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Notices

of the American Mathematical Society

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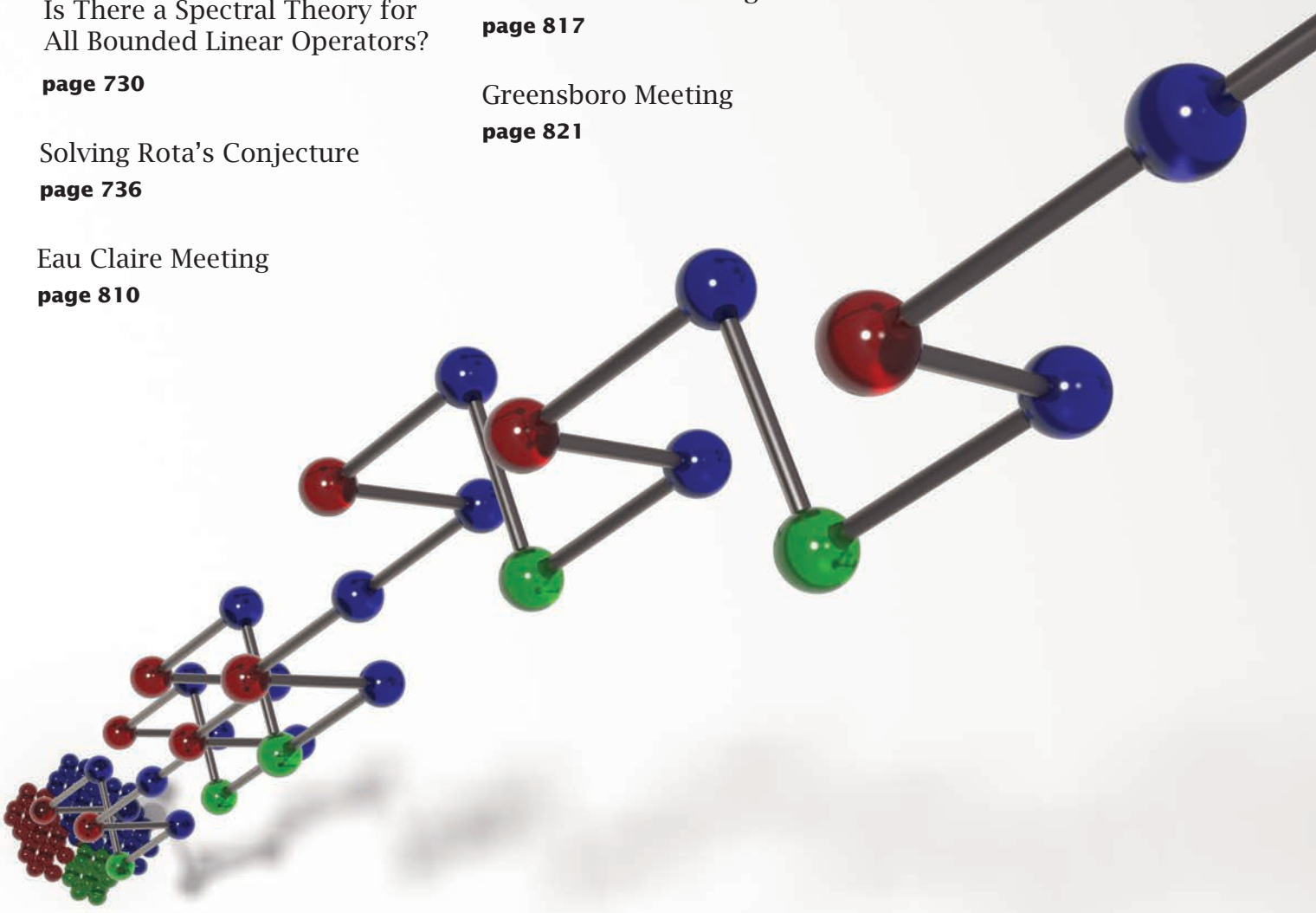

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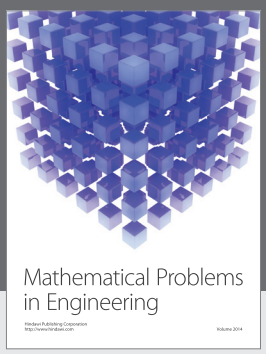

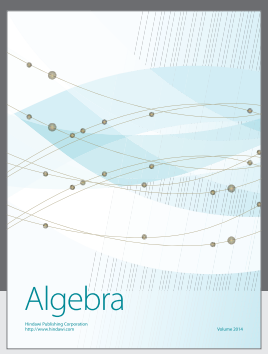

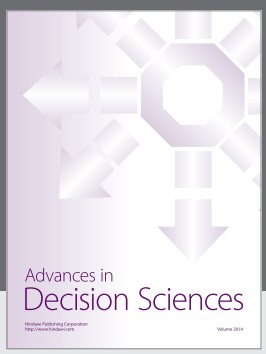

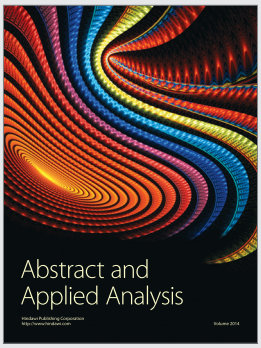

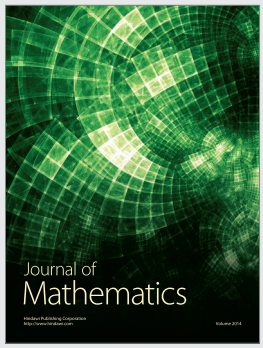

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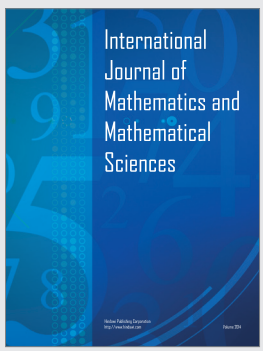

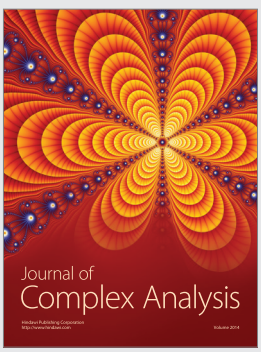

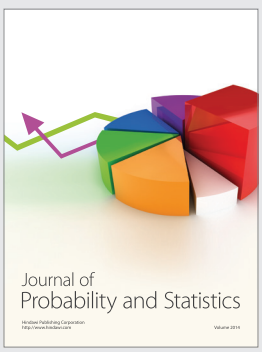

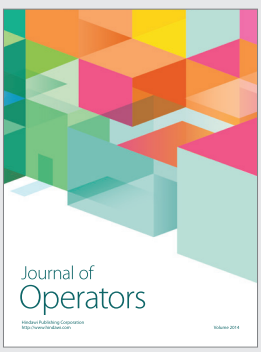

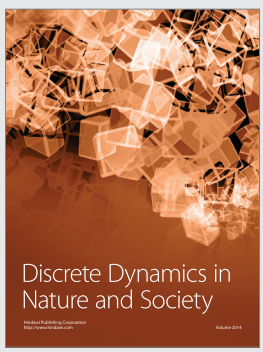

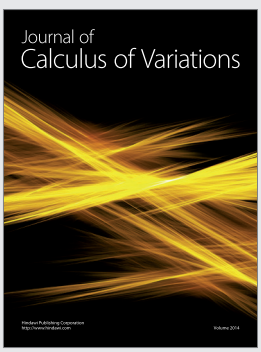

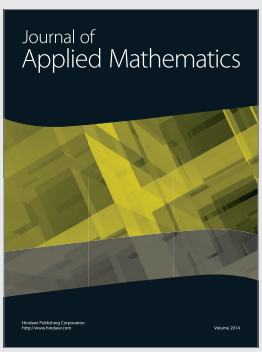

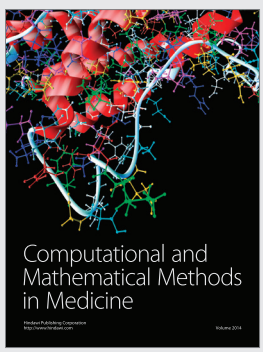

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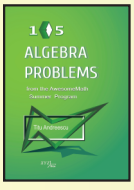

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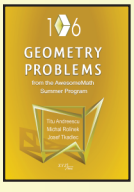

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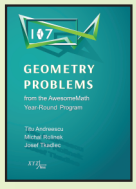

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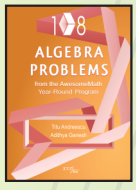

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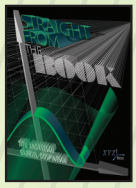

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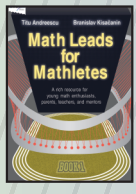

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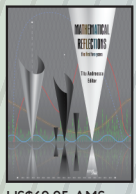

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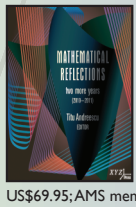

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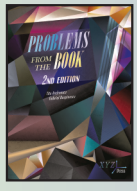

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of the American Mathematical Society

August 2014

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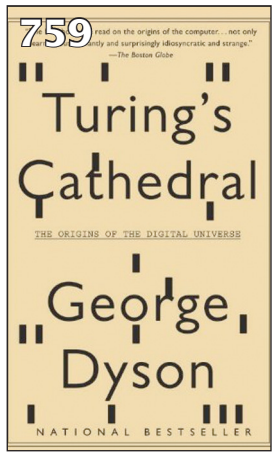

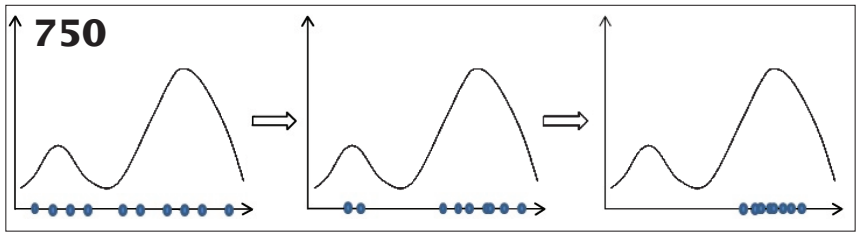

The August issue offers many delights. There is an article about a spectral theory for all bounded linear operators, an article about the new proof of Rota's conjecture regarding a combinatorial characterization of linear dependence in vector spaces, and a memorial article for the important German mathematician Friedrich Hirzebruch. We also offer a *Scripta Manent* about open texts on the Web.

—Steven G. Krantz, Editor

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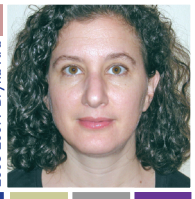
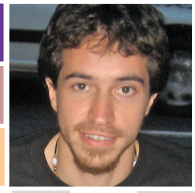


2005-2006: Yuan-Pin Lee

2012-2013: Karin Melnick
Photo by Riza Falk

2010-2011: Joel Bellaiche

2008-2009: Christopher Hoffman



2009-2010: Antonio Montalbán

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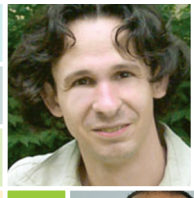

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Mathematics Is a Quest for Truth

The question of how to teach mathematics in primary and secondary education has appeared in newspaper opinion pages regularly during the last few years. The topic is a complicated one and does not allow for easy or simple answers. I am most alarmed, however, by proposals to eliminate abstract mathematical reasoning and subjects such as algebra and Euclidean geometry from the curriculum, presenting math as a collection of formulas and algorithms motivated by their applications to the "real world". Instead, I believe that mathematics should be taught because it is a fundamental human endeavor, an essential part of the search for truth and meaning in our lives.

The notion of truth appears to be in short supply today, despite the overflow of information. We are inundated daily through the news media with ambiguous definitions, unstated premises, and questionable theories about human affairs. Science is certainly not immune to this problem—one need only look a few decades in the past to see how the prevailing orthodoxy in a given field affects the state of the art. Mathematics stands out among human pursuits because its conclusions enjoy a permanency unmatched in other subjects. The mathematical wisdom of ancient times is just as valid today as it was then, and we ignore it at our own peril. On the other hand, mathematicians are typically humble about their own achievements, because they stand in awe before the vastness of what they do not know.

The word "mathematics" comes from the Greek "mathema", which means "lesson". For the ancient Greeks, one was not considered educated without a thorough grasp of mathematics, and famously could not enter into Plato's academy without knowing geometry. This reflects not only mathematics's connections to philosophical thought, but the uncanny way in which it seems to explain, and indeed to govern, the world. But mathematics is not merely a Platonic realm of our imagination, best left to the few that can climb its intellectual heights. The most important reason to provide abstract mathematics to the general population is to teach people to think critically about the world, to question their assumptions, and to illustrate the power of logical deduction. For mathematics is one of the few areas where the boundary between what is known and what is not known is well defined, and where we can always answer the question "why?" about the former.

Whenever one slices through a carrot or a log of wood along a slanted plane, the border of the oval-shaped cross section is a curve called an ellipse. Surprisingly, the paths that the planets trace as they move around the sun are also described by ellipses. This fact was first observed by Kepler, and proved mathematically by Newton, in one of the great triumphs of scientific thought. Nearly two thousand years of inquiry separate these two very different ways of viewing the same curve. Many examples like this show how abstract mathematical constructions stemming from everyday human experience arise in unexpected places and instill within us a sense of wonder at the inner workings of creation.

The most familiar of all mathematical objects are the numbers we use to count; yet even their genealogy is far from simple. The number zero provides a striking example, because it has a traceable history. The ancient Greeks and Romans lacked it, as was made clear during the turn of the millennium: did it occur in 2000 or in 2001? The problem is that there was no year 0 A.D., because there was no Roman numeral zero. Indeed, why does one need a number to count objects which do not exist? The invention (or discovery) of the number zero occurred independently in different parts of the world, but principally in India and Central America—and in both cases, the reason for its introduction was religious. This story indicates that the roots of mathematical thought lie within the deepest recesses of the human mind, where *logos* and *mythos* come together, in search of our very nature.

There are many practical problems that arise when trying to get the above message across to students. However, I am encouraged by two personal convictions: I believe that students are capable of much more than we give them credit for, and that they respond positively to challenges, provided that they are suitably motivated. I am also convinced that there is a thirst for mathematical education, that people are inherently fascinated by the profound beauty and power of the subject, and that a knowledgeable, passionate teacher can do wonders with it.

Mathematics has been called the music of reason, and we do our children a grave disservice if we reduce it to a cacophony of disconnected formulas. Indeed, we risk losing what is perhaps the most precious inheritance of all.

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Letters to the Editor

Where Are the Women?

The April 2014 issue of the *Notices* contains a list of the winners of AMS prizes awarded at the 2014 Joint Mathematics Meetings. While the list represents an impressive group of mathematicians, it is discouraging to note that of the seventeen AMS prize recipients (nineteen if you include the Bergman Prize), not a single one is female.

One can argue that the lack of female prize recipients is simply a reflection of the paucity of women at the higher ranks of top mathematics departments. The two phenomena are surely intertwined and equally depressing. According to an article by Lenore Blum on the founding of the Association for Women in Mathematics, at the 1971 JMM, 100 percent of the invited speakers were male ("A brief history of the Association for Women in Mathematics: The president's perspective", *Notices*, September 1991, pages 738–754). In 2014, we can look back on that statistic in shock. Let's hope it does not take another forty years before we can look back on this year's list of prize winners with equal disbelief.

—*Ruth Charney, President,*
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About the cover

abacabaabacababacabaabacabaca ...

This month's cover was produced by Edmund Harriss, coauthor (with Pierre Arnoux) of the article "WHAT IS... a Rauzy fractal?" in this issue. As the article explains, first of all a string of infinite length is constructed by starting with a, then iterating over and over again substitutions $a \longrightarrow ab$, $b \longrightarrow ac$, $c \longrightarrow a$:

$$a, \quad ab, \quad abac, \quad abacaba \quad \ldots$$

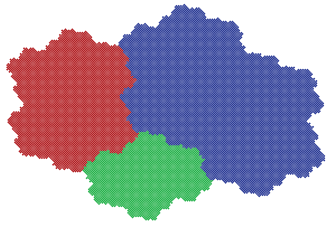
Each of these strings is a prefix in its successor. Then a path in 3D is built from this, starting at the origin and moving according to the rules

$$a = (1,0,0), \qquad b = (0,0,1), \qquad c = (0,1,0).$$

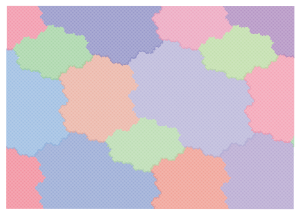
Next, the endpoints of the path segments are projected onto the plane $x + y + z = 1$, and the point (x,y) is plotted, with colors according to the direction of the segment:

abacabaabacababacabaabacabacabaabacababacaba ...

As was first discovered by the late Gérard Rauzy, the closure of these projections give us a remarkable figure:



Each component of the figure is obtained by applying some powers of a certain affine transformation to itself, and integral translations of the figure tile the plane:



The nodes of the path cluster around the line with direction $(1, \zeta, \zeta^2)$, where $\zeta = 1/\theta$, and θ equal to the largest root of the Pisot polynomial

$$x^3 - x^2 - x - 1 = 0.$$

Phenomena occurring are related to diophantine approximations of ζ. As Arnoux and Harriss explain, some aspects of such figures are still quite mysterious.

Harriss tells us that he used the commercial 3D imaging software *Rhinoceros*, *Grasshopper*, and *Thearender* to produce the cover image.

He adds, "Since Rauzy's time a lot of the work in this area has focused on the things that are easier to generalize—in particular, an approach from dynamical systems derived from letter substitution rules. In this case we want to know if the Rauzy fractal gives a domain exchange map (a 2D version of an interval exchange map). Also, as domain exchange maps are invertible almost everywhere, the sequence can be generated in the other direction as well, creating a sequence without beginning or end. The question of when the projection of points in this manner gives a domain exchange map is closely tied to nontrivially equivalent questions in combinatorics and number theory. An affirmative answer is one of the many consequences of the Pisot Conjecture."

—*Bill Casselman, Graphics Editor*
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Friedrich Hirzebruch (1927–2012)

Michael Atiyah and Don Zagier, Coordinating Editors

Friedrich Hirzebruch (universally known as Fritz) died on May 27, 2012, at the age of eighty-four. He was the outstanding German mathematician of the postwar years who helped to restore mathematics in his country after the devastation of the Nazi era. Appointed at a very early age to a full professorship at the University of Bonn, he remained there for the rest of his very active life and moved the center of gravity of German mathematics from the traditional centers of Göttingen and Berlin to Bonn. The famous *"Arbeitstagungs"* (more properly *Arbeitstagungen*), which he established in Bonn in 1957, have been running annually or biannually ever since and are a focal point of mathematics worldwide. They carried his personal imprint in their content, attendance, and style, being always broad, topical, and informal and doing much to educate succeeding generations and to foster cross-fertilization. Many new ideas and collaborations grew out of these encounters. Another lasting contribution to mathematical research in Germany and in the world is the Max Planck Institute for Mathematics, which he founded, operating on the same lines and creating bonds between mathematicians from many countries, including those that were otherwise cut off from the international scene.

Although Fritz, given his multiple roles, retired several times, he remained active till the very end and was preparing to attend a conference in his honor in Poland when he was struck down.

In this introduction we will give an overview of Fritz's life and of some of his most important achievements. More detailed accounts will then follow in the individual articles by the two coordinating editors, with the one by Atiyah concentrating on the work in topology and the years before 1970, and the one by Zagier on the work in number theory and the years after 1970. The subsequent articles by the invited contributors describe further aspects of his personality, his scientific work, and the role that he played in the mathematical lives of many individuals, organizations, and countries.

* * *

Friedrich Hirzebruch in 2006 at the Max Planck Institute.

Friedrich Ernst Peter Hirzebruch was born on October 17, 1927, in Hamm, Germany, to Dr. Fritz Hirzebruch and Martha Hirzebruch (née Holtschmit). His father, who was the headmaster of a secondary school and himself an inspiring teacher of mathematics, gave him his first introduction to

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the subject—including, when he was nine years old, the proof that $\sqrt{2}$ is irrational—and the love of it that was to last throughout his life.

Still a teenager, Fritz was drafted into the German army during the final year of World War II, but his military career was mercifully short and he was never sent into combat, being assigned instead to an antiaircraft battery with the task of computing artillery trajectories. He was even able to attend some scientific courses, though when his commanding officer asked him on one such occasion to confirm that winter and summer are caused by the earth's varying distance to the sun and Fritz dared to contradict him, pointing out that then the seasons in Germany and Australia would coincide, he was punished for insubordination. In the final months of the war the Americans put him into a prisoner of war camp, and even there he managed to do mathematics (partly on toilet paper, still preserved today). He was released in July 1945 and entered Münster University that winter.

The city and the university lay in ruins and conditions were very difficult, with lectures being held only at long intervals, but he had very good teachers, especially Heinrich Behnke, from whom he learned the function theory of several complex variables, and Behnke's assistant, Karl Stein, a former pupil of his father's. His third teacher was Heinz Hopf, a German who had gone to Switzerland before the Nazi takeover and who invited the young Fritz, first to be his house guest and then for one and a half years to be a research student at the ETH in Zürich. Fritz returned to Münster with the essentials of a beautiful doctoral thesis about the resolution of certain singularities in complex surfaces. Already this earliest work showed the characteristics of all of his mathematics: elegance and brevity of thought and exposition, an effortless synthesis of sophisticated theoretical ideas with insights inspired by nontrivial concrete examples, and the fusion of ideas from analysis, topology, and number theory.

In 1952 came the development that was not only to be a turning point in Fritz's mathematical career but, as it transpired, to have a major influence on the later development of mathematics in Germany and in Europe: he was invited to the IAS in Princeton, where he remained for two years. At the IAS, he came into contact with many of the most brilliant mathematicians and most exciting new ideas of the period and where he made the two discoveries with which his name is most strongly associated: the Signature Theorem and the Hirzebