
Information: `http://www.gpsd-ulm2014.de`.

10–26 **School and Workshop on Classification and Regression Trees**, Institute for Mathematical Sciences, National University of Singapore, Singapore. (May. 2013, p. 655)

* 17–21 **ICERM Workshop: Stochastic Graph Models**, ICERM, Providence, Rhode Island.
Description: Random graphs, stochastic processes on graphs and algorithms for computations on these structures continue to play a dominant role in algorithmic research and discrete mathematics, with recent applications ranging from web search and recommendation engines to social networks and system biology. This workshop will be an opportunity for researchers from diverse fields to get together and share problems and techniques for handling and analyzing graphs structures. The connections—mathematical, computational, and practical—that arise between these seemingly diverse problems and approaches will be emphasized.
Information: `http://icerm.brown.edu/sp-s14-w2`.

* 21–23 **Sectional Meeting**, University of Tennessee, Knoxville, Knoxville, Tennessee.
Description: 2014 Southeastern Spring Sectional Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

24–April 17 **Mathematical, Statistical and Computational Aspects of the New Science of Metagenomics**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Mar. 2013, p. 363)

* 29–30 **Sectional Meeting**, University of Maryland, Baltimore County, Baltimore, Maryland.
Description: 2014 Spring Eastern Sectional Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

31–April 3 **SIAM Conference on Uncertainty Quantification (UQ14)**, Hyatt Regency Savannah, Savannah, Georgia. (Dec. 2012, p. 1597)

April 2014

* 5–6 **Sectional Meeting**, University of New Mexico, Albuquerque, New Mexico.
Description: 2014 Western Spring Sectional Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

* 7–11 **AIM Workshop: The many facets of the Maslov index**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to the Maslov index, a collective name for many related invariants counting the jumps of functions, starting in the 19th century with the principal value of the complex logarithm.
Information: `http://www.aimath.org/ARCC/workshops/maslov.html`.

* 7–11 **ICERM Workshop: Electrical Flows, Graph Laplacians, and Algorithms: Spectral Graph Theory and Beyond**, ICERM, Providence, Rhode Island.
Description: Spectral graph theory, which studies how the eigenvalues and eigenvectors of the graph Laplacian and other related matrices interact with the combinatorial structure of a graph, is a classical tool in both the theory and practice of algorithm design. The success of this approach has been rooted in the efficiency with which eigenvalues and eigenvectors can be computed and in the large number of ways that a graph's properties are connected to the Laplacian's spectrum, particularly to the value of its second smallest eigenvalue $\lambda 2$. While the eigenvalues and eigenvectors of the Laplacian capture a striking amount of the structure of the graph, they do not capture it all. Recent work suggests that we have only scratched the surface of what can be done if we are to broaden our investigation to include more general linear-algebraic properties of the matrices we associate to graphs. The workshop will bring researchers together to study and advance this emerging frontier in algorithmic graph theory.
Information: `http://icerm.brown.edu/sp-s14-w3`.

7–11 **Reimagining the Foundations of Algebraic Topology**, Mathematical Sciences Research Institute, Berkeley, California. (May 2013, p. 719)

* 11–13, 2014 **Sectional Meeting**, Texas Tech University, Lubbock, Texas.
Description: 2014 Spring Central Sectional Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

22–May 16 **Advanced Monte Carlo Methods for Complex Inference Problems**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Mar. 2013, p. 364)

May 2014

12–14 **SIAM Conference on Imaging Science (IS14)**, Hong Kong Baptist University, Hong Kong, China. (Aug. 2012, p. 1021)

* 12–16 **ICERM Topical Workshop: Robust Discretization and Fast Solvers for Computable Multi-Physics Models**, ICERM, Providence, Rhode Island.
Description: This workshop will gather together experts in the core related fields in applied and computational mathematics to exchange ideas regarding the development of robust and efficient numerical schemes that preserve the key physics of these models, and to study the development of fast and efficient linear and nonlinear solvers that are scalable and optimal. This workshop will also target young researchers and members of under-represented groups to help launch their research in this area.
Information: `http://icerm.brown.edu/tw14-2-cmpm`.

12–16 **Model Theory in Geometry and Arithmetic**, Mathematical Sciences Research Institute, Berkeley, California. (June/July 2012, p. 870)

* 19–23 **Representations of reductive groups: A conference dedicated to David Vogan on his 60th birthday**, MIT, Cambridge, Massachusetts.
Description: The conference will address recent developments in the representation theory of reductive Lie groups and algebraic groups over finite and local fields, as well as connections of this theory with other subjects, such as number theory, automorphic forms, algebraic geometry and combinatorics. It will be an occasion to celebrate the 60th birthday of David Vogan, who has inspired and shaped the development of this field for almost 40 years.
Information: `http://math.mit.edu/conferences/Vogan/`.

* 26–29 **VI Workshop on Dynamical Systems: On the occasion of Marco Antonio Teixeira's 70th birthday (MAT70)**, Campinas, SP, Brazil.
Description: In 2014 we wish to celebrate Marco Antonio Teixeira's 70th birthday and his significant mathematical contribution. With this in mind, we wish to honor him with a Scientific Conference.
Information: `http://www.mat70.com/`.

26–30 **Constructive Functions 2014**, Vanderbilt University, Nashville, Tennessee. (May 2013, p. 655)

* 28–30 **IWCIA 2014 – 16th International Workshop on Combinatorial Image Analysis**, Brno University of Technology, Technická 2, Brno, Czech Republic.
Description: The 16th International Workshop on Combinatorial Image Analysis will be hosted by the Brno University of Technology, Faculty of Mechanical Engineering. The researchers from all areas of image analysis and its applications are cordially invited to participate.
Information: `http://iwcia2014.fme.vutbr.cz/`.

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.

June 2014

* 9–13 **AIM Workshop: The Cauchy-Riemann equations in several variables**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will focus on the many interesting questions that remain about the interaction between estimates for solutions of the Cauchy-Riemann equations and the behavior of the Bergman kernel associated to the given norm.
Information: `http://www.aimath.org/ARCC/workshops/crscv.html`.

* 9–13 **Tenth edition of the Advanced Course in Operator Theory and Complex Analysis**, Sevilla, Spain.
Invited speakers: Filippo Bracci, Universita di Roma "Tor Vergata", Italy; James Brennan, University of Kentucky, Kentucky; Yurii Lyubarskii, NTNU, Trondheim, Norway; Alexander Olevskii, Tel Aviv University, Israel; Tatiana Smirnova-Nagnibeda, Universite de Geneve, Switzerland.
Information: You can find further information about the courses at `http://congreso.us.es/ceacyto/2013`. Apart of attending the course, you may also have the opportunity to deliver a contributed talk.

* 23–25 **17th Conference on Integer Programming and Combinatorial Optimization (IPCO 2014)**, University of Bonn, Bonn, Germany.
Description: The IPCO-conference is a forum for researchers and practitioners working on various aspects of integer programming and combinatorial optimization. The aim is to present recent developments in theory, computation, and applications in these areas.
Information: `http://www.or.uni-bonn.de/ipco/`.

* 23–27 **What Next? The mathematical legacy of Bill Thurston**, Cornell University, Ithaca, New York.
Description: This conference will celebrate the profound influence of Bill Thurston's work on the entire mathematical community. Thurston made fundamental contributions to topology, geometry, and dynamical systems. But beyond these specific accomplishments he introduced new ways of thinking about and of seeing mathematics. He discovered connections between disciplines which led to the creation of entirely new fields. The goal of this meeting is to bring together mathematicians from a broad spectrum of areas to describe recent advances and explore future directions motivated by Thurston's transformative ideas.
Organizers: Dave Gabai, John Hubbard, Steve Kerckhoff, John Smillie, DylanThurston and Karen Vogtmann.
Information: `http://www.math.cornell.edu/~festival`.

July 2014

* 14–18 **AIM Workshop: Mori program for Brauer log pairs in dimension three**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to the Mori program for Brauer log pairs in dimension three.
Information: `http://www.aimath.org/ARCC/workshops/moribrauerlog.html`.

August 2014

* 4–9 **10th International Conference on Clifford Algebras and their Applications in Mathematical Physics (ICCA10)**, University of Tartu, Tartu, Estonia.
Description: The aim of the ICCA10 is to bring together the leading scientists in the field of Clifford algebras, differential geometry and their various applications in mathematics, physics, engineering and other applied sciences. We invite you to participate in the exchange of the latest results in research and application.
Information: `http://icca10.ut.ee`.

* 11–14 **SIAM Conference on Nonlinear Waves and Coherent Structures (NW14)**, Churchill College, University of Cambridge, Cambridge, United Kingdom.
Description: The call for submissions will be linked from `http://www.siam.org/meetings/nw14/` in October 2013.
Information: `http://www.siam.org/meetings/nw14/`.

September 2014

* 20–21 **Sectional Meeting**, University of Wisconsin-Eau Claire, Eau Claire, Wisconsin.
Description: 2014 Central Fall Section Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

October 2014

* 18–19 **Sectional Meeting**, Dalhousie University, Halifax, Canada.
Description: 2014 Fall Eastern Sectional Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

* 25–26 **Sectional Meeting**, San Francisco State University, San Francisco, California.
Description: 2014 Fall Western Section Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

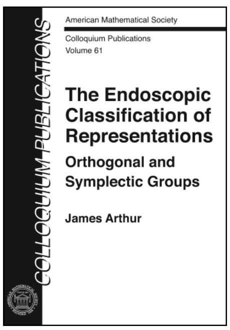
November 2014

* 8–9 **Sectional Meeting**, University of North Carolina, Greensboro, North Carolina.
Description: 2014 Fall Southeastern Section Meeting.
Information: `http://www.ams.org/meetings/sectional/sectional.html`.

New Publications Offered by the AMS

To subscribe to email notification of new AMS publications, please go to http://www.ams.org/bookstore-email.

Algebra and Algebraic Geometry



The Endoscopic Classification of Representations

James Arthur, *University of Toronto, ON, Canada*

Within the Langlands program, endoscopy is a fundamental process for relating automorphic representations of one group with those of another. In this book, Arthur establishes an endoscopic classification of automorphic representations of orthogonal and symplectic groups G. The representations are shown to occur in families (known as global L-packets and A-packets), which are parametrized by certain self-dual automorphic representations of an associated general linear group $GL(N)$. The central result is a simple and explicit formula for the multiplicity in the automorphic discrete spectrum of G for any representation in a family.

The results of the volume have already had significant applications: to the local Langlands correspondence, the construction of unitary representations, the existence of Whittaker models, the analytic behaviour of Langlands L-functions, the spectral theory of certain locally symmetric spaces, and to new phenomena for symplectic epsilon-factors. One can expect many more. In fact, it is likely that both the results and the techniques of the volume will have applications to almost all sides of the Langlands program.

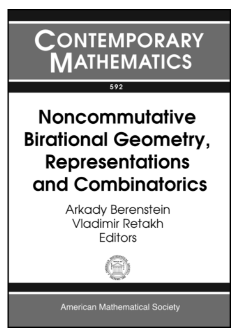
The methods are by comparison of the trace formula of G with its stabilization (and a comparison of the twisted trace formula of $GL(N)$ with its stabilization, which is part of work in progress by Moeglin and Waldspurger). This approach is quite different from methods that are based on L-functions, converse theorems, or the theta correspondence. The comparison of trace formulas in the volume ought to be applicable to a much larger class of groups. Any extension at all will have further important implications for the Langlands program.

This item will also be of interest to those working in number theory.

Contents: Parameters; Local transfer; Global stabilization; The standard model; A study of critical cases; The local classification; Local nontempered representations; The global classification; Inner forms; Bibliography; Index.

Colloquium Publications, Volume 61

September 2013, approximately 595 pages, Hardcover, ISBN: 978-0-8218-4990-3, LC 2013004694, 2010 *Mathematics Subject Classification:* 22E55, 22E50, 11R37, 11F66, 58C40, **AMS members US$92**, List US$115, Order code COLL/61



Noncommutative Birational Geometry, Representations and Combinatorics

Arkady Berenstein, *University of Oregon, Eugene, OR*, and **Vladimir Retakh**, *Rutgers University, Piscataway, NJ*, Editors

This volume contains the proceedings of the AMS Special Session on Noncommutative Birational Geometry, Representations and Cluster Algebras, held from January 6–7, 2012, in Boston, MA.

The papers deal with various aspects of noncommutative birational geometry and related topics, focusing mainly on structure and representations of quantum groups and algebras, braided algebras, rational series in free groups, Poisson brackets on free algebras, and related problems in combinatorics.

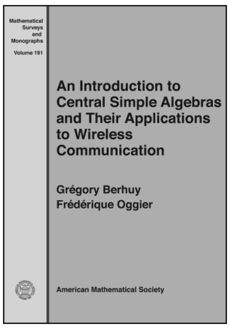
This volume is useful for researchers and graduate students in mathematics and mathematical physics who want to be introduced to different areas of current research in the new area of noncommutative algebra and geometry.

This item will also be of interest to those working in discrete mathematics and combinatorics.

Contents: R. Bacher and **C. Reutenauer**, The number of right ideals of given codimension over a finite field; **Y. Bazlov** and **A. Berenstein**, Cocycle twists and extensions of braided doubles; **A. Berenstein** and **J. Greenstein**, Quantum Chevalley groups; **A. Berenstein**, **V. Retakh**, **C. Reutenauer**, and **D. Zeilberger**, The reciprocal of $\Sigma_{n\geq 0} a^n b^n$ for non-commuting a and b_1, Catalan numbers and non-commutative quadratic equations; **A. Carroll** and **J. Weyman**, Semi-invariants for gentle algebras; **S. Gautam** and **V. T. Laredo**, Monodromy of the trigonometric Casimir connection for $\mathfrak{sl}_2$; **A. Lauve** and **C. Reutenauer**, Rational series in the free group and the Connes operator; **K. Lee** and **L. Li**, On natural maps from strata of quiver Grassmannians to ordinary Grassmannians; **D. Nacin**, Properties of a minimal non-Koszul $A(\Gamma)$; **A. Odesskii**, **V. Rubtsov**, and **V. Sokolov**, Double Poisson brackets on free associative algebras; **M. Vancliff** and **P. P. Veerapen**, Generalizing the notion of rank to noncommutative quadratic forms.

Contemporary Mathematics, Volume 592

May 2013, 250 pages, Softcover, ISBN: 978-0-8218-8980-0, LC 2013008249, 2010 *Mathematics Subject Classification:* 17B37, 16G99, 16T30, 08B20, 05E10, **AMS members US$71.20**, List US$89, Order code CONM/592



An Introduction to Central Simple Algebras and Their Applications to Wireless Communication

Grégory Berhuy, *Université Joseph Fourier, Grenoble, France*, and **Frédérique Oggier**, *Nanyang Technological University, Singapore, Singapore*

Central simple algebras arise naturally in many areas of mathematics. They are closely connected with ring theory, but are also important in representation theory, algebraic geometry and number theory.

Recently, surprising applications of the theory of central simple algebras have arisen in the context of coding for wireless communication. The exposition in the book takes advantage of this serendipity, presenting an introduction to the theory of central simple algebras intertwined with its applications to coding theory. Many results or constructions from the standard theory are presented in classical form, but with a focus on explicit techniques and examples, often from coding theory.

Topics covered include quaternion algebras, splitting fields, the Skolem-Noether Theorem, the Brauer group, crossed products, cyclic algebras and algebras with a unitary involution. Code constructions give the opportunity for many examples and explicit computations.

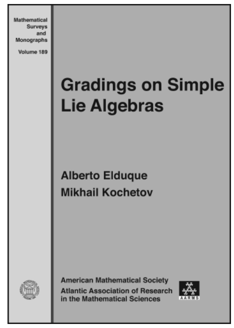
This book provides an introduction to the theory of central algebras accessible to graduate students, while also presenting topics in coding theory for wireless communication for a mathematical audience. It is also suitable for coding theorists interested in learning how division algebras may be useful for coding in wireless communication.

This item will also be of interest to those working in applications.

Contents: Introduction; Central simple algebras; Quaternion algebras; Fundamental results on central simple algebras; Splitting fields of central simple algebras; The Brauer group of a field; Crossed products; Cyclic algebras; Central simple algebras of degree 4; Central simple algebras with unitary involutions; Tensor products; A glimpse of number theory; Complex ideal lattices; Bibliography; Index.

Mathematical Surveys and Monographs, Volume 191

August 2013, 276 pages, Hardcover, ISBN: 978-0-8218-4937-8, LC 2013009629, 2010 *Mathematics Subject Classification:* 12E15; 11T71, 16W10, **AMS members US$78.40**, List US$98, Order code SURV/191



Gradings on Simple Lie Algebras

Alberto Elduque, *Universidad de Zaragoza, Zaragoze, Spain*, and **Mikhail Kochetov**, *Memorial University of Newfoundland, St. John's, NL, Canada*

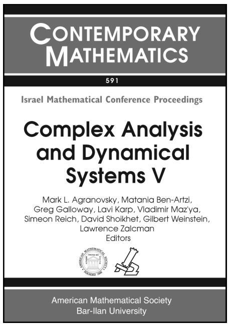
Gradings are ubiquitous in the theory of Lie algebras, from the root space decomposition of a complex semisimple Lie algebra relative to a Cartan subalgebra to the beautiful Dempwolff decomposition of E_8 as a direct sum of thirty-one Cartan subalgebras. This monograph is a self-contained exposition of the classification of gradings by arbitrary groups on classical simple Lie algebras over algebraically closed fields of characteristic not equal to 2 as well as on some nonclassical simple Lie algebras in positive characteristic. Other important algebras also enter the stage: matrix algebras, the octonions, and the Albert algebra. Most of the presented results are recent and have not yet appeared in book form. This work can be used as a textbook for graduate students or as a reference for researchers in Lie theory and neighboring areas.

Contents: Introduction; Gradings on algebras; Associative algebras; Classical Lie algebras; Composition algebras and type G_2; Jordan algebras and type F_4; Other simple Lie algebras in characteristic zero; Lie algebras of Cartan type in prime characteristic; Affine group schemes; Irreducible root systems; Bibliography; Index of notation; Index.

Mathematical Surveys and Monographs, Volume 189

July 2013, approximately 342 pages, Hardcover, ISBN: 978-0-8218-9846-8, LC 2013007217, 2010 *Mathematics Subject Classification:* 17B70; 17B60, 16W50, 17A75, 17C50, **AMS members US$78.40**, List US$98, Order code SURV/189

Analysis



Complex Analysis and Dynamical Systems V

Mark L. Agranovsky, *Bar-Ilan University, Ramat-Gan, Israel*, **Matania Ben-Artzi**, *Hebrew University of Jerusalem, Israel*, **Greg Galloway**, *University of Miami, Coral Gables, FL*, **Lavi Karp**, *ORT Braude College, Karmiel, Israel*, **Vladimir Maz'ya**, *Linköping University, Sweden*, **Simeon Reich**, *Technion-Israel Institute of Technology, Haifa, Israel*, **David Shoikhet**, *ORT Braude College, Karmiel, Israel*, **Gilbert Weinstein**, *University of Alabama at Birmingham, AL*, and **Lawrence Zalcman**, *Bar-Ilan University, Ramat-Gan, Israel*, Editors

This volume contains the proceedings of the Fifth International Conference on Complex Analysis and Dynamical Systems, held from May 22–27, 2011, in Akko (Acre), Israel.

The papers cover a wide variety of topics in complex analysis and partial differential equations, including meromorphic functions, one-parameter semigroups, subordination chains, quasilinear hyperbolic systems, and the Euler-Poisson-Darboux equation. In addition, there are several articles dealing with various aspects of fixed point theory, hyperbolic geometry, and optimal control.

This item will also be of interest to those working in differential equations.

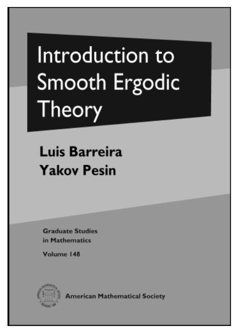
This book is co-published with Bar-Ilan University (Ramat-Gan, Israel).

Contents: **L. Aizenberg** and **A. Vidras**, Duality and the class of holomorphic functions representable by Carleman's formula; **E. Ames**, **F. Beyer**, **J. Isenberg**, and **P. G. LeFloch**, Quasilinear symmetric hyperbolic Fuchsian systems in several space dimensions; **G. Barsegian**, Revisiting a general property of meromorphic functions; **D. Batenkov**, **V. Golubyatnikov**, and **Y. Yomdin**, Reconstruction of planar domains from partial integral measurements; **C. de Fabritiis**, An introduction to one-parameter semigroups in non-strictly convex domains: The case of Cartan factors of type IV; **P. C. Fenton**, Remark on a theorem of Hayman; **I. Graham**, **H. Hamada**, **G. Kohr**, and **M. Kohr**, Univalent subordination chains in reflexive complex Banach spaces; **S. Grudsky** and **N. Tarkhanov**, A note on Muskhelishvili-Vekua reduction; **S. V. Gryshchuk** and **S. A. Plaksa**, Basic properties of monogenic functions in a biharmonic plane; **L. A. Harris**, Bivariate polynomial interpolation at the Geronimus nodes; **W. K. Hayman**, **T. F. Tyler**, and **D. J. White**, The Blumenthal conjecture; **A. M. Kytmanov** and **S. G. Myslivets**, On the families of complex lines sufficient for holomorphic continuation of functions defined on a domain boundary; **A. Lecko** and **D. Partyka**, A revised proof of spirallikeness; **E. Liflyand** and **U. Stadtmüller**, A multidimensional Euler-Maclaurin formula and an application; **M. Obradović** and **S. Ponnusamy**, Injectivity and starlikeness of sections of a class of univalent functions; **S. Reich** and **A. J. Zaslavski**, A fixed point theorem for contractive non-self mappings; **V. Ryazanov**, **R. Salimov**, **U. Srebro**, and **E. Yakubov**, On boundary value problems for the Beltrami equations; **Y. Salman**, Global extendibility phenomenon for the Euler-Poisson-Darboux equation; **I. Shestakov**, On the Zaremba problem for the p-Laplace operator; **M. Vuorinen** and **G. Wang**, Bisection of geodesic segments in hyperbolic geometry; **A. J. Zaslavski**, Existence of solutions for a class of infinite horizon optimal control problems without discounting arising in economic dynamics.

Contemporary Mathematics, Volume 591

July 2013, 314 pages, Softcover, ISBN: 978-0-8218-9024-0, 2010 *Mathematics Subject Classification:* 30-XX, 32-XX, 35-XX, 44-XX, 47-XX, 49-XX, 83-XX, **AMS members US$88.80**, List US$111, Order code CONM/591

Differential Equations



Introduction to Smooth Ergodic Theory

Luis Barreira, *Instituto Superior Técnico, Lisbon, Portugal*, and **Yakov Pesin**, *Pennsylvania State University, State College, PA*

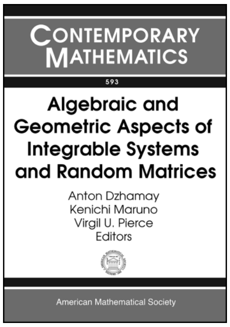
This book is the first comprehensive introduction to smooth ergodic theory. It consists of two parts: the first introduces the core of the theory and the second discusses more advanced topics. In particular, the book describes the general theory of Lyapunov exponents and its applications to the stability theory of differential equations, the concept of nonuniform hyperbolicity, stable manifold theory (with emphasis on the absolute continuity of invariant foliations), and the ergodic theory of dynamical systems with nonzero Lyapunov exponents. The authors also present a detailed description of all basic examples of conservative systems with nonzero Lyapunov exponents, including the geodesic flows on compact surfaces of nonpositive curvature.

This book is a revised and considerably expanded version of the previous book by the same authors: *Lyapunov Exponents and Smooth Ergodic Theory* (University Lecture Series, Vol. 23, AMS, 2002). It is aimed at graduate students specializing in dynamical systems and ergodic theory as well as anyone who wants to acquire a working knowledge of smooth ergodic theory and to learn how to use its tools. With more than 80 exercises, the book can be used as a primary textbook for an advanced course in smooth ergodic theory. The book is self-contained and only a basic knowledge of real analysis, measure theory, differential equations, and topology is required and, even so, the authors provide the reader with the necessary background definitions and results.

Contents: *The core of the theory:* Examples of hyperbolic dynamical systems; General theory of Lyapunov exponents; Lyapunov stability theory of nonautonomous equations; Elements of the nonuniform hyperbolicity theory; Cocycles over dynamical systems; The multiplicative ergodic theorem; Local manifold theory; Absolute continuity of local manifolds; Ergodic properties of smooth hyperbolic measures; Geodesic flows on surfaces of nonpositive curvature; *Selected advanced topics:* Cone technics; Partially hyperbolic diffeomorphisms with nonzero exponents; More examples of dynamical systems with nonzero Lyapunov exponents; Anosov rigidity; C^1 pathological behavior: Pugh's example; Bibliography; Index.

Graduate Studies in Mathematics, Volume 148

July 2013, 277 pages, Hardcover, ISBN: 978-0-8218-9853-6, LC 2013007773, 2010 *Mathematics Subject Classification:* 37D25, 37C40, **AMS members US$52**, List US$65, Order code GSM/148



Algebraic and Geometric Aspects of Integrable Systems and Random Matrices

Anton Dzhamay, *University of Northern Colorado, Greeley, CO*, and **Kenichi Maruno** and **Virgil U. Pierce**, *University of Texas-Pan American, Edinburg, TX*, Editors

This volume contains the proceedings of the AMS Special Session on Algebraic and Geometric Aspects of Integrable Systems and Random Matrices, held from January 6–7, 2012, in Boston, MA.

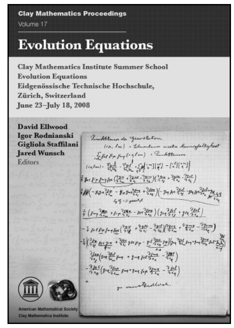
The very wide range of topics represented in this volume illustrates the importance of methods and ideas originating in the theory of integrable systems to such diverse areas of mathematics as algebraic geometry, combinatorics, and probability theory. The volume offers a balanced combination of survey articles and research papers with important new results.

This item will also be of interest to those working in probability and statistics and discrete mathematics and combinatorics.

Contents: **M. Adler**, **M. Cafasso**, and **P. van Moerbeke**, Nonlinear PDEs for Fredholm determinants arising from string equations; **J. C. DiFranco** and **P. D. Miller**, The semiclassical modified nonlinear Schrödinger equation II: Asymptotic analysis of the Cauchy problem. The elliptic region for transsonic initial data; **J. Szmigielski** and **L. Zhou**, Peakon-antipeakon interactions in the Degasperis-Procesi equation; **A. Kasman**, Duality and collisions of harmonically constrained Calogero particles; **T. Suzuki**, A class of higher order Painlevé systems arising from integrable hierarchies of type A; **H. Kawakami**, **A. Nakamura**, and **H. Sakai**, Toward a classification of four-dimensional Painlevé-type equations; **Y. Ohyama** and **S. Okumura**, R. Fuchs' problem of the Painlevé equations from the first to the fifth; **S. Chakravarty**, Differential equations for triangle groups; **A. Doliwa**, Hirota equation and the quantum plane; **A. S. Carstea**, On the geometry of Q_4 mapping; **D. Korotkin** and **P. Zograf**, Tau function and the Prym class; **O. Dumitrescu**, **M. Mulase**, **B. Safnuk**, and **A. Sorkin**, The spectral curve of the Eynard-Orantin recursion via the Laplace transform; **V. U. Pierce**, Continuum limits of Toda lattices for map enumeration.

Contemporary Mathematics, Volume 593

July 2013, approximately 348 pages, Softcover, ISBN: 978-0-8218-8747-9, 2010 *Mathematics Subject Classification:* 34M55, 34M56, 37K10, 05C30, 14D21, 14H15, 39A20, 33E17, 60B20, **AMS members US$88.80**, List US$111, Order code CONM/593



Evolution Equations

David Ellwood, *Harvard University, Cambridge, MA*, **Igor Rodnianski** and **Gigliola Staffilani**, *Massachusetts Institute of Technology, Cambridge, MA*, and **Jared Wunsch**, *Northwestern University, Evanston, IL*, Editors

This volume is a collection of notes from lectures given at the 2008 Clay Mathematics Institute Summer School, held in Zürich, Switzerland. The lectures were designed for graduate students and mathematicians within five years of the Ph.D., and the main focus of the program was on recent progress in the theory of evolution equations. Such equations lie at the heart of many areas of mathematical physics and arise not only in situations with a manifest time evolution (such as linear and nonlinear wave and Schrödinger equations) but also in the high energy or semi-classical limits of elliptic problems.

The three main courses focused mainly on microlocal analysis and spectral and scattering theory, the theory of the nonlinear Schrödinger and wave equations, and evolution problems in general relativity. These major topics were supplemented by several mini-courses reporting on the derivation of effective evolution equations from microscopic quantum dynamics; on wave maps with and without symmetries; on quantum N-body scattering, diffraction of waves, and symmetric spaces; and on nonlinear Schrödinger equations at critical regularity.

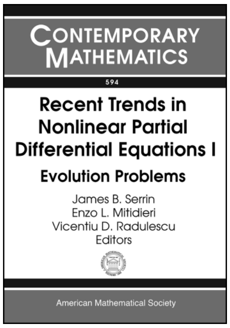
Although highly detailed treatments of some of these topics are now available in the published literature, in this collection the reader can learn the fundamental ideas and tools with a minimum of technical machinery. Moreover, the treatment in this volume emphasizes common themes and techniques in the field, including exact and approximate conservation laws, energy methods, and positive commutator arguments.

Titles in this series are co-published with the Clay Mathematics Institute (Cambridge, MA).

Contents: **J. Wunsch**, Microlocal analysis and evolution equations: Lecture notes from the 2008 CMI/ETH Summer School; **D. Baskin** and **R. Mazzeo**, Some global aspects of linear wave equations; **M. Dafermos** and **I. Rodnianski**, Lectures on black holes and linear waves; **G. Staffilani**, The theory of nonlinear Schrödinger equations; **P. Raphaël**, On the singularity formation for the nonlinear Schrödinger equation; **R. Killip** and **M. Višan**, Nonlinear Schrödinger equations at critical regularity; **A. Vasy**, Geometry and analysis in many-body scattering; **M. Struwe**, Wave maps with and without symmetries; **B. Schlein**, Derivation of effective evolution equations from microscopic quantum dynamics.

Clay Mathematics Proceedings, Volume 17

July 2013, approximately 574 pages, Softcover, ISBN: 978-0-8218-6861-4, LC 2013002427, 2010 *Mathematics Subject Classification:* 35L05, 35L70, 35P25, 35Q41, 35Q55, 35Q76, 58J40, 58J47, 58J50, 83C57, 35-XX, 42-XX, 53-XX, 58-XX, 83-XX, **AMS members US$119.20**, List US$149, Order code CMIP/17



Recent Trends in Nonlinear Partial Differential Equations I

Evolution Problems

James B. Serrin, **Enzo L. Mitidieri**, *University of Trieste, Italy*, and **Vincenţiu D. Rădulescu**, *University of Craiova, Romania*, Editors

This book is the first of two volumes which contain the proceedings of the Workshop on Nonlinear Partial Differential Equations, held from May 28–June 1, 2012, at the University of Perugia in honor of Patrizia Pucci's 60th birthday.

The workshop brought together leading experts and researchers in nonlinear partial differential equations to promote research and to stimulate interactions among the participants. The workshop program testified to the wide ranging influence of Professor Pucci on the field of nonlinear analysis and partial differential equations.

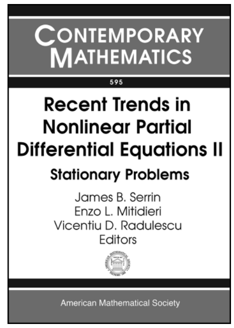
In her own work, Patrizia Pucci has been a seminal influence in many important areas: the maximum principle, qualitative analysis of solutions to many classes of nonlinear PDEs (Kirchhoff problems, polyharmonic systems), mountain pass theorem in the critical case, critical exponents, variational identities, as well as various degenerate or singular phenomena in mathematical physics. This same breadth is reflected in the mathematical papers included in this volume.

The companion volume (Contemporary Mathematics, Volume 595) is devoted to stationary problems in nonlinear partial differential equations.

Contents: **J. Mawhin**, A tribute to Patrizia Pucci; **G. Vinti**, A scientific profile of Patrizia Pucci; **J. Serrin**, The Liouville theorem for homogeneous elliptic differential inequalities; **B. Abdellaoui**, **I. Peral**, and **M. Walias**, Multiplicity results for porous media and fast diffusion equations with a quadratic gradient term; **G. Autuori**, A priori estimates for solutions of p-Kirchhoff systems under dynamic boundary conditions; **G. Barbatis** and **F. Gazzola**, Higher order linear parabolic equations; **N. Bellomo** and **V. Coscia**, Sources of nonlinearity in the kinetic theory for active particles with focus on the formation of political opinions; **B. Bianchini**, **L. Mari**, and **M. Rigoli**, Yamabe type equations with sign-changing nonlinearities on the Heisenberg group, and the role of Green functions; **M. Chipot** and **K. Yeressian**, Asymptotic behavior of the solution to variational inequalities with joint constraints on its value and its gradient; **F. Colasuono** and **M. C. Salvatori**, Existence and uniqueness of solutions to a Cauchy problem modeling the dynamics of socio-political conflicts; **F. Farroni**, **R. Giova**, and **C. Sbordone**, Regularity points of ACL-homeomorphisms in the plane; **S. Fornaro**, **M. Sosio**, and **V. Vespri**, Energy estimates and integral Harnack inequality for some doubly nonlinear singular parabolic equations; **K. T. Gkikas** and **L. Véron**, Initial value problems for diffusion equations with singular potential; **E. Lanconelli** and **A. Montanari**, On a class of fully nonlinear PDEs from complex geometry; **A. Malchiodi**, Concentration of conformal volume, improved Moser-Trudinger inequalities and Toda systems; **J. Mawhin**, Periodic solutions of Lagrangian difference systems: Periodic nonlinearities (almost) don't matter; **D. Mugnai**, A limit problem for degenerate quasilinear variational inequalities in cylinders; **E. Vitillaro**, Strong solutions for the wave equation with a kinetic boundary condition.

Contemporary Mathematics, Volume 594

July 2013, approximately 307 pages, Softcover, ISBN: 978-0-8218-8736-3, 2010 *Mathematics Subject Classification:* 35-06; 34-06, 35K55, 35L70, 47-06, 58-06, **AMS members US$88.80**, List US$111, Order code CONM/594



Recent Trends in Nonlinear Partial Differential Equations II

Stationary Problems

James B. Serrin, **Enzo L. Mitidieri**, *University of Trieste, Italy*, and **Vincenţiu D. Rădulescu**, *University of Craiova, Romania*, Editors

This book is the second of two volumes that contain the proceedings of the Workshop on Nonlinear Partial Differential Equations, held from May 28–June 1, 2012, at the University of Perugia in honor of Patrizia Pucci's 60th birthday.

The workshop brought together leading experts and researchers in nonlinear partial differential equations to promote research and to stimulate interactions among the participants. The workshop program testified to the wide ranging influence of Patrizia Pucci on the field of nonlinear analysis and partial differential equations.

In her own work, Patrizia Pucci has been a seminal influence in many important areas: the maximum principle, qualitative analysis of solutions to many classes of nonlinear PDEs (Kirchhoff problems, polyharmonic systems), mountain pass theorem in the critical case, critical exponents, variational identities, as well as various degenerate or singular phenomena in mathematical physics. This same breadth is reflected in the mathematical papers included in this volume.

The companion volume (Contemporary Mathematics, Volume 594) is devoted to evolution problems in nonlinear partial differential equations.

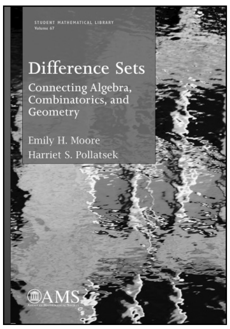
Contents: **S. Almi** and **M. Degiovanni**, On degree theory for quasilinear elliptic equations with natural growth conditions; **D. Arcoya**, **J. Carmona**, and **P. J. Martínez-Aparicio**, Radial solutions for a Gelfand type quasilinear elliptic problem with quadratic gradient terms; **M.-F. Bidaut-Véron**, **M. García-Huidobro**, and **L. Véron**, Remarks on some quasilinear equations with gradient terms and measure data; **L. Boccardo**, The effect of a linear term in some nonlinear elliptic equations with singular data; **M. Bonforte**, **G. Grillo**, and **J. L .Vazquezo**, Quantitative bounds for subcritical semilinear elliptic equations; **M.-M. Boureanu**, **B. Noris**, and **S. Terracini**, Sub and supersolutions, invaraint cones and multiplicity results for p-Laplace equations; **D. Cassani**, **B. Ruf**, and **C. Tarsi**, A Moser type inequality in Zygmund spaces without boundary conditions; **E. Colorado**, Existence results for some systems of coupled fractional nonlinear Schrödinger equations; **V. C. Zelati** and **M. Nolasco**, Ground states for pseudo-relativistic equations with combined power and Hartree-type nonlinearities; **G. Cupini**, **P. Marcellini**, and **E. Mascolo**, Local boundedness of solutions to some anisotropic elliptic systems; **L. Damascelli**, **F. Gladiali**, and **F. Pacella**, A symmetry result for semilinear cooperative elliptic systems; **L. D'Ambrosio** and **E. Mitidieri**, An application of Kato's inequality to quasilinear elliptic problems; **F. Faraci**, **A. Iannizzotto**, and **C. Varga**, Multiplicity results for constrained Neumann problems; **A. Farina**, On the classification of entire local minimizers of the Ginzburg-Landau equation; **R. Filippucci**, A Liouville result on a half space; **M. Ghergu**, Singular elliptic systems of Lane-Emden type; **H.-C. Grunau** and

F. Robert, Uniform estimates for polyharmonic Green functions in domains with small holes; **G. Molica Bisci**, Variational problems on the sphere; **N. S. Papageorgiou** and **V. Rădulescu**, Semilinear Neumann problems with indefinite and unbounded potential and crossing nonlinearity; **R. Servadei**, Infinitely many solutions for fractional Laplace equations with subcritical nonlinearity.

Contemporary Mathematics, Volume 595

August 2013, approximately 340 pages, Softcover, ISBN: 978-0-8218-9861-1, 2010 *Mathematics Subject Classification:* 35-06; 34-06, 35J47, 35J60, 47-06, 58-06, **AMS members US$88.80**, List US$111, Order code CONM/595

Discrete Mathematics and Combinatorics



Difference Sets

Connecting Algebra, Combinatorics, and Geometry

Emily H. Moore, *Grinnell College, IA*, and **Harriet S. Pollatsek**, *Mount Holyoke College, South Hadley, MA*

Difference sets belong both to group theory and to combinatorics. Studying them requires tools from geometry, number theory, and representation theory. This book lays a foundation for these topics, including a primer on representations and characters of finite groups. It makes the research literature on difference sets accessible to students who have studied linear algebra and abstract algebra, and it prepares them to do their own research.

This text is suitable for an undergraduate capstone course, since it illuminates the many links among topics that the students have already studied. To this end, almost every chapter ends with a *coda* highlighting the main ideas and emphasizing mathematical connections. This book can also be used for self-study by anyone interested in these connections and concrete examples.

An abundance of exercises, varying from straightforward to challenging, invites the reader to solve puzzles, construct proofs, and investigate problems—by hand or on a computer. Hints and solutions are provided for selected exercises, and there is an extensive bibliography. The last chapter introduces a number of applications to real-world problems and offers suggestions for further reading.

Both authors are experienced teachers who have successfully supervised undergraduate research on difference sets.

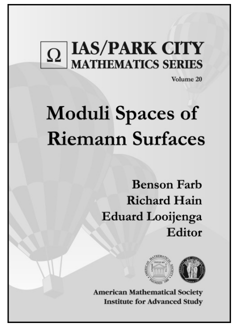
This item will also be of interest to those working in number theory and algebra and algebraic geometry.

Contents: Introduction; Designs; Automorphisms of designs; Introducing difference sets; Bruck-Ryser-Chowla theorem; Multipliers; Necessary group conditions; Difference sets from geometry; Families from Hadamard matrices; Representation theory; Group characters; Using algebraic number theory; Applications; Background; Notation; Hints and solutions to selected exercises; Bibliography; Index; Index of parameters.

Student Mathematical Library, Volume 67

July 2013, 298 pages, Softcover, ISBN: 978-0-8218-9176-6, LC 2013006295, 2010 *Mathematics Subject Classification:* 05B10, 05B20, 05B25, 11R04, 20C15, 51E15, **AMS members US$39.20**, List US$49, Order code STML/67

Geometry and Topology



Moduli Spaces of Riemann Surfaces

Benson Farb, *University of Chicago, IL*, **Richard Hain**, *Duke University, Durham, NC*, and **Eduard Looijenga**, *Universiteit Utrecht, Netherlands, and Tsinghua University, Beijing, China*, Editors

Mapping class groups and moduli spaces of Riemann surfaces were the topics of the Graduate Summer School at the 2011 IAS/Park City Mathematics Institute. This book presents the nine different lecture series comprising the summer school, covering a selection of topics of current interest. The introductory courses treat mapping class groups and Teichmüller theory. The more advanced courses cover intersection theory on moduli spaces, the dynamics of polygonal billiards and moduli spaces, the stable cohomology of mapping class groups, the structure of Torelli groups, and arithmetic mapping class groups.

The courses consist of a set of intensive short lectures offered by leaders in the field, designed to introduce students to exciting, current research in mathematics. These lectures do not duplicate standard courses available elsewhere. The book should be a valuable resource for graduate students and researchers interested in the topology, geometry and dynamics of moduli spaces of Riemann surfaces and related topics.

This item will also be of interest to those working in analysis.

Titles in this series are co-published with the Institute for Advanced Study/Park City Mathematics Institute. Members of the Mathematical Association of America (MAA) and the National Council of Teachers of Mathematics (NCTM) receive a 20% discount from list price.

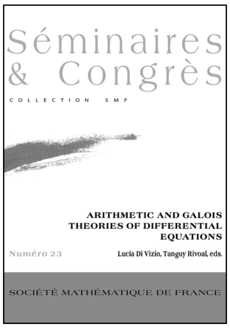
Contents: **B. Farb**, **R. Hain**, and **E. Looijenga**, Introduction; **Y. N. Minsky**, A brief introduction to mapping class groups; **U. Hamenstädt**, Teichmüller theory; **N. Wahl**, The Mumford conjecture, Madsen-Weiss and homological stability for mapping class groups of surfaces; **S. Galatius**, Lectures on the Madsen-Weiss theorem; **A. Putman**, The Torelli group and congruence subgroups of the mapping class group; **C. Faber**, Tautological algebras of moduli spaces of curves; **S. A. Wolpert**, Mirzakhani's volume recursion and approach for the Witten-Kontsevich theorem on moduli tautological intersection numbers; **M. Möller**, Teichmüller curves, mainly from the viewpoint of algebraic geometry; **M. Matsumoto**, Introduction to arithmetic mapping class groups.

IAS/Park City Mathematics Series, Volume 20

August 2013, approximately 364 pages, Hardcover, ISBN: 978-0-8218-9887-1, LC 2013007216, 2010 *Mathematics Subject Classification:* 14-06, 14H10, 32G15, 55R40, 57S05, **AMS members US$60**, List US$75, Order code PCMS/20

New AMS-Distributed Publications

Algebra and Algebraic Geometry



Arithmetic and Galois Theories of Differential Equations

Lucia Di Vizio, *Institut de Mathématiques de Jussieu, France*, and **Tanguy Rivoal**, *Université Grenoble 1, Saint-Martin d'Héres, France*, Editors

This volume contains the proceedings of the summer school Galoisian and Arithmetic Theory of Differential Equations, held at the CIRM in Luminy from September 21 to September 25, 2009. This school brought together mathematicians from various areas of research, united by their interest in ordinary differential equations, particularly those that arise in arithmetic.

This volume consists of five surveys, corresponding to the five lecture courses given during the school, plus six original papers, corresponding to research talks also given on this occasion. The volume also contains a reworking, by B. Chiarellotto, G. Gerotto, and F. J. Sullivan, of notes of the lectures on exponential modules given by B. M. Dwork at the University of Padova in 1994.

This item will also be of interest to those working in number theory.

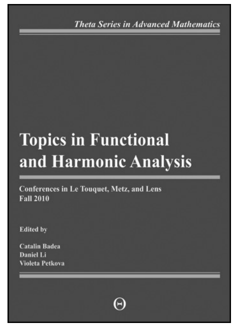
A publication of the Société Mathématique de France, Marseilles (SMF), distributed by the AMS in the U.S., Canada, and Mexico. Orders from other countries should be sent to the SMF. Members of the SMF receive a 30% discount from list.

Contents: D. Bertrand, Galois descent in Galois theories; **F. Beukers**, Notes on A-hypergeometric functions; **V. Bosser** and **F. Pellarin**, Drinfeld A-quasi-modular forms; **G. Casale**, An introduction to Malgrange pseudogroup; **B. Chiarellotto**, An invitation to p-adic differential equations (**Edited with the aid of G. Gerotto and F. Sullivan**); **L. Di Vizio** and **J. Sauloy**, Outils pour la classification locale des equations aux q-differences linéaires complexes; **C. Hardouin**, Unipotent radicals of Tannakian Galois groups in positive characteristic; **C. Krattenthaler** and **T. Rivoal**, Multivariate p-adic formal congruences and integrality of Taylor coefficients of mirror maps; **A. Pulita**, A basic introduction to deformation and confluence of ultrametric differential and q-difference equations; **J. Roques**, On the Galois groups of families of regular singular difference systems; **V. P. Spiridonov**, Elliptic hypergeometric terms; **B. Chiarellotto**, **G. Gerotto**, and **F. J. Sullivan**, Dwork's 1994 Padova lectures on exponential modules.

Séminaires et Congrès, Number 23

February 2013, 405 pages, Softcover, ISBN: 978-285629-331-7, 2010 *Mathematics Subject Classification:* 33C70, 12H05, 14K15, 11G10, 12G05, 33C60, 11F52, 11J93, 34M15, 11D88, 34M03, 34M35, 39A13, 12H10, 18D10, 39A05, 11S80, 14J32, 11J99, 12H25, 12H20, 12H99, 11S15, 11S20, 39A10, 33E20, 33E05, **AMS members US$93.60**, List US$117, Order code SECO/23

Analysis



Topics in Functional and Harmonic Analysis

Catalin Badea, *Université de Lille I, Villeneuve d'Ascq, France*, **Daniel Li**, *Université d'Artois, Lens, France*, and **Violeta Petkova**, *Université de Metz, France*, Editors

The book contains a selection of tutorial papers, surveys, and original articles, written by leading experts in functional and harmonic analysis. They are based on contributions presented at three conferences organized in 2010 in France. The topics covered include:

- Probabilistic methods in linear dynamics
- Spectral sets for matrices
- Banach space theory
- Composition operators on function spaces
- Interpolation in Hardy spaces
- Partial differential equations on bounded domains.

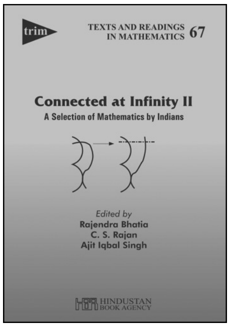
A publication of the Theta Foundation. Distributed worldwide, except in Romania, by the AMS.

Contents: F. Bayart, Probabilistic methods in linear dynamics; **M. Crouzeix**, Spectral sets and 3×3 nilpotent matrices; **V. Ferenczi** and **G. Godefroy**, Tightness of Banach spaces and Baire category; **G. Godefroy**, The Kalton calculus; **K. Kellay**, Composition operators on analytic weighted Hilbert spaces; **G. Lancien**, A short course on nonlinear geometry of Banach spaces; **J. R. Partington**, Interpolation in Hardy spaces, with applications; **E. Russ**, Inversion of the divergence on bounded domains of $\mathbb{R}^n$.

International Book Series of Mathematical Texts

May 2013, 149 pages, Hardcover, ISBN: 978-606-8443-00-3, 2010 *Mathematics Subject Classification:* 00B15, 42-06, 46-06, 47-06, **AMS members US$35.20**, List US$44, Order code THETA/17

General Interest



Connected at Infinity II

A Selection of Mathematics by Indians

Rajendra Bhatia, *Indian Statistical Institute, Delhi, India*, **C. S. Rajan**, *Tata Institute of Fundemental Research, Mumbai, India*, and **Ajit Iqbal Singh**, *Indian Statistical Institute, Delhi, India*, Editors

Like the first volume, this is a special collection of articles describing the work of some of the best-known mathematicians from India. It contains eight articles written by experts, each of whom has chosen one major research contribution by an Indian mathematician and explained its context, significance, and impact. This is done in a way that makes the main ideas accessible to someone whose own research interests might be in a different area. Included here are commentaries on important works by:

- R. C. Bose, S. S. Shrikhande and E. T. Parker
- H. Cramer and C. R. Rao
- V. B. Mehta and A. Ramanathan
- R. Narasimha
- K. R. Parthasarathy, R. Ranga Rao, and V. S. Varadarajan
- R. Parthasarathy
- D. N. Verma
- N. Wiener and P. R. Masani

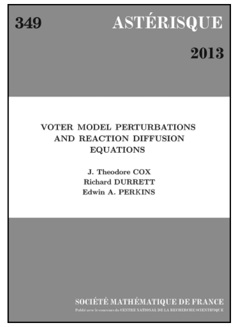
A publication of Hindustan Book Agency; distributed within the Americas by the American Mathematical Society. Maximum discount of 20% for all commercial channels.

Contents: A. Dey, Orthogonal Latin squares and the falsity of Euler's conjecture; **F. Nielsen**, Cramer-Rao lower bound and information geometry Frobenius splittings; **A. S. V. Murthy**, On the string equation of Narasimha; **A. Khare**, Representations of complex semi-simple Lie groups and Lie algebras; **S. Mehdi**, Parthasarathy Dirac operators and discrete series representations; **H. H. Andersen**, The Role of Verma in representation theory; **V. Mandrekar**, The work of Wiener and Masani on prediction theory and harmonic analysis.

Hindustan Book Agency

March 2013, 194 pages, Hardcover, ISBN: 978-93-80250-51-9, 2010 *Mathematics Subject Classification:* 00B15, **AMS members US$40**, List US$50, Order code HIN/62

Probability and Statistics



Voter Model Perturbations and Reaction Diffusion Equations

J. Theodore Cox, *Syracuse University, NY*, **Richard Durrett**, *Duke University, Durham, NC*, and **Edwin A. Perkins**, *University of British Columbia, Vancouver, Canada*

The authors consider particle systems that are perturbations of the voter model and show that when space and time are rescaled the system converges to a solution of a reaction diffusion equation in dimensions $d \geq 3$. Combining this result with properties of the P.D.E., some methods arising from a low density super-Brownian limit theorem, and a block construction, the authors give general, and often asymptotically sharp, conditions for the existence of non-trivial stationary distributions, and for extinction of one type.

As applications, the authors describe the phase diagrams of four systems when the parameters are close to the voter model: (i) a stochastic spatial Lotka-Volterra model of Neuhauser and Pacala, (ii) a model of the evolution of cooperation of Ohtsuki, Hauert, Lieberman, and Nowak, (iii) a continuous time version of the non-linear voter model of Molofsky, Durrett, Dushoff, Griffeath, and Levin, and (iv) a voter model in which opinion changes are followed by an exponentially distributed latent period during which voters will not change again.

The first application confirms a conjecture of Cox and Perkins, and the second confirms a conjecture of Ohtsuki *et al.* in the context of certain infinite graphs. An important feature of the authors' general results is that they do not require the process to be attractive.

This item will also be of interest to those working in differential equations.

A publication of the Société Mathématique de France, Marseilles (SMF), distributed by the AMS in the U.S., Canada, and Mexico. Orders from other countries should be sent to the SMF. Members of the SMF receive a 30% discount from list.

Contents: Introduction and statement of results; Construction, duality and coupling; Proofs of Theorems 1.2 and 1.3; Achieving low density; Percolation results; Existence of stationary distributions; Extinction of the process; Bibliography.

Astérisque, Number 349

March 2013, 113 pages, Softcover, ISBN: 978-285629-355-3, 2010 *Mathematics Subject Classification:* 60K35; 35K57, 60J68, 60F17, 92D15, 92D40, **AMS members US$41.60**, List US$52, Order code AST/349

Classified Advertisements

Positions available, items for sale, services available, and more

MINNESOTA

THE INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS (IMA)
Now Accepting Board of Governors Nominations

The Institute for Mathematics and its Applications (IMA) is now accepting nominations for its Board of Governors. Applicants may either self-nominate or they may be nominated by others.

The IMA's board consists of 15 distinguished members from academia, industry, and government. The board is the principal governing body of the IMA. Incoming members of the board will serve a five-year term, beginning on January 1, 2014.

The role of the board is twofold: first, to provide oversight and advice on matters of institute management, development, and institutional relationships. And second, board members play an active scientific role in planning and developing annual program themes as well as identifying lead program organizers. The board meets for two days annually and subcommittees meet several times annually by conference call.

Submission of Nominations. Prospective applicants should submit an application via the online form at `http://www.ima.umn.edu/bog`. All nominations will be reviewed by the Nominations Committee. Applicants will be notified of the committee's decision no later than December 1, 2013.

Closing Date. Nominations are due no later than July 31, 2013.

Questions? Contact IMA Director Fadil Santosa (`santosa@ima.umn.edu`), or Thomas Hou (`hou@cms.caltech.edu`), chair, IMA Board of Governors.

000020

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 2013 rate is \$3.50 per word with a minimum two-line headline. 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.

Advertisements in the "Positions Available" classified section will be set with a minimum one-line headline, consisting of the institution name above body copy, unless additional headline copy is specified by the advertiser. Headlines will be centered in boldface at no extra charge. Ads will appear in the language in which they are submitted.

There are no member discounts for classified ads. Dictation over the telephone will not be accepted for classified ads.

Upcoming deadlines for classified advertising are as follows: August 2013 issue–May 29, 2013; September 2013 issue–July 1, 2013, October 2013 issue–July 26, 2013; November 2013 issue–August 29, 2013; December 2013 issue–September 30, 2013; January 2014 issue–October 29, 2013.

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 1373 (vol. 44).

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 be billed 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.

Alba Iulia, Romania

University of Alba Iulia

June 27–30, 2013

Thursday – Sunday

Meeting #1091

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*: January 2013
Program first available on AMS website: Not applicable
Program issue of electronic *Notices*: Not applicable
Issue of *Abstracts*: Not applicable

Deadlines

For organizers: Expired
For abstracts: Expired

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/internmtgs.html`.

Invited Addresses

Viorel Barbu, Universitatea Al. I. Cuza, *Stabilization of Navier-Stokes equations by boundary and point feedback controllers*.

Sergiu Klainerman, Princeton University, *Are black holes real?*

George Lusztig, Massachusetts Institute of Technology, *On conjugacy classes in the Lie group E8*.

Stefan Papadima, Institute of Mathematics of the Romanian Academy, *Geometry of homology jump loci and topology*.

Mihnea Popa, University of Illinois at Chicago, *Vanishing theorems and holomorphic one-forms*.

Dan Timotin, Institute of Mathematics of the Romanian Academy, *Horn inequalities: Finite and infinite dimensions*.

Special Sessions

Algebraic Geometry, **Marian Aprodu**, Institute of Mathematics of the Romanian Academy, **Mircea Mustata**, University of Michigan, Ann Arbor, and **Mihnea Popa**, University of Illinois, Chicago.

Articulated Systems: Combinatorics, Geometry and Kinematics, **Ciprian S. Borcea**, Rider University, and **Ileana Streinu**, Smith College.

Calculus of Variations and Partial Differential Equations, **Marian Bocea**, Loyola University, Chicago, **Liviu Ignat**, Institute of Mathematics of the Romanian Academy, **Mihai Mihailescu**, University of Craiova, and **Daniel Onofrei**, University of Houston.

Commutative Algebra, **Florian Enescu**, Georgia State University, and **Cristodor Ionescu**, Institute of Mathematics of the Romanian Academy.

Discrete Mathematics and Theoretical Computer Science, **Sebastian Cioaba**, University of Delaware, **Gabriel Istrate**, Universitatea de Vest, Timisoara, **Ioan Tomescu**, University of Bucharest, and **Marius Zimand**, Towson University.

Domain Decomposition Methods and their Applications in Mechanics and Engineering, **Lori Badea**, Institute of Mathematics of the Romanian Academy, and **Marcus Sarkis**, Worcester Polytechnic Institute.

Geometry and Topology of Arrangements of Hypersurfaces, **Daniel Matei**, Institute of Mathematics of the Romanian Academy, and **Alexandru I. Suciu**, Northeastern University.

Harmonic Analysis and Applications, **Ciprian Demeter**, Indiana University, Bloomington, and **Camil Muscalu**, Cornell University.

Hopf Algebras, Coalgebras, and their Categories of Representations, **Miodrag C. Iovanov**, University of Bucharest and University of Iowa, **Susan Montgomery**, University of Southern California, and **Siu-Hung Ng**, Iowa State University.

Local and Nonlocal Models in Wave Propagation and Diffusion, **Anca V. Ion**, Institute of Mathematical Statistics and Applied Mathematics of the Romanian Academy, **Petronela Radu**, University of Nebraska, Lincoln, and **Lorena Bociu**, North Carolina State University.

Mathematical Finance, Stochastic Analysis, and Partial Differential Equations, **Lucian Beznea**, Institute of Mathematics of the Romanian Academy, **Paul Feehan**, Rutgers University, **Victor Nistor**, Pennsylvania State University, **Camelia Pop**, University of Pennsylvania, and **Mihai Sirbu**, University of Texas, Austin.

Mathematical Models in Life and Environment, **Gabriela Marinoschi**, Institute of Mathematical Statistics and Applied Mathematics of the Romanian Academy, and **Fabio Augusto Milner**, Arizona State University.

Mathematical Models in Materials Science and Engineering, **Marian Bocea**, Loyola University, Chicago, and **Bogdan Vernescu**, Worcester Polytechnic Institute.

Noncommutative Ring Theory and Applications, **Toma Albu**, Institute of Mathematics of the Romanian Academy, and **Lance W. Small**, University of California, San Diego.

Nonlinear Evolution Equations, **Daniel Tataru**, University of California, Berkeley, and **Monica Visan**, University of California, Los Angeles.

Operator Algebra and Noncommutative Geometry, **Marius Dadarlat**, Purdue University, and **Florin Radulescu**, Institute of Mathematics of the Romanian Academy and University of Rome Tor Vergata.

Operator Theory and Function Spaces, **Aurelian Gheondea**, Institute of Mathematics of the Romanian Academy and Bilkent University, **Mihai Putinar**, University of California, Santa Barbara, and **Dan Timotin**, Institute of Mathematics of the Romanian Academy.

Probability and its Relation to Other Fields of Mathematics, **Krzysztof Burdzy**, University of Washington, and **Mihai N. Pascu**, Transilvania University of Braşov.

Random Matrices and Free Probability, **Ioana Dumitriu**, University of Washington, and **Ionel Popescu**, Georgia Institute of Technology and Institute of Mathematics of the Romanian Academy.

Several Complex Variables, Complex Geometry and Dynamics, **Dan Coman**, Syracuse University, and **Cezar Joita**, Institute of Mathematics of the Romanian Academy.

Topics in Geometric and Algebraic Topology, **Stefan Papadima**, Institute of Mathematics of the Romanian Academy, and **Alexandru I. Suciu**, Northeastern University.

Louisville, Kentucky

University of Louisville

October 5–6, 2013

Saturday – Sunday

Meeting #1092

Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: June/July 2013
Program first available on AMS website: August 22, 2013
Program issue of electronic *Notices*: October 2013
Issue of *Abstracts*: Volume 34, Issue 3

Deadlines

For organizers: Expired
For abstracts: August 13, 2013

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Michael Hill, University of Virginia, *Framed manifolds and equivalent homotopy: A solution to the Kervaire Invariant One problem.*

Suzanne Lenhart, University of Tennessee and NIMBioS, *Using optimal control of PDEs to investigate population questions.*

Ralph McKenzie, Vanderbilt University, *A perspective on fifty years of work, delight and discovery in general algebra.*

Victor Moll, Tulane University, *2-adic valuations of classical sequences: A collection of examples.*

Special Sessions

Algebraic Coding Theory (Code: SS 5A), **Steve Szabo**, Eastern Kentucky University, and **Heide Gluesing-Luerssen**, University of Kentucky.

Algebraic Cryptography (Code: SS 12A), **Daniel Smith**, University of Louisville.

Applied Analysis and Inverse Problems (Code: SS 9A), **Peijun Li**, Purdue University, **Jiguang Sun**, Michigan Technological University, and **Yongzhi Steve Xu**, University of Louisville.

Combinatorial Commutative Algebra (Code: SS 4A), **Juan Migliore**, University of Notre Dame, and **Uwe Nagel**, University of Kentucky.

Commutative Rings, Ideals, and Modules (Code: SS 3A), **Ela Celikbas** and **Olgur Celikbas**, University of Missouri-Columbia.

Extremal Graph Theory (Code: SS 2A), **Jozsef Balogh**, University of Illinois at Urbana-Champaign, and **Louis DeBiasio** and **Tao Jiang**, Miami University, Oxford, OH.

Finite Universal Algebra (Code: SS 6A), **Ralph McKenzie**, Vanderbilt University, and **Matthew Valeriote**, McMaster University.

Fixed Point Theorems and Applications to Integral, Difference, and Differential Equations (Code: SS 8A), **Jeffrey W. Lyons**, Nova Southeastern University, and **Jeffrey T. Neugebauer**, Eastern Kentucky University.

Harmonic Analysis and Partial Differential Equations (Code: SS 10A), **Russell Brown** and **Katharine Ott**, University of Kentucky.

History of Mathematics and Its Use in Teaching (Code: SS 20A), **Daniel J. Curtin**, Northern Kentucky University, and **Daniel E. Otero**, Xavier University.

Homogenization of Partial Differential Equations (Code: SS 14A), **Zhongwei Shen**, University of Kentucky, and **Yifeng Yu**, University of California, Irvine.

Mathematical Analysis of Complex Fluids and Flows (Code: SS 15A), **Xiang Xu**, Carnegie Mellon University, and **Changyou Wang**, University of Kentucky.

Mathematical Issues in Ecological and Epidemiological Modeling (Code: SS 19A), **K. Renee Fister**, Murray State University, and **Suzanne Lenhart**, University of Tennessee.

Mathematical Models in Biology and Physiology (Code: SS 21A), **Yun Kang**, Arizona State University, and **Jiaxu Li**, University of Louisville.

Partial Differential Equations from Fluid Mechanics (Code: SS 16A), **Changbing Hu**, University of Louisville, and **Florentina Tone**, University of West Florida.

Partially Ordered Sets (Code: SS 18A), **Csaba Biro** and **Stephen J. Young**, University of Louisville.

Recent Advances on Commutative Algebra and Its Applications (Code: SS 11A), **Hamid Kulosman** and **Jinjia Li**, University of Louisville, and **Hamid Rahmati**, Miami University.

Set Theory and Its Applications (Code: SS 1A), **Paul Larson**, Miami University, **Justin Moore**, Cornell University, and **Grigor Sargsyan**, Rutgers University.

Spreading Speeds and Traveling Waves in Spatial-Temporal Evolution Systems (Code: SS 17A), **Bingtuan Li**, University of Louisville, and **Roger Lui**, Worcester Polytechnic Institute.

The Work of Mathematicians and Mathematics Departments in Mathematics Education (Code: SS 22A), **Benjamin Braun**, **Carl Lee**, and **David Royster**, University of Kentucky.

Topological Dynamics and Ergodic Theory (Code: SS 13A), **Alica Miller**, University of Louisville, and **Joe Rosenblatt**, University of Illinois at Urbana-Champaign.

Weak Convergence in Probability and Statistics (Code: SS 7A), **Cristina Tone**, **Ryan Gill**, and **Kiseop Lee**, University of Louisville.

Session for Contributed Talks

There also will be a session for 10-minute contributed talks. Please see the abstracts submission form at http://www.ams.org/cgi-bin/abstracts/abstract.pl. **The deadline for all submissions is August 13, 2013**.

Accommodations

Participants should make their own arrangements directly with the properties listed below. Special rates for the meeting have been negotiated and are available at the properties shown below for Friday and Saturday nights, October 4 and 5, 2013; rates may be extended to one day before or after these dates if rooms are available; please ask when you make your reservation. When making reservations **participants should state that they are with the American Mathematical Society (AMS) meeting on campus**, unless noted otherwise. Hotels have varying cancellation or early checkout penalties; be sure to ask for details when making your reservation. The room rates listed do not include applicable taxes; the current tax rate on hotel rooms is 15.01%. All properties are smoke free.

Downtown hotels:

The Seelbach Hilton, 500 Fourth St., Louisville, KY 40202; 502-585-3200 (phone), US$149 for single or double (king or two queen beds); special rate can be extended beyond the meetings dates. Onsite restaurants include The Oakroom (5-star), The Old Seelbach bar (featuring live jazz), Otto's Cafe, and Starbucks. Deluxe in-room amenities including complimentary high-speed or wireless Internet; fitness center access; business center with computer workstations; parking is US$22 (self) or US$26 (valet); lots nearby with 24-hour rates of US$3-6. Located about 2.5 miles from campus. **Deadline for reservations is September 5, 2013.** www3.hilton.com/en/hotels/kentucky/the-seelbach-hilton-louisville-SDFSHHF/index.html?WT.srch=1.

Galt House, 140 North Fourth St., Louisville, KY 40202 (on the Ohio river); 502-589-5200 or 800-843-4258; email info@galthouse.com. US$105/deluxe single or US$115/deluxe double in the Rivue Tower. US$125/single suite or US$135/double suite in the Suite Tower. Triple and quad rates are available. Complimentary wireless access in public areas, fee for in-room use; rooftop fitness center; business center; parking is US$12 (self) or US$18 (valet). Seven restaurants are on premises, including RIVUE Restaurant & Lounge, a rooftop restaurant with expansive views of downtown and the waterfront; Café Magnolia for breakfast, lunch, or dinner; Al J's at the Conservatory, with a 30-foot aquarium bar and pub menu, offers sweeping views of downtown and the waterfront; Jockey Silks Bourbon Bar is a place to relax; Thelma's at the Conservatory is a 24-hour deli. Located about 3.1 miles from campus. **Deadline for reservations is September 5, 2013**. www.GaltHouse.com.

Hampton Inn Louisville Downtown, 101 East Jefferson St., Louisville, KY 40202; 502-566-0205 (phone); US$134/single or double. Amenities include free parking, business center, complimentary in-room high-speed Internet access, free hot breakfast, indoor pool, and fitness center access. Free shuttle from and to airport, and within eight blocks of the hotel (pending availability). Located about 2.7 miles from campus. **Deadline for reservations is September 5, 2013.** http://hamptoninn3.hilton.com/en/hotels/kentucky/hampton-inn-louisville-downtown-SDFDTHX/index.html

Courtyard by Marriott Louisville Downtown, 100 South Second St., Louisville, KY 40202; 502-562-0200 (phone); US$119/single or double; in-room complimentary Internet, coffee maker, and refrigerator; fitness center;

business center; indoor pool; parking is US$1 per hour or US$6 overnight. The Bistro offers a variety of breakfast and dinner options, an evening bar, and specialty beverages made with Starbucks® coffee. Complimentary shuttle service from/to airport (SDF) only. Located about 2.7 miles from campus. **Deadline for reservations is September 13, 2013.** `http://www.marriott.com/hotels/travel/sdfdt-courtyard-louisville-downtown`.

Hotels near the airport:

Crowne Plaza Louisville Airport, 830 Phillips Lane, Louisville, KY 40209; 888-233-9527 (phone); US$99 single or double; in-room complimentary Internet; indoor/outdoor pool; business center, fitness center. At the hotel you will find The Blue Horse restaurant and lounge open for breakfast, lunch, and dinner. Free airport shuttle, as well as local shuttle service within three miles of the hotel (pending availability). Located about 2.8 miles from campus. **Deadline for reservations is September 18, 2013.** `www.ihg.com/crowneplaza/hotels/us/en/louisville/sdfpl/hoteldetail`.

LaQuinta Inn & Suites Louisville Airport Expo, 4125 Preston Highway, Louisville, KY 40213; 502-368-0007 or 866-477-0007. US$94.50/single or double. Amenities include complimentary hot breakfast, free in-room wireless and long distance (national) phone calls, microwave, refrigerator, and coffee maker. Onsite you will find a business center with computer workstations and a printer, fitness center, and seasonal outdoor pool. There is also complimentary airport shuttle service. Located about 3.2 miles from campus. **Deadline for reservations is September 13, 2013; please cite Group No. 1043 for special rates.** `www.lqairport.com`.

Best Western Plus Airport East/Expo Center; 1921 Bishop Lane, Louisville, KY 40218; 502-456-4411 (phone). The rate is US$79/single or double, and includes complimentary full hot breakfast, fitness center, and free high speed Internet throughout the hotel. Restaurant on site serves lunch and dinner. Free shuttle service from/to airport. Located about 5.9 miles from campus. **Deadline for reservations is September 6, 2013.** `http://book.bestwestern.com/bestwestern/US/KY/Louisville-hotels/BEST-WESTERN-PLUS-Airport-East-Expo-Center/Hotel-Overview.do?propertyCode=18090`.

Holiday Inn Lakeview (formerly the Holiday Inn Louisville-North), 505 Marriott Dr., Clarksville, IN 47129; 813-283-1618 (phone); the rate of US$79/single or double includes a coffee maker and complimentary Wi-Fi in guest rooms. Full service hotel including indoor and outdoor pools, fitness center, and 24-hour business center; the Quarter Pole Lounge and Champions Restaurant are located on the property. Free aiport shuttle service provided for guests. Located about 4.9 miles from campus, across the Ohio River in Indiana. **Deadline for reservations is September 20, 2013.** `www.holidayinn.com/clarksvilleky`.

Red Roof Inn Louisville Fair and Expo, 3322 Red Roof Inn Place, Louisville, KY 40218; 800-733-7663 or 502-456-2993 (phone). Rates are US$59.49/single in a standard room, and include free Wi-Fi. Coffee is available in the lobby on a 24-hour basis. Property is within walking distance of several restaurants, and is about 5.8 miles from campus. **Deadline for reservations is September 4, 2013. Please cite Block Code B134ULMATH for special rates.** `www.redroof.com/property/Louisville/KY/40218/Hotels-close-to-Louisville-Airport-Churchill-Downs-I-264/RRI134`.

Super 8 Louisville Airport, 4800 Preston Hwy., Louisville, KY 40213; 502-968-0088. The rate is US$55.25/single or double and includes an in-room coffee maker, free Internet access, complimentary continental breakfast, and a business center with printing services. **Deadline for reservations is September 4**. Located about 4.4 miles from campus. `www.super8.com/hotels/kentucky/louisville/super-8-louisville-airport/hotel-overview`.

Dining on Campus

Information about dining options on campus and in the surrounding area will be published on the meeting website at a later date.

Information for Students

The AMS, with support from a private gift, is accepting applications for partial support for full time doctoral students to participate in this meeting. To see more information and to submit an application, please visit `www.ams.org/programs/travel-grants/grad-students/emp-student-JMM`. **Applications will be accepted between June 6 and July 18, 2013 only.**

Local Information and Maps

The University of Louisville Department of Mathematics website is found at `http://www.math.louisville.edu/`. An area map showing the general location of the campus is found at `http://louisville.edu/about/campuses.html#belknap`.

A campus map is found at `http://louisville.edu/registrar/registration-information/map2.html`; the Department of Mathematics is in the Natural Sciences Building, #34 on this map.

Other Activities

AMS Book Sale: Stop by the onsite AMS bookstore and celebrate the AMS's 125th Anniversary. You can browse new titles, buy a new 125th t-shirt, enter to win a US$125 AMS Bookstore Gift Certificate, pick up some 125th give-aways, become an AMS member, or pay your dues. Not only will you receive a 25% discount from the list price on most AMS titles, you may also purchase any AMS title, even if it is not on display, at the exhibit discount.

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

Please watch the AMS website at `http://www.ams.org/meetings/sectional/sectional.html` and follow the link for this meeting for information on regulations, fees, and locations to park near the buildings where sessions will be held.

Registration and Meeting Information

Louisville, Kentucky is in the Eastern Time Zone and Daylight Savings Time will be in effect during the course of the meeting.

The meeting will take place on the main campus (Belknap) of the University of Louisville. Sessions and Invited Addresses will be held in the Natural Sciences Building and the Bingham Humanities Building. The registration desk will be located in Bingham and will be open Saturday, 7:30 a.m.–4:00 p.m., and Sunday, 8:00 a.m.–noon. Fees are US$54 for AMS members, US$76 for nonmembers; and US$5 for students, unemployed mathematicians, and emeritus members. Fees are payable on-site by cash, check, or credit card.

Travel Information

The nearest large airport is Louisville International Airport (**SDF**), 911 Grade Ln # 2, Louisville, KY 40213; 502-367-4636. The airport is about 6.5 miles southeast of campus. Many hotels offer complimentary shuttles from the airport to the hotel. Taxi fare to campus would be about US $15.

Getting to the West Information Center on campus by car: The West Information Center, 2301 S. Third St., Louisville, KY 40292, is located very near the Department of Mathematics. If coming from I-265 (Gene Snyder) or I-264 (Watterson Expressway), you will want to head North on I-65. If coming from I-71 South or I-64 East or West, you will want to head south on I-65. The exits for the University of Louisville are directly off of I-65 North or South.

If coming from the North: Take I-65 South (toward Nashville) to the Arthur Street exit. If you reach the Fairgrounds/Watterson Expressway exits, you have gone too far. Continue to the first stop sign, at Arthur St. and Brandeis Ave. Turn right onto Brandeis Ave. which turns into Cardinal Boulevard. Continue on Cardinal Boulevard until Third Street. Turn left onto Third Street. Go approximately three blocks and the University of Louisville West Entrance will be on your left. Turn left into the West Entrance. The West Information Center is on your right; proceed to the drive-up window.

If coming from the South: Take I-65 North (toward Indianapolis) to the Warnock St. exit. Turn left onto Warnock St. Turn left onto Floyd St. at the first stop light. Turn right onto Central Avenue. Turn right onto Third Street at the stoplight. Turn right into the West Entrance. Information Center West is on the right; proceed to the drive-up window.

Car Rental

Hertz is the official car rental company for the meeting. To make a reservation accessing our special meeting rates online at `www.hertz.com`, click on the box "I have a discount", and type in our convention number **(CV): 04N30003**. You can also call Hertz directly at 800-654-2240 (U.S. and Canada) or 405-749-4434 (other countries). At the time this announcement was prepared, rates started at US$29.11 per day on the weekend. At the time of your reservation, the meeting rates will be automatically compared to other Hertz rates and you will be quoted the best comparable rate available.

Weather

Early October weather is usually pleasant, with daytime temperatures ranging from 63º to 73º and dropping to 45º to 50º in the evenings, so dressing in layers is advised. Passing showers are a possibility.

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 `dls@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.

Philadelphia, Pennsylvania

Temple University

October 12–13, 2013

Saturday – Sunday

Meeting #1093

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: June/July 2013
Program first available on AMS website: August 29, 2013
Program issue of electronic *Notices*: October 2013
Issue of *Abstracts*: Volume 34, Issue 3

Deadlines

For organizers: Expired
For abstracts: August 20, 2013

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Patrick Brosnan, University of Maryland, *Normal functions.*

Xiaojun Huang, Rutgers University at New Brunswick, *Equivalence problems in several complex variables.*

Barry Mazur, Harvard University, *Arithmetic statistics: Elliptic curves and other mathematical objects* (Erdős Memorial Lecture).

Robert Strain, University of Pennsylvania, *On the Boltzmann equation without angular cut-off.*

Special Sessions

Analysis and Computing for Electromagnetic Waves (Code: SS 10A), **David Ambrose** and **Shari Moskow**, Drexel University.

Combinatorial Commutative Algebra (Code: SS 12A), **Tái Huy Há**, Tulane University, and **Fabrizio Zanello**, Massachusetts Institute of Technology and Michigan Technological University.

Contact and Symplectic Topology (Code: SS 5A), **Joshua M. Sabloff**, Haverford College, and **Lisa Traynor**, Bryn Mawr College.

Difference Equations and Applications (Code: SS 9A), **Michael Radin**, Rochester Polytechnic Institute, and **Faina Berezovskaya**, Howard University.

Geometric Aspects of Topology and Group Theory (Code: SS 17A), **David Futer**, Temple University, and **Ben McReynolds**, Purdue University.

Geometric Topology of Knots and 3-manifolds (Code: SS 16A), **Abhijit Champanerkar**, **Ilya Kofman**, and **Joseph Maher**, College of Staten Island and The Graduate Center, City University of New York.

Geometric and Spectral Analysis (Code: SS 3A), **Thomas Krainer**, Pennsylvania State Altoona, and **Gerardo A. Mendoza**, Temple University.

Higher Structures in Algebra, Geometry and Physics (Code: SS 2A), **Jonathan Block**, University of Pennsylvania, **Vasily Dolgushev**, Temple University, and **Tony Pantev**, University of Pennsylvania.

History of Mathematics in America (Code: SS 4A), **Thomas L. Bartlow**, Villanova University, **Paul R. Wolfson**, West Chester University, and **David E. Zitarelli**, Temple University.

Mathematical Biology (Code: SS 8A), **Isaac Klapper**, Temple University, and **Kathleen Hoffman**, University of Maryland, Baltimore County.

Meshfree, Particle, and Characteristic Methods for Partial Differential Equations (Code: SS 21A), **Toby Driscoll** and **Louis Rossi**, University of Delaware, and **Benjamin Seibold**, Temple University.

Modular Forms and Modular Integrals in Memory of Marvin Knopp (Code: SS 20A), **Helen Grundman**, Bryn Mawr College, and **Wladimir Pribitkin**, College of Staten Island and the Graduate Center, City University of New York.

Multiple Analogues of Combinatorial Special Numbers and Associated Identities (Code: SS 11A), **Hasan Coskun**, Texas A&M University Commerce.

Nonlinear Elliptic and Wave Equations and Applications (Code: SS 15A), **Nsoki Mavinga**, Swarthmore College, and **Doug Wright**, Drexel University.

Parabolic Evolution Equations of Geometric Type (Code: SS 18A), **Xiaodong Cao**, Cornell University, **Longzhi Lin**, Rutgers University, and **Peng Wu**, Cornell University.

Partial Differential Equations, Stochastic Analysis, and Applications to Mathematical Finance (Code: SS 14A), **Paul Feehan** and **Ruoting Gong**, Rutgers University, and **Camelia Pop**, University of Pennsylvania.

Recent Advances in Harmonic Analysis and Partial Differential Equations (Code: SS 1A), **Cristian Gutiérrez** and **Irina Mitrea**, Temple University.

Recent Developments in Noncommutative Algebra (Code: SS 6A), **Edward Letzter** and **Martin Lorenz**, Temple University.

Representation Theory, Combinatorics and Categorification (Code: SS 19A), **Corina Calinescu**, New York City College of Technology, City University of New York, **Andrew Douglas**, New York City College of Technology and Graduate Center, City University of New York, **Joshua Sussan**, Medgar Evers College, City University of New York, and **Bart Van Steirteghem**, Medgar Evers College,City University of New York.

Several Complex Variables and CR Geometry (Code: SS 7A), **Andrew Raich**, University of Arkansas, and **Yuan Zhang**, Indiana University-Purdue University Fort Wayne.

The Geometry of Algebraic Varieties (Code: SS 13A), **Karl Schwede**, Pennsylvania State University, and **Zsolt Patakfalvi**, Princeton University.

Session for Contributed Talks

There also will be a session for 10-minute contributed talks. Please see the abstracts submission form at http://www.ams.org/cgi-bin/abstracts/abstract.pl. **The deadline for all submissions is August 13, 2013**.

Accommodations

Participants should make their own arrangements directly with the hotel of their choice. Special discounted rates were negotiated with the hotels listed below. Rates quoted do not include hotel tax. At the time of publication current Philadelphia sales tax per room per night was 15.2%. It is anticipated that effective July 1, 2013 this rate will increase to 15.5%. Participants must state that they are with the **American Mathematical Society (AMS) Meeting at Temple University** to receive the discounted rate. The AMS is not responsible for rate changes or for the quality of the accommodations. **Hotels have varying cancellation and early checkout penalties; be sure to ask for details.**

The Hampton Inn Center City Philadelphia Hotel, 1301 Race Street, Philadelphia, PA, (215) 665-9100; http://hamptoninn3.hilton.com/en/hotels/pennsylvania/hampton-inn-philadelphia-center-city-convention-center. Rates are US$139 per night for single/double occupancy. Amenities include complimentary full hot American breakfast buffet, complimentary wireless throughout the hotel, complimentary beverage area, business center on-site, fitness center and indoor pool. Secured parking provided by 3rd party vendor is available at the rates of US$25 for self-parking and US$35 valet parking per day. This property is located approximately 2.1 miles from the campus by car and approximately 16 minutes by public transportation (walking and subway). Check in time is 4:00 p.m.; check out time is 11:00 a.m. **The deadline for reservations at this rate is September 11, 2013.**

The Windsor Suites, 1700 Benjamin Franklin Parkway, Philadelphia, Pennsylvania 19103, (215) 981-5678; http://www.thewindsorsuites.com/philadelphia-hotel-suites.aspx. Rates are US$159 per night for single/double occupancy. Amenities include fully equipped kitchen, complimentary wireless Internet access, business center, 24-hour fitness center, two full-service restaurants, room service, complimentary newspaper, and parking on-site. Valet parking is available to hotel guests for a rate of US$34.80, inclusive of tax and this rate includes in/out privileges. This property is located approximately 2.4 miles from the campus by car and approximately 21 minutes by public transportation (walking and subway). Check in time is 3:00 p.m. and check out time is 11:00 a.m. **The deadline for reservations at this rate is September 11, 2013.**

Club Quarters, 1628 Chestnut St (at 17th St), Philadelphia, PA, 19103, (215) 282-5000; http://www.clubquarters.com/philadelphia. Rates are US$149 per night for single occupancy, with an extra US$15 charge per extra person, per room. **Please identify yourself as a participant at the American Mathematical Society (AMS) meeting at Temple University and use the group code TU1011**. Amenities include complimentary wireless Internet throughout the hotel; Private Club Living Room with complimentary coffee, tea, newspapers, magazines and games; complimentary purified bottled water; fitness center; and complimentary self-serve laundry facilities. Parking is available at the Parkway Garage at Liberty Place for US$24.00 for up to 24 hours, there are no in and out privileges. Please inquire for additional details about parking when reserving this property. This property is located approximately 2.7 miles from the campus by car and approximately 23 minutes by by public transportation (walking and subway). Check in time is 3:00 p.m. and check out time is 12:00 noon. **The deadline for reservations at this rate is September 11, 2013.**

The Embassy Suites, 1776 Benjamin Franklin Parkway, Philadelphia, Pennsylvania 19103, (215) 561-1776; http://embassysuites3.hilton.com. Rates are US$159 per night for single/double occupancy in a room with a king or two double beds. All suites include wet bar, refrigerator, microwave, and coffeemaker. Amenities include complimentary morning newspaper, complimentary cooked-to-order breakfast, complimentary beverage area, fitness center, wireless Internet access for a fee, business center, and parking on-site. Valet parking is available to hotel guests for a rate of US$45.60 inclusive of tax and this rate includes in/out privileges. This property is located approximately 2.5 miles from the campus by car and approximately 22 minutes by public transportation (walking and subway). Check in time is 3:00 p.m. and check out time is 12:00 noon. **The deadline for reservations at this rate is September 11, 2013.**

Doubletree by Hilton Philadelphia Center City, 237 South Broad Street, Philadelphia, Pennsylvania, 19107, (215) 893-1600; http://doubletree3.hilton.com/en/index.html. Rates are US$169 per night for single/double occupancy. Amenities include discounted Internet (US$5), business center, indoor pool, fitness room, and room service. There are two restaurants on property. Secured parking is available at the rates of US$25 for self-parking and US$38 for valet parking per day, with in/out privileges available. This property is located approximately 2.6 miles from the campus by car and approximately 17 minutes by by public transportation (walking and subway). Check in time is 3:00 p.m. and check out time is 12:00 p.m. **The deadline for reservations at this rate is September 11, 2013.**

Food Services

On Campus: At the time of publication it appears that there will not be any Temple-operated dining options open on weekends in the vicinity of the buildings hosting the meeting. As an urban campus, the neighborhoods surrounding the campus offer a multitude of dining options. **Off Campus:** There are many choices for dining convenient to campus:

Jimmy Johns, 1601 N 15th St., (215) 765-8800, open Saturday and Sunday 10:30 a.m.–3 a.m., http://www.jimmyjohns.com; serving sandwiches, delivery available.

Cityview Pizza, 1434 Cecil B. Moore, (215) 769-7437, open Saturday11a.m.–11:30 p.m. and Sunday 12:00 p.m.–9:30 p.m., http://cityviewpizzaandgrill.com; serving pizza, sandwiches, and Italian specialities.

The Fresh Grocer, 1501 N. Broad St., (215) 531-9333, Saturday and Sunday 6 a.m.–12-a.m.; supermarket with prepared foods.

Koja Grille, 1600 N. Broad St., (215) 763-5652, open Saturday 12 p.m.–11 p.m. and Sunday 12 p.m.–9 p.m., http://www.kojagrille.com/menu; serving Korean and Japanese food for dine-in and take-out.

Noshery Gourmet Cafe, 1600 N. Broad St., Suite 7, (215) 769-1289, open Saturday and Sunday 11 a.m.–9 p.m.; serving sushi, sandwiches, and salads.

Qdoba, 1600 N. Broad St., Suite 12, (215) 763-4090, open Saturday 11 a.m.–10 p.m.; serving Mexican fast food options.

Draught Horse Pub, 1431 Cecil B. Moore Ave., (215) 235-1010, open Saturday 12 p.m.–11 p.m. and Sunday 12 p.m.–7 p.m., http://www.draughthorse.com; serving craft beer and pub food.

Eddie's Pizza, 1200 W. Berks St., (215) 763-8028, open Saturday 11:30 a.m.–4 p.m.; serving pizza.

Orient Express, 1835 N 12th St., (215) 236-5191, open Saturday 12:30 p.m.–4 p.m.; serving Asian cuisine.

Tai's Vietnamese Food, 1835 N. 12th St., (215) 232-3711, open Saturday 12:30 p.m.–4 p.m; serving Vietnamese cuisine

Subway, 1511 N. 15th St, (215) 769-7827, open Saturday 8 a.m.–10 p.m. and Sunday 9 a.m.–10 p.m.; national sandwich chain.

Registration and Meeting Information

Registration will be located in the lobby of Tuttleman Learning Center. The AMS book exhibit will be located in the same building on the fourth floor in the Tuttleman Owl's Nest Lounge, also know as room 409. Special Sessions will be held in Tuttleman Learning Center and in Barton Hall B. All Invited Addresses and the Erdős Memorial Lecture will be given in Beury Hall, Room 160. Please refer to the campus map for the Main Campus at http://temple.edu/sites/temple/files/uploads/documents/TUMain_map.pdf for specific locations. The registration desk will be open on Saturday, October 12, 7:30 a.m.–4:00 p.m. and Sunday, October 13, 8:00 a.m.–12:00 p.m. Fees are US$54 for AMS members, US$76 for nonmembers; and US$5 for students, unemployed mathematicians, and emeritus members. Fees are payable on-site via cash, check, or credit card; advance registration is not available.

Information for Students: The AMS, with support from a private gift, is accepting applications for partial support for full-time doctoral students to participate in this meeting. To see more information and to submit an application, please visit www.ams.org/programs/travel-grants/grad-students/emp-student-JMM. Applications will be accepted between June 6 and July 18, 2013, only.

Other Activities

AMS Book Sale: Stop by the onsite AMS bookstore and celebrate the AMS's 125th Anniversary. You can browse new titles, buy a new 125th t-shirt, enter to win a US$125 AMS Bookstore Gift Certificate, pick up some 125th giveaways, become an AMS member, or pay your dues. Not only will you receive a 25% discount from the list price on most AMS titles, you may also purchase any AMS title, even if it is not on display, at the exhibit discount.

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.

There will be an Erdős Memorial Lecture given by Barry Mazur on the topic of *Arithmetic statistics: Elliptic curves and other mathemtical objects*. This lecture will take place in Beury Hall, in Room 160 at 5:00 p.m. on Saturday.

There will be a **reception** for participants on Saturday evening immediately following the Erdős lecture, between 6:00 p.m. and 8:00 p.m. Please watch for more details on this event on the AMS website and at the registration desk on site at the meeting. The AMS thanks our hosts for their gracious hospitality.

Local Information and Maps

This meeting will take place on the Main Campus of Temple University. A campus map can be viewed at http://temple.edu/sites/temple/files/uploads/documents/TUMain_map.pdf. Information about the Temple University Department of Mathematics may be found at https://math.temple.edu/. Please watch the website available at www.ams.org/meetings/sectional/sectional.html for additional information on this meeting. Please visit the Temple University website at www.temple.edu for additional information on the campus.

Parking

Visitor parking on campus is only available in the garage on campus. If you're interested in parking, please use the Liacouras Garage, located at 1776 N. Broad Street. The rate at the time of publication is US$14 and is cash only.

Additional information on visitor parking can be found at http://www.temple.edu/parking/.

Travel

Temple University is located in the heart of Philadelphia, PA. The campus is approximately 2 miles away from the Center City area of Philadelphia and the heart of the city's historical landmarks and cultural treasures.

By Air: Philadelphia International Airport (PHL) is the closest airport to Temple University. It is located just 7.2 miles southwest of downtown Philadelphia and is conveniently accessible by I-95, I-76, and Route 291 as well as public transit.

The Airport Line Regional Rail train provides service to Philadelphia International Airport every 30 minutes from about 4 a.m. to 11:30 p.m. each day. To get to campus take SEPTA Airport Line (R1) to the Temple University stop. The fare is approximately US$6.50. Bus Routes 37 and 108 service Philadelphia International Airport as well.

Taxi services can be accessed at Zone 5 on the Commercial Transportation Roadway. All taxi rates are based per trip, not per person. There is a US$10.00 minimum fare from the airport to any destination and a US$28.50

flat rate from the airport to the central Philadelphia area. All taxis accept credit cards. For additional information, contact the Ground Transportation Hotline at 215-937-6958. The approximate cost for a taxi from the airport to Temple University Main Campus is at least US$30.00 plus tip.

Rental cars are available through a number of rental agencies at the airport and information phones are available at all baggage claim areas for each of the on-airport car rental agencies. To pick up your vehicle from the airport, please proceed to Zone 2 outside the baggage claim area.

Other options for ground transportation from the airport include shuttle and sedan services. Information on these service providers can be found at `http://www.phl.org/passengerinfo/transportationservices/Pages/shuttlesLimousines.aspx`. All hotel shuttles pick up in Zone 4, van services pick up in Zone 7, and charter buses pick up in Zone 8.

By Train: The Philadelphia region is served by Amtrak and Acela, reservations can be made at `www.amtrak.com`. If traveling by rail, you will arrive at 30th Street Station, located in Center City Philadelphia. At 30th Street Station you may take a SEPTA commuter train to Temple University. The ticket price is approximately US$5.00. Another option for transportation to campus is to take a taxi cab for approximately US$15.00, one way.

By Bus: The Philadelphia region is served by Greyhound Lines and Bolt Bus; reservations can be made at `www.greyhound.com`. Buses for these lines arrive at 1001 Filbert St, Philadelphia. Public transportation is available nearby to this station, and taxi service directly from the station to Temple costs approximately US$20. Megabus also serves the Philadelphia region; information on schedules of service and to purchase tickets online, please visit `www.megabus.com`. You will arrive at 30th St. Station; for ground transportation options please see the "by train", listing above.

By Car: If you are driving to campus and using a GPS, please note that Temple University's GPS Address is 1101 West Montgomery Avenue, Philadelphia, PA 19122 Once you arrive on campus, you may park in the Liacouras Garage, located at 1776 N. Broad Street. This garage is accessible from Norris Street and also from Broad Street , in both the northbound and southbound directions.

From the Pennsylvania Turnpike: Take Exit 326 (Philadelphia/Valley Forge). Follow I-76 East (Schuylkill Expy.) approx. 18 miles to Exit 344 (Central Philadelphia/I-676) Note: Exit is on left. Follow I-676 approximately 1 mile to Central Phila./Broad Street exit. Take Broad Street exit (stay to left). In one block go left onto Broad Street. Follow Broad Street to Cecil B. Moore (approx. 2 miles). Turn right onto Cecil B. Moore and right again onto Park Ave. Visitors Parking Lot 3 entrance is on right. You may also park at the Liacouras Center Parking Garage, located at 15th Street and Montgomery Avenue.

From the Northeast Extension Pennsylvania Turnpike: Take Exit 20 to I-476 South to I-76. Exit at I-76 East (approx. 5 miles). Take I-76 East approx. 15 miles to Exit 344 (Central Philadelphia/I-676) Note: Exit is on left. Follow directions from I-676 above. From I-95 North: Take Exit 22 (Central Philadelphia/I-676). Follow Central Philadelphia signs to Broad Street exit. At next intersection (Vine Street) turn left. In one block, turn left onto Broad Street. Follow Broad Street to Cecil B. Moore (approx. 2 miles). Turn right onto Cecil B. Moore and right again onto Park Ave. Visitors Parking Lot 3 is on right. You may also park at the Liacouras Center Parking Garage, located at 15th Street and Montgomery Avenue.

From I-95 South: Take Exit 22 (Central Philadelphia/I-676). Note: left lane exit. I-676 West to Broad Street exit. See above directions from Broad Street exit.

From the New Jersey Turnpike: Take Exit 4 to Route 73 North. Approx. 1 mile to Route 38 West. Follow for 5.5 miles to Benjamin Franklin Bridge. Take I-676 West to Broad Street exit. Follow above directions from Broad Street exit.

Car Rental: Hertz is the official car rental company for the meeting. To make a reservation accessing our special meeting rates online at `www.hertz.com`, click on the box "I have a discount", and type in our convention number **(CV): 04N30003**. You can also call Hertz directly at 800-654-2240 (U.S. and Canada) or 405-749-4434 (other countries). At the time this announcement was prepared, rates were US$23.00 to US$73.00 per day on the weekend. At the time of your reservation, the meeting rates will be automatically compared to other Hertz rates and you will be quoted the best comparable rate available.

Local Transportation

Bus and Subway service: SEPTA's Broad Street Line is a convenient mode of transportation to Temple Main Campus by subway with its Cecil B. Moore stop. If you are taking public transportation, you can find more information at the Southeastern Pennsylvania Transportation Authority (SEPTA) website `http://septa.org/`. *Please note, you must take a local train on the Broad St. Line, not an express train to most easily access the Temple campus.*

SEPTA also operates bus and trolley routes throughout the city. For more information on utilizing these modes of transportation please visit the SEPTA website.

Customers have a variety of fare options to suit their travel needs. Paying the cash fare of US$2.00 on transit services is the simplest way to ride, however tickets, tokens, and passes offer additional savings. To ride aboard Regional Rail, cash, a ticket, or a pass are accepted forms of payment. The base cash fare for bus, trackless trolley, subway, and trolley service is US$2.00. Cash is accepted for travel on all services. Exact fare must be used. Tokens provide a discount off the base cash fare and cost US$1.55 each. A-one day convenience pass is also available and is valid for eight rides on any bus, trolley, or subway route in one calendar day by one person for US$7.00.

Taxi Service: Licensed, metered taxis are available throughout the Philadelphia metropolitan area.

Weather

The average high temperature for October is approximately 67 degrees Fahrenheit and the average low is approximately 48 degrees Fahrenheit. Visitors should be prepared for inclement weather and check weather forecasts in advance of their arrival.

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 `mac@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.

St. Louis, Missouri

Washington University

October 18–20, 2013

Friday – Sunday

Meeting #1094

Central Section
Associate secretary: Georgia M. Benkart
Announcement issue of *Notices*: August 2013
Program first available on AMS website: September 5, 2013
Program issue of electronic *Notices*: October 2013
Issue of *Abstracts*: Volume 34, Issue 4

Deadlines

For organizers: Expired
For abstracts: August 27, 2013

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Ronny Hadani, University of Texas at Austin, *Title to be announced*.

Effie Kalfagianni, Michigan State University, *Title to be announced*.

Jon Kleinberg, Cornell University, *Title to be announced*.

Vladimir Sverak, University of Minnesota, *Title to be announced*.

Special Sessions

Advances in Difference, Differential, and Dynamic Equations with Applications (Code: SS 12A), **Elvan Akin**, Missouri S&T University, **Youssef Raffoul**, University of Dayton, and **Agacik Zafer**, American University of the Middle East.

Advances in Mathematical Methods for Disease Modeling (Code: SS 21A), **Jimin Ding**, Washington University in St. Louis, **Necibe Tuncer**, University of Tulsa, and **Naveen K. Vaidya**, University of Missouri-Kansas City.

Algebraic Cycles and Coherent Sheaves (Code: SS 19A), **Roya Beheshti**, **Matt Kerr**, and **N. Mohan Kumar**, Washington University, St. Louis.

Algebraic and Combinatorial Invariants of Knots (Code: SS 1A), **Heather Dye**, McKendree University, **Allison Henrich**, Seattle University, **Aaron Kaestner**, North Park University, and **Louis Kauffman**, University of Illinois.

Automorphic Forms and Representation Theory (Code: SS 7A), **Dubravka Ban** and **Joe Hundley**, Southern Illinois University, and **Shuichiro Takeda**, University of Missouri, Columbia.

Commutative Algebra (Code: SS 11A), **Lianna Sega**, University of Missouri, Kansas City, and **Hema Srinivasan**, University of Missouri, Columbia.

Computability Across Mathematics (Code: SS 2A), **Wesley Calvert**, Southern Illinois University, and **Johanna Franklin**, University of Connecticut.

Convex Geometry and its Applications (Code: SS 16A), **Susanna Dann**, **Alexander Koldobsky**, and **Peter Pivovarov**, University of Missouri.

Geometric Aspects of 3-Manifold Invariants (Code: SS 10A), **Oliver Dasbach**, Louisiana State University, and **Effie Kalfagianni**, Michigan State University.

Geometric Topology in Low Dimensions (Code: SS 4A), **William H. Kazez**, University of Georgia, and **Rachel Roberts**, Washington University in St. Louis.

Groupoids in Analysis and Geometry (Code: SS 6A), **Alex Kumjian**, University of Nevada at Reno, **Markus Pflaum**, University of Colorado, and **Xiang Tang**, Washington University in St. Louis.

Interactions between Geometric and Harmonic Analysis (Code: SS 3A), **Leonid Kovalev**, Syracuse University, and **Jeremy Tyson**, University of Illinois, Urbana-Champaign.

Linear and Non-linear Geometry of Banach Spaces (Code: SS 13A), **Daniel Freeman** and **Nirina Lovasoa Randrianarivony**, St. Louis University.

Noncommutative Rings and Modules (Code: SS 5A), **Greg Marks** and **Ashish Srivastava**, St. Louis University.

Operator Theory (Code: SS 9A), **John McCarthy**, Washington University in St. Louis.

PDEs of Fluid Mechanics (Code: SS 17A), **Roman Shvydkoy**, University of Illinois Chicago, and **Vladimir Sverak**, University of Minnesota.

p-local Group Theory, Fusion Systems, and Representation Theory (Code: SS 18A), **Justin Lynd**, Rutgers University, and **Julianne Rainbolt**, Saint Louis University.

Spectral, Index, and Symplectic Geometry (Code: SS 15A), **Alvaro Pelayo** and **Xiang Tang**, Washington University, St. Louis.

Statistical Properties of Dynamical Systems (Code: SS 14A), **Timothy Chumley** and **Renato Feres**, Washington University in St. Louis, and **Hongkun Zhang**, University of Massachusetts, Amherst.

Topological Combinatorics (Code: SS 20A), **John Shareshian**, Washington University, St. Louis, and **Russ Woodroofe**, Mississippi State University.

Wavelets, Frames, and Related Expansions (Code: SS 8A), **Marcin Bownik**, University of Oregon, **Darrin Speegle**, Saint Louis University, and **Guido Weiss**, Washington University, St. Louis.

Riverside, California

University of California Riverside

November 2–3, 2013

Saturday – Sunday

Meeting #1095

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: August 2013
Program first available on AMS website: September 19, 2013
Program issue of electronic *Notices*: November 2013
Issue of *Abstracts*: Volume 34, Issue 4

Deadlines

For organizers: Expired
For abstracts: September 10, 2013

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Michael Christ, University of California, Berkeley, *Title to be announced.*

Mark Gross, University of California, San Diego, *Title to be announced.*

Matilde Marcolli, California Institute of Technology, *Title to be announced.*

Paul Vojta, University of California, Berkeley, *Title to be announced.*

Special Sessions

Algebraic Structures in Knot Theory (Code: SS 19A), **Allison Henrich**, Seattle University, and **Sam Nelson**, Claremont McKenna College.

Analysis and Geometry of Metric Spaces (Code: SS 12A), **Asuman G. Aksoy**, Claremont McKenna College, and **Zair Ibragimov**, California State University, Fullerton.

Categorification in Representation Theory (Code: SS 15A), **Aaron Lauda** and **David Rose**, University of Southern California.

Commutative Algebra and its Interaction with Algebraic Geometry and Combinatorics (Code: SS 10A), **Kuei-Nuan Lin** and **Paolo Mantero**, University of California, Riverside.

Computational Problems on Large Graphs and Applications (Code: SS 16A), **Kevin Costello** and **Laurent Thomas**, University of California, Riverside.

Computer, Mathematics, Imaging, Technology, Network, Health, Big Data, and Statistics (Code: SS 3A), **Subir Ghosh**, University of California, Riverside.

Developments in Markov Chain Theory and Methodology (Code: SS 2A), **Jason Fulman**, University of California, Riverside, and **Mark Huber**, Claremont McKenna College.

Diophantine Geometry and Nevanlinna Theory (Code: SS 14A), **Aaron Levin**, Michigan State University, **David McKinnon**, University of Waterloo, and **Paul Vojta**, University of California, Berkeley.

Dynamical Systems (Code: SS 13A), **Nicolai Haydn**, University of Southern California, and **Huyi Hu**, Michigan State University.

Fluids and Boundaries (Code: SS 5A), **James P. Kelliher**, **Juhi Jang**, and **Gung-Min Gie**, University of California, Riverside.

Fractal Geometry, Dynamical Systems, and Mathematical Physics (Code: SS 9A), **Michel L. Lapidus**, University of California, Riverside, **Erin P. J. Pearse**, California State Polytechnic University, San Luis Obispo, and **John A. Rock**, California State Polytechnic University, Pomona.

From Harmonic Analysis to Partial Differential Equations: in Memory of Victor Shapiro (Code: SS 11A), **Alfonso Castro**, Harvey Mudd College, **Michel L. Lapidus**, University of California, Riverside, and **Adolfo J. Rumbos**, Pomona College.

Geometric Analysis (Code: SS 4A), **Zhiqin Lu**, University of California, Irvine, **Bogdan D. Suceava**, California State University, Fullerton, and **Fred Wilhelm**, University of California, Riverside.

Geometric and Combinatorial Aspects of Representation Theory (Code: SS 8A), **Wee Liang Gan** and **Jacob Greenstein**, University of California, Riverside.

Geometry of Algebraic Varieties (Code: SS 6A), **Karl Fredrickson**, University of California, Riverside, **Mark Gross**, University of California, San Diego, and **Ziv Ran**, University of California, Riverside.

Heights, Diophantine Problems, and Lattices (Code: SS 17A), **Lenny Fukshansky**, Claremont McKenna College, and **David Krumm**, University of Georgia and Claremont McKenna College.

Homotopy Theory and K-Theory (Code: SS 7A), **Julie Bergner**, University of California, Riverside, and **Christian Haesemeyer**, University of California, Los Angeles.

Teaching ODEs: Best Practices from CODEE (Community of Ordinary Differential Equations Educators) (Code: SS 18A), **Nishu Lal**, Pomona College and Pitzer College, and **Ami Radunskaya**, Pomona College.

The Mathematics of Planet Earth (Code: SS 1A), **John Baez**, University of California, Riverside.

Baltimore, Maryland

Baltimore Convention Center, Hilton Baltimore, and Baltimore Marriott Inner Harbor Hotel

January 15–18, 2014

Wednesday – Saturday

Meeting #1096

Joint Mathematics Meetings, including the 120th Annual Meeting of the AMS, 97th Annual Meeting of the Mathematical Association of America (MAA), 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 M. Benkart
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: Expired
For abstracts: September 17, 2013

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/national.html`.

Joint Invited Addresses

Eitan Grinspun, Columbia University, *Title to be announced* (MAA-AMS-SIAM Gerald and Judith Porter Public Lecture).

AMS Invited Addresses

Andrew Blake, Microsoft Research Cambridge, *Title to be announced* (AMS Josiah Willard Gibbs Lecture).

Emmanuel Candès, Stanford University, *Title to be announced.*

Christopher Hacon, University of Utah, *Title to be announced.*

Dusa McDuff, Columbia University, *Title to be announced* (AMS Colloquium Lectures).

H.-T. Yau, Harvard University, *Title to be announced.*

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.

Contributed Paper Sessions with Themes

Assessing Quantitative Reasoning and Literacy, organized by **Semra Kilic-Bahi**, Colby-Sawyer College; **Eric Gaze**, Bowdoin College; **Andrew Miller**, Belmont University; and **Aaron Montgomery**, Central Washington University; Wednesday morning.

For more than a decade, the focus of introductory general education mathematics undergraduate courses has shifted towards quantitative literacy and reasoning at many academic institutions. The emphasis of these courses is to provide students the quantitative tools they will need for successful decision making in their personal, professional, and civic lives. Assessing and evaluating the impact of this curriculum change at the course, department, program, and campus-wide levels is crucial to dissemination of best practices at other institutions. Sponsored by the SIGMAA on Quantitative Literacy.

Assessing Student Learning: Alternative Approaches, organized by **Jane Butterfield**, University of Minnesota; **Robert Campbell III**, College of St. Benedict/St. John's University; **David Clark**, University of Minnesota; **John Peter**, Utica College; and **Cassie Williams**, James Madison University; Wednesday afternoon.

Classroom assessment is central to determining a student's level of mastery, yet traditional methods of assessment (such as exams, quizzes, and homework) may not accurately and robustly measure student understanding. With the recent increase in the popularity of non-lecture-based course structures, techniques that assess deeper learning have come to the forefront. This session invites presenters to describe innovative methods of assessment with which they have experimented in the attempt to accurately reflect the diversity of ways students learn and understand course material. Presenters should focus on practical issues of implementation and discuss the level of success of the method in the college classroom. Presenters may also consider sharing methods to determine validity of their assessments, advice for others looking to implement or create alternative assessment methods, or how these methods can help instructors evaluate the effectiveness of a non-traditional classroom.

Assessment of Proof Writing Throughout the Mathematics Major, organized by **Sarah Cook**, Washburn University, and **Miriam Harris-Botzum**, Lehigh Carbon Community College; Thursday morning.

Proof writing is a critical component of any mathematics major's academic career. Typically students develop these skills throughout their work in the major. How do you assess whether or not your students have successfully attained appropriate proof-writing skills? What are your proof-writing expectations for a beginning student versus an experienced student? Have you developed methods for assessing specific aspects of proof, such as logic, writing style, or critiquing of proofs? Do you assess proof writing with rubrics? Do you use portfolios? Is your assessment of proof writing course-specific or department-wide? This session invites presentations that include a description of the proof-writing objectives that are assessed, the assessment methods used, feedback received, and how student data has been used to improve student learning. Assessment in any level of proof course, not just introduction to proof, is appropriate for this session. Sponsored by the MAA Committee on Assessment.

At the Intersection of Mathematics and the Arts, organized by **Douglas Norton**, Villanova University; Thursday afternoon.

Practitioners and educators in the separate domains of mathematics and the arts continue to discover new territory to explore and to share, finding not a wall between disjoint sets but a fertile ground of intersection between the two. Participants are invited to share and learn of various areas of the traditional and newly-explored territories at the intersection of mathematics and the many visual, musical, dramatic, architectural, literary, and performing arts. Sponsored by the SIGMAA on Mathematics and the Arts.

Bridging the Gap: Designing an Introduction to Proofs Course, organized by **Sarah Mabrouk**, Framingham State University; Thursday morning.

This session invites papers regarding the creation of "bridge" and introductory proofs courses and the effects of such courses on students' abilities to read, analyze, and write proofs in subsequent courses such as number theory, abstract algebra, real/complex analysis, and applied mathematics. Information about textbook selection, assignments/projects, and activities that help students to read and analyze statements as well as to understand when it is appropriate to use, for example, the contrapositive or proof by contradiction are of particular interest; papers promoting or abasing particular textbooks will not be considered. Papers providing information about approaches that have not been successful are welcome as are those about how ineffective initial attempts were modified to help students to understand statement analysis, recognize/write equivalent statements, select appropriate rather than inappropriate methods of proof, realize when proofs are complete or incomplete, and use meaningful language and terminology in good proof writing while minimizing student-frustration and the student's view that the instructor is being picky about sentence structure and diction.

While papers providing evidence of course effectiveness in helping students to read, analyze, and write proofs are encouraged, the focus of this session is neither course assessment nor assessment of proof writing.

Data, Modeling, and Computing in the Introductory Statistics Course, organized by **Andrew Zieffler**, University of Minnesota; **Scott Alberts**, Truman State University; and **Randall Pruim**, Calvin College; Friday afternoon.

The prevalence and use of data, models, and computing have long been relevant in the introductory statistics course. Recently, media coverage of the use of data, models and computing for prediction has garnered an awareness that goes beyond the classroom. How can statistics instructors take advantage of this current popularity to engage students? We invite submissions that provide details about learning activities, technologies, resources, or teaching methods that have made use of current trends in data, modeling, and computing in teaching introductory statistics courses. We particularly encourage submissions related to teaching introductory statistics using nonconventional data, models and computing (e.g., 'big' data, web scraping, etc.). Presenters will be considered for the Dex Whittinghill Award for Best Contributed Paper. Sponsored by the SIGMAA on Statistics Education.

Flipping the Classroom, organized by **Krista Maxson**, Shawnee State University, and **Zsuzsanna Szaniszlo**, Valparaiso University; Saturday morning.

A flipped classroom is one where instruction is delivered outside of class (typically online) and class time is used for homework and activities to illustrate concepts with guidance from the instructor. This session invites presentations from faculty with experience in using flipped classroom instruction. We are interested in presentations that describe the effect of this teaching method on student learning while demonstrating the nuts and bolts of flipping a classroom. Presenters should describe goals, expectations, results, time commitment, technology used, and lessons learned from the experience. We are especially interested in descriptions and results of controlled studies, and the use of existing online material in the college classroom. The discussion of available appropriate technology is encouraged.

The History of Mathematical Communities, organized by **Amy Shell-Gellasch**, Hood College, and **Linda McGuire**, Muhlenberg College; Thursday afternoon.

The year 2015 marks the centennial of the MAA. Looking forward to that milestone, this session presents talks that highlight the history and contributions of not only the MAA, but the broad spectrum of mathematical communities. Talks may address the history of mathematical organizations such as the MAA, AMS, SIAM, AWM, CSHPM; institutions such as the Museum of Alexandria, the Universities of Chicago and Göttingen; mathematical communities such as the ICM; or any other community of mathematicians or mathematics educators that has been influential in affecting the direction and growth of mathematics. Sponsored by the SIGMAA on the History of Mathematics.

Innovative and Effective Ways to Teach Linear Algebra, organized by **David Strong**, Pepperdine University; **Gilbert Strang**, MIT; and **Megan Wawro**, Virginia Tech; Friday morning.

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.

Instructional Approaches to Increase Awareness of the Societal Value of Mathematics, organized by **Jessica Deshler**, West Virginia University, and **Elizabeth Burroughs**, Montana State University; Friday afternoon.

While students in undergraduate mathematics courses may be exposed to a breadth and depth of mathematical content, often absent from their mathematical experience is an awareness of how mathematics is exercised as a social endeavor. Undergraduate mathematics instructors can facilitate an awareness of the utility value of mathematics by choosing particular pedagogical strategies or content topics that illustrate mathematics in its social context.

We invite papers that address the development or implementation of such curriculum materials and pedagogical approaches. We envision papers that would fit one of two broad topics: (1) the introduction of topics into the mathematics curriculum that illustrate the societal uses of mathematics and (2) implementation of pedagogical changes that lead students towards understanding the social dimension of mathematics.

Papers should have a sound theoretical or empirical foundation and description of how the approach is intended to increase awareness of the societal impact of mathematics among students. Papers should describe the means used to evaluate whether the approach is successful. We are particularly interested in papers that address courses in the calculus sequence.

Is Mathematics the Language of Science?, organized by **Carl Behrens**, Alexandria, VA; **Thomas Drucker**, University of Wisconsin Whitewater; and **Dan Sloughter**, Furman University; Wednesday morning.

In 1960 physicist Eugene Wigner published an article titled: “The Unreasonable Effectiveness of Mathematics in the Natural Sciences”, in which he raised the question of the relationship between mathematics and the empirical sciences. Discussions of Wigner’s article often reflect the assumption that mathematics has relevance only as a means of exploring the physical world: as Wigner puts it, “in discovering the laws of inanimate nature.” Many mathematicians would find this an unacceptable restriction on the definition of their pursuits and activities.

This session will explore the extent to which Wigner’s approach defines the role of mathematics, and entertain alternative or additional functions and purposes. Other papers of a philosophical nature will be considered for inclusion as time permits. Sponsored by the SIGMAA for the Philosophy of Mathematics.

Mathematics and Sports, organized by **Drew Pasteur**, College of Wooster, and **John David**, Virginia Military Institute; Saturday morning.

The expanding availability of play-by-play statistics and video-based spatial data, for professional and some collegiate sports, is leading to innovative kinds of research, using techniques from various areas of the mathematical sciences. By modeling the outcome distributions in certain situations, researchers can develop new metrics for player or team performance in various aspects of a sport, comparing actual results to expected values. Such work often has implications for strategic game management and personnel evaluation. Classic areas of study, such as tournament design, ranking methodology, forecasting future performance, insight into rare or record events, and physics-based analysis, also remain of interest. This session will include both presentations of original research and expository talks; topics related to the use of sports applications in curriculum are welcome. With a broad audience in mind, all talks are requested to be accessible to mathematics majors. Undergraduates and their mentors are particularly encouraged to submit abstracts for consideration.

Mathematics Experiences in Business, Industry, and Government, organized by **Carla Martin**, James Madison University; **Phil Gustafson**, Mesa State University; and **Michael Monticino**, University of North Texas; Friday afternoon.

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. Sponsored by the SIGMAA on MAA Business, Industry and Government.

Open Source Mathematics Textbooks, organized by **Albert Schueller**, Whitman College, and **Kent Morrison**, American Institute of Mathematics; Friday morning.

Open-source/open-access publishing is on the rise among academic mathematicians. We seek presentations on topics such as the promotion, evaluation, revision, preparation, technology, and public policy of open-source texts. Talks that are directed towards potential authors and/or adopters of open-source texts are particularly encouraged. Also, talks about novel methods of integrating these texts with technology (e.g., Sage, WeBWorK) are encouraged. While it is appropriate to discuss the lessons learned from the development of individual textbooks, this session is not intended for the promotion of specific works.

Programs and Approaches for Mentoring Women and Minorities in Mathematics, organized by **Jenna Carpenter**, Louisiana Tech University, and **Brooke Shipley**, University of Chicago; Wednesday afternoon.

Women (~45%) and minorities (ranging from ~6% for African American and Hispanic students to 0.4% for Native American students) have long been underrepresented in mathematics, from the B.S. to the Ph.D. level, as well as in the faculty ranks. There are, however, examples of initiatives which do successfully mentor women and minorities to success at all levels. This session focuses on strategies and programs (from one-on-one mentoring to funded programs) that effectively mentor these students or faculty in mathematics. Papers should refer to relevant research and include assessment where possible, share lessons learned, as well as focus on aspects that could be adopted by others. Sharing of example materials, brochures, websites, etc., are also encouraged.

Projects, Demonstrations, and Activities that Engage Liberal Arts Mathematics Students, organized by **Sarah Mabrouk**, Framingham State University; Thursday afternoon.

Many colleges/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, strengths, and levels of interest/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, presented, and evaluated, as well as 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.

Putting a Theme in a History of Mathematics Course, organized by **Eugene Boman**, Penn State Harrisburg, and **Robert Rogers**, SUNY Fredonia; Saturday morning.

Anyone who has taught a course in the history of mathematics has bumped up against this problem: the topic is far too vast to fit into one semester, or even two. What gets left out is always much more than what is put in, so an organizing theme must be imposed. The simplest such theme is linear time: Start in prehistory and move forward. Other themes (great theorems, famous mathematicians, history of analysis, etc.) can highlight other aspects. What themes do you use when organizing your course? How do you organize the topics, readings, and problems to tell the stories you want to tell? This session is about overarching course themes/goals and not individual topics of interest. Sponsored by the SIGMAA on the History of Mathematics.

Reinventing the Calculus Sequence, organized by **David Dwyer** and **Mark Gruenwald**, University of Evansville; Saturday afternoon.

This session showcases innovative approaches to the standard, three-semester calculus sequence as well as the development of alternative, discipline-specific calculus courses and sequences.

The standard calculus sequence was shaped largely by the demands of math, physics, and engineering curricula. But there is an emerging recognition that traditional three-semester calculus sequences are not a good fit for students in certain STEM disciplines. Some institutions have responded by creating discipline-specific calculus sequences (such as calculus for the life sciences), while others have attempted to make significant changes to the standard sequence (such as an early multivariate approach). In either case, challenges arise involving course prerequisites, transferability, and compatibility with the AP exams.

The organizers of this session invite submissions that provide information on efforts to reinvent the calculus sequence either by creating a customized sequence for specific disciplines or by making substantial changes to the choice of topics or the way in which they are ordered. The emphasis should be on modifications to content rather than pedagogical approach or method of delivery. Evidence as to the effectiveness of the changes should be included.

Research on the Teaching and Learning of Undergraduate Mathematics, organized by **Kyeong Hah Roh**, Arizona State University, **Mikael Oehrtman**, University of Northern Colorado; and **Timothy Fukawa-Connelly**, University of New Hampshire; Thursday morning and afternoon.

This session presents research reports on undergraduate mathematics education. The session will feature research in a number of mathematical areas including linear algebra, advanced calculus, abstract algebra, and mathematical proof. The goals of this session are to foster high quality research in undergraduate mathematics education, to disseminate well-designed educational studies to the greater mathematics community, and to transform theoretical work into practical consequences in college mathematics. Examples of such types of research include rigorous and scientific studies about students' mathematical cognition and reasoning, teaching practice in inquiry-oriented mathematics classrooms, design of research-based curricular materials, and professional development of mathematics teachers, with intention to support and advance college students' mathematical thinking and activities. The presentation should report results of completed research that builds on the existing literature in mathematics education and employs contemporary educational theories of the teaching and learning of mathematics. The research should use well established or innovative methodologies (e.g., design experiment, classroom teaching experiment, and clinical interview, with rigorous analytic methods) as they pertain to the study of undergraduate mathematics education. We also welcome preliminary reports on research projects in early stages of development or execution. Sponsored by the SIGMAA on Research in Undergraduate Mathematics Education.

The Scholarship of Teaching and Learning in Collegiate Mathematics, organized by **Jackie Dewar**, Loyola Marymount University; **Tom Banchoff**, Brown University; **Curtis Bennett**, Loyola Marymount University; **Pam Crawford**, Jacksonville University; and **Edwin Herman**, University of Wisconsin Stevens Point; Wednesday afternoon.

In the scholarship of teaching and learning, faculty bring disciplinary knowledge to bear on questions of teaching and learning and systematically gather evidence to support their conclusions. Work in this area includes investigations of the effectiveness of pedagogical methods, assignments, or technology, as well as probes of student understanding. The goals of this session are to (1) feature scholarly work focused on the teaching of postsecondary mathematics, (2) provide a venue for teaching mathematicians to make public their scholarly investigations into teaching/learning, and (3) highlight evidence-based arguments for the value of teaching innovations or in support of new insights into student learning. Appropriate for this session are preliminary or final reports of post-secondary classroom-based investigations of teaching methods, student learning difficulties, curricular assessment, or insights into student (mis)understandings. Abstract submissions should: (1) have a clearly stated question that was or is under investigation, and (2) indicate the type of evidence that has been gathered and will be presented. In particular, abstracts might reference any of the following types of evidence: student work, participation or retention data, pre/post tests, interviews, surveys, think-alouds, etc.

Student Activities, organized by **Lisa Marano**, West Chester University of Pennsylvania, and **Jennifer Bergner**, Salisbury State University; Thursday morning.

In an effort to encourage community amongst your math club members, what activities have you hosted? Integration Bee, Monthly Game Night? Presentations should discuss the activity, the specific challenges present in the logistics of hosting the activity (such as funding) and outline the way the club resolved these. Also include the impact the hosted activity had on the club and its membership. Sponsored by the MAA Committee on Undergraduate Student Activities and Chapters.

Teaching with Technology: Impact, Evaluation and Reflection, organized by **Peter Gavin LaRose**, University of Michigan; Saturday afternoon.

Technology in a wide range of forms has been introduced to enhance teaching in many places in the mathematics curriculum. Uses of technology with teaching include in-class labs, computer demonstrations, and lecture response systems; out-of-class online homework, peer-reviewed and edited documents, and use of social media communication; and many variations on these, including video lecture, mobile applications, and more. We invite papers describing uses of technology to enhance teaching that speak to the impact of the technology on student learning, evaluation of the nature of the success of the technology use, and careful reflection on how it changes the learning process. We specifically solicit papers that describe the use of technology and are able to assess its impact in quantitative and particularly reflective qualitative manners.

This session will not consider specific technologies, but instead seeks to explore the boundary between student learning and the technology being used: how it changes the amount students learn, what they learn, and how we are able to determine this. Reflection on the impact on teaching with similarly strong evaluation will also be considered.

Topics and Techniques for Teaching Real Analysis, organized by **Paul Musial**, Chicago State University; **Robert W. Vallin**, Slippery Rock University; **Erik Talvila**, University of the Fraser Valley; and **James Peterson**, Benedictine University; Wednesday 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. In this session, mathematicians will have the opportunity to share their ideas for teaching an undergraduate real analysis course.

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.

Trends in Undergraduate Mathematical Biology Education, organized by **Timothy Comar**, Benedictine University; Friday morning.

This session highlights successful implementations of biomathematics courses and content in the undergraduate curriculum, entire biomathematics curricula, efforts to recruit students into biomathematics courses, undergraduate research projects, 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 recent reports emphasize that aspects of biological research are becoming more quantitative and that life science students, including pre-med students, should be introduced to a greater array of mathematical, statistical, and computational techniques and to the integration of mathematics and biological content at the undergraduate level. Mathematics majors also benefit from coursework at the intersection of mathematics and biology because there are interesting, approachable research problems and mathematics students need to be trained to collaborate with scientists in other disciplines, particularly biology.

Topics may include scholarly work addressing the issues related to the design of effective biomathematics courses and curricula, how to gear content toward pre-med students, integration of biology into mathematics courses, collaborations between mathematicians and biologists that have led to new courses, course modules, or undergraduate research projects, effective use of t echnology in biomathematics courses, and assessment issues. Sponsored by the SIGMAA on Mathematics and Biology.

USE Math: Undergraduate Sustainability Experiences in the Introductory Mathematics Classroom, organized by **Ben Galluzzo**, Shippensburg University; **Monika Kiss**, Saint Leo University; and **Corrine Taylor**, Wellesley College; Saturday morning.

Humanity continually faces the task of how to balance human needs against the world's resources while operating within the constraints imposed by the laws of nature. Mathematics helps us better understand these complex issues that span disciplines: from measuring energy and other resources, to understanding variability in air and water quality, to modeling climate change. Moreover, these and other real-world-driven sustainability topics have the potential for motivating students to pursue STEM courses and fields of study more deeply. This session seeks proposals from faculty interested in integrating sustainability-focused activities, projects, and modules into the introductory college mathematics curriculum. Abstracts of accepted papers will be published on the SIGMAA EM website, and authors will be encouraged to submit classroom-ready materials for broader dissemination on the USE Math website hosted by SERC, the Science Education Resource Center at Carleton College. Sponsored by the SIGMAA on Environmental Mathematics.

Using Online Resources to Augment the Traditional Classroom, organized by **Mike May**, Saint Louis University, and **Paul Seeburger**, Monroe Community College; Friday morning.

Web-based resources used to teach and learn mathematics can be used in traditional face-to-face courses as well as in strictly online courses. However, since students do not usually use these resources during class time (in traditional courses), instructors often must require students to use these resources outside the classroom. This session provides an opportunity to report on efforts to use web resources in traditional classrooms, including both innovations in the resources used and in the method of incorporating these resources into students' learning experiences. Preference will be given to papers that use resources or methods that are easily adopted in a broad range of institutions and can be accessed by a wide range of devices (mobile phones, tablets, laptops, desktops, etc.). Sponsored by the SIGMAA on Mathematics Instruction Using the Web and the MAA Committee on Technology in Mathematics Education.

Wavelets in Undergraduate Education, organized by **Caroline Haddad**, SUNY Geneseo; **Edward Aboufadel**, Grand Valley State University; and **John Merkel**, Oglethorpe University; Saturday 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, the design of medical equipment, and the detection of potholes. 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.

We Did More with Less: Streamlining the Undergraduate Mathematics Curriculum, organized by **Wade Ellis**, West Valley College, and **Barbara Edwards**, Oregon State University; Wednesday afternoon.

Contributed papers in this session should describe and document how mathematics programs maintain and enhance the quality of student learning in original, creative, and innovative ways with less money or less time. Papers in this session may focus on new approaches to classroom teaching, use of technology in teaching, placement procedures, outside funding, or volunteers from industry that improve programs at lower cost. We also welcome papers on successful new approaches to structuring programs that allow students to complete programs more quickly. Sponsored by the MAA Subcommittee on Curriculum Reform Across the First Two Years and the MAA Committee on Two-Year Colleges.

General Contributed Paper Session, organized by **Jennifer Beineke**, Western New England University; **Bem Cayco**, San Jose State University; and **Kimberly Presser**, Shippensburg University of Pennsylvania; Wednesday, Thursday, Friday, and Saturday mornings and afternoons.

This session accepts contributions in all areas of mathematics, curriculum, and pedagogy. When you submit your abstract you will be asked to classify it according to the following scheme: Assessment and Outreach; Calculus; History and Philosophy of Mathematics; Interdisciplinary Topics; Mathematics Education; Mathematics and Technology; Modeling and Applications of Mathematics; Probability and Statistics; Research in Geometry and Linear Algebra; Research in Analysis; Research in Number Theory; Research in Graph Theory and Combinatorics; Research in Algebra and Topology; Research in Applied Mathematics; Teaching Introductory Mathematics; Teaching Mathematics Beyond the Calculus Sequence; or Other Assorted Topics.

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, click "New Abstract", and then follow the step-by-step instructions. **The deadline for abstracts is Tuesday, September 17, 2013**.

Each participant may give at most one talk in any one themed contributed paper session or the general contributed paper session. If your paper cannot be accommodated in the session for which it was 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.

Knoxville, Tennessee

University of Tennessee, Knoxville

March 21–23, 2014

Friday – Sunday

Meeting #1097

Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: January 2014
Program first available on AMS website: February 6, 2014
Program issue of electronic *Notices*: March 2014
Issue of *Abstracts*: Volume 35, Issue 2

Deadlines

For organizers: August 21, 2013
For abstracts: January 28, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Special Sessions

Commutative Ring Theory (in honor of the retirement of David E. Dobbs) (Code: SS 1A), **David Anderson**, University of Tennessee, Knoxville, and **Jay Shapiro**, George Mason University.

Diversity of Modeling and Optimal Control: A Celebration of Suzanne Lenhart's 60th Birthday (Code: SS 3A), **Wandi Ding**, Middle Tennessee State University, and **Renee Fister**, Murrray State University.

Fractal Geometry and Ergodic Theory (Code: SS 2A), **Mrinal Kanti Roychowdhury**, University of Texas Pan American.

Baltimore, Maryland

University of Maryland, Baltimore County

March 29–30, 2014

Saturday – Sunday

Meeting #1098

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: January 2014
Program first available on AMS website: February 6, 2014
Program issue of electronic *Notices*: March 2014
Issue of *Abstracts*: Volume 35, Issue 2

Deadlines

For organizers: August 29, 2013
For abstracts: January 28, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Maria Gordina, University of Connecticut, *Title to be announced*.

L. Mahadevan, Harvard University, *Title to be announced*.

Nimish Shah, Ohio State University, *Title to be announced*.

Dani Wise, McGill University, *Title to be announced*.

Albuquerque, New Mexico

University of New Mexico

April 5–6, 2014

Saturday – Sunday

Meeting #1099

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: January 2014
Program first available on AMS website: February 20, 2014
Program issue of electronic *Notices*: April 2014
Issue of *Abstracts*: Volume 35, Issue 2

Deadlines

For organizers: September 5, 2013
For abstracts: February 11, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Special Sessions

The Inverse Problem and Other Mathematical Methods Applied in Physics and Related Sciences (Code: SS 1A), **Hanna Makaruk**, Los Alamos National Laboratory, and **Robert Owczarek**, University of New Mexico and Enfitek, Inc.

Lubbock, Texas

Texas Tech University

April 11–13, 2014

Friday – Sunday

Meeting #1100

Central Section
Associate secretary: Georgia M. Benkart
Announcement issue of *Notices*: February 2014
Program first available on AMS website: February 27, 2014
Program issue of electronic *Notices*: April 2014
Issue of *Abstracts*: Volume 35, Issue 2

Deadlines

For organizers: September 18, 2013
For abstracts: February 10, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Special Sessions

Analysis and Applications of Dynamic Equations on Time Scales (Code: SS 2A), **Heidi Berger**, Simpson College, and **Raegan Higgins**, Texas Tech University.

Fractal Geometry and Dynamical Systems (Code: SS 3A), **Mrinal Kanti Roychowdhury**, The University of Texas-Pan American.

Issues Regarding the Recruitment and Retention of Women and Minorities in Mathematics (Code: SS 5A), **James Valles Jr.** and **Doug Scheib**, Saint Mary-of-the-Woods College.

Recent Advancements in Differential Geometry and Integrable PDEs, and Their Applications to Cell Biology and Mechanical Systems (Code: SS 4A), **Giorgio Bornia**, **Akif Ibragimov**, and **Magdalena Toda**, Texas Tech University.

Topology and Physics (Code: SS 1A), **Razvan Gelca** and **Alastair Hamilton**, Texas Tech University.

Tel Aviv, Israel

Bar-Ilan University, Ramat-Gan and Tel-Aviv University, Ramat-Aviv

June 16–19, 2014

Monday – Thursday

Meeting #1101

The Second Joint International Meeting between the AMS and the Israel Mathematical Union.
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: January 2014
Program first available on AMS website: Not applicable
Program issue of electronic *Notices*: Not applicable
Issue of *Abstracts*: None

Deadlines

For organizers: Expired
For abstracts: To be announced

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/internmtgs.html.

Special Sessions

Mirror Symmetry and Representation Theory, **David Kazhdan**, Hebrew University, and **Roman Bezrukavnikov**, Massachusetts Institute of Technology.

Nonlinear Analysis and Optimization, **Boris Mordukhovich**, Wayne State University, and **Simeon Reich** and **Alexander Zaslavski**, The Technion-Israel Institute of Technology.

Qualitative and Analytic Theory of ODEs, **Yosef Yomdin**, Weizmann Institute.

Eau Claire, Wisconsin

University of Wisconsin-Eau Claire

September 20–21, 2014

Saturday – Sunday

Meeting #1102

Central Section
Associate secretary: Georgia M. Benkart
Announcement issue of *Notices*: June 2014
Program first available on AMS website: August 7, 2014
Program issue of electronic *Notices*: September 2014
Issue of *Abstracts*: Volume 35, Issue 3

Deadlines

For organizers: March 20, 2014
For abstracts: July 29, 2014

Halifax, Canada

Dalhousie University

October 18–19, 2014
Saturday – Sunday

Meeting #1103
Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: August 2014
Program first available on AMS website: September 5, 2014
Program issue of electronic *Notices*: October 2014
Issue of *Abstracts*: Volume 35, Issue 3

Deadlines
For organizers: March 18, 2014
For abstracts: August 19, 2014

San Francisco, California

San Francisco State University

October 25–26, 2014
Saturday – Sunday

Meeting #1104
Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: August 2014
Program first available on AMS website: September 17, 2014
Program issue of electronic *Notices*: October 2014
Issue of *Abstracts*: Volume 35, Issue 4

Deadlines
For organizers: March 25, 2014
For abstracts: September 3, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Special Sessions

Algebraic Geometry (Code: SS 1A), **Renzo Cavalieri**, Colorado State University, **Noah Giansiracusa**, University of California, Berkeley, and **Burt Totaro**, University of California, Los Angeles.

Greensboro, North Carolina

University of North Carolina, Greensboro

November 8–9, 2014
Saturday – Sunday

Meeting #1105
Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: August 2014
Program first available on AMS website: September 25, 2014
Program issue of electronic *Notices*: November 2014
Issue of *Abstracts*: Volume 35, Issue 4

Deadlines
For organizers: April 8, 2014
For abstracts: September 16, 2014

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 (MAA), 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 (ASL), 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 abstracts: To be announced

Washington, District of Columbia

Georgetown University

March 7–8, 2015
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: August 7, 2014
For abstracts: To be announced

Huntsville, Alabama

University of Alabama in Huntsville

March 20–22, 2015
Friday – Sunday
Southeastern Section
Associate secretary: Brian D. Boe
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: August 20, 2014
For abstracts: To be announced

Las Vegas, Nevada

University of Nevada, Las Vegas

April 18–19, 2015
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: September 18, 2014
For abstracts: To be announced

Porto, Portugal

University of Porto

June 11–14, 2015
Thursday – Sunday
First Joint International Meeting involving the American Mathematical Societry (AMS), the European Mathematical Society (EMS), and the Sociedade de Portuguesa Matematica (SPM).
Associate secretary: Georgia M. 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*: Not applicable

Deadlines
For organizers: To be announced
For abstracts: To be announced

Chicago, Illinois

Loyola University Chicago

October 3–4, 2015
Saturday – Sunday
Central Section
Associate secretary: Georgia M. Benkart
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: October 2015
Issue of *Abstracts*: To be announced

Deadlines
For organizers: March 10, 2015
For abstracts: To be announced

Fullerton, California

California State University, Fullerton

October 24–25, 2015
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*: October 2015
Issue of *Abstracts*: To be announced

Deadlines
For organizers: March 27, 2015
For abstracts: To be announced

Seattle, Washington

Washington State Convention Center and the Sheraton Seattle Hotel

January 6–9, 2016

Wednesday – Saturday

Joint Mathematics Meetings, including the 122nd Annual Meeting of the AMS, 99th Annual Meeting of the Mathematical Association of America (MAA), 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 (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: October 2015
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: January 2016
Issue of *Abstracts*: Volume 37, Issue 1

Deadlines

For organizers: April 1, 2015
For abstracts: To be announced

Atlanta, Georgia

Hyatt Regency Atlanta and Marriott Atlanta Marquis

January 4–7, 2017

Wednesday – Saturday

Joint Mathematics Meetings, including the 123rd Annual Meeting of the AMS, 100th 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: Brian D. Boe
Announcement issue of *Notices*: October 2016
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: January 2017
Issue of *Abstracts*: Volume 38, Issue 1

Deadlines

For organizers: April 1, 2016
For abstracts: To be announced

San Diego, California

San Diego Convention Center and San Diego Marriott Hotel and Marina

January 10–13, 2018

Wednesday – Saturday

Joint Mathematics Meetings, including the 124th Annual Meeting of the AMS, 101st Annual Meeting of the Mathematical Association of America (MAA), 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 (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Georgia M. Benkart
Announcement issue of *Notices*: October 2017
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 1, 2017
For abstracts: To be announced

Baltimore, Maryland

Baltimore Convention Center, Hilton Baltimore, and Baltimore Marriott Inner Harbor Hotel

January 16–19, 2019

Wednesday – Saturday

Joint Mathematics Meetings, including the 125th Annual Meeting of the AMS, 102nd Annual Meeting of the Mathematical Association of America (MAA), 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 (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: October 2018
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, 2018
For abstracts: To be announced

Meetings and Conferences of the AMS

Associate Secretaries of the AMS

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.

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Southeastern Section: **Brian D. Boe,** Department of Mathematics, University of Georgia, 220 D W Brooks Drive, Athens, GA 30602-7403, e-mail: brian@math.uga.edu; telephone: 706-542-2547.

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.

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

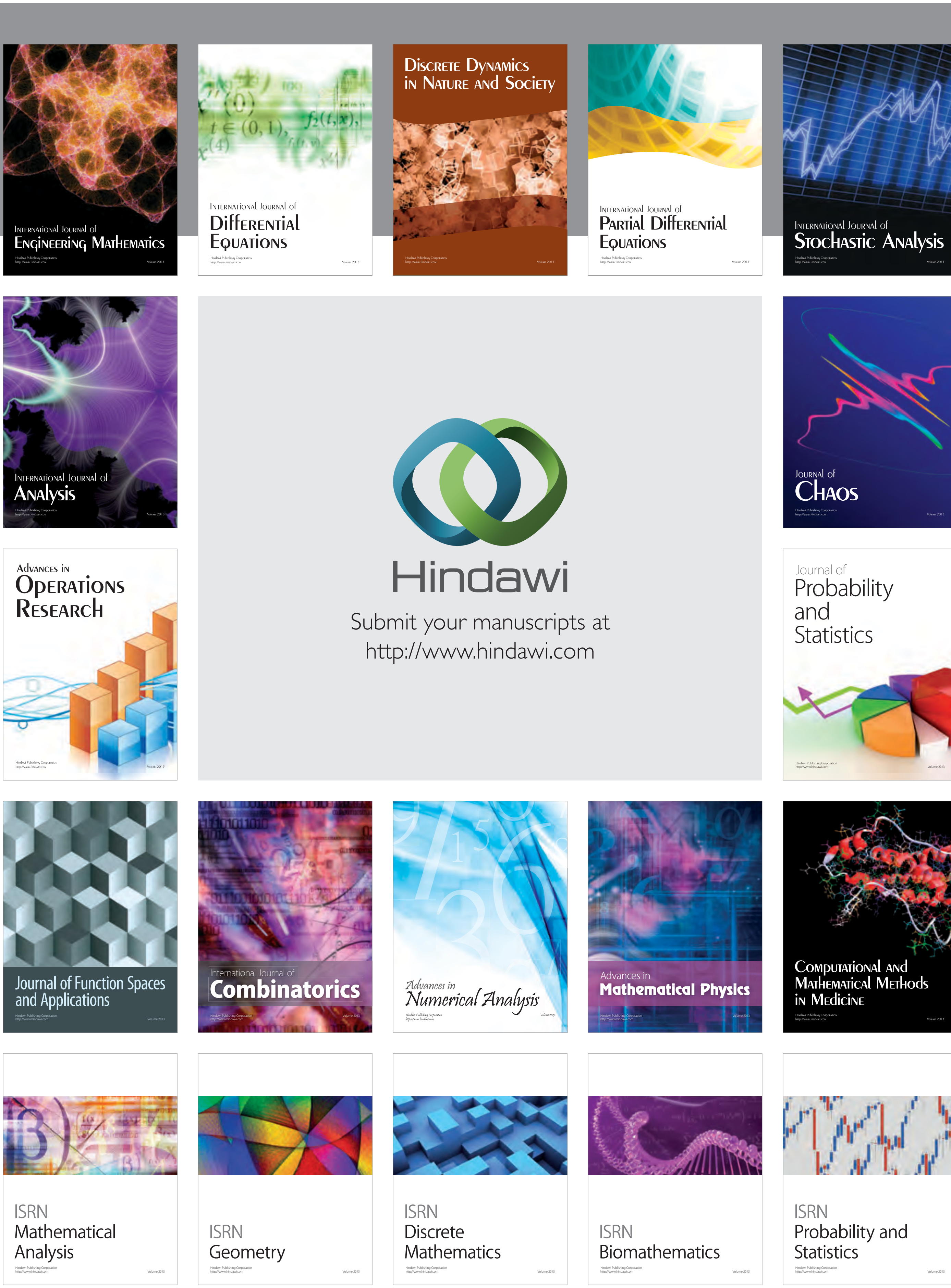
Potential organizers, speakers, and hosts should refer to page 274 in the the February 2013 issue of the *Notices* for general information regarding participation in AMS meetings and conferences.

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 in Cooperation with the AMS: (see http://www.ams.org/meetings/ for the most up-to-date information on these conferences.)

July 22–26, 2013: Samuel Eilenberg Centenary Conference (E100), Warsaw, Poland.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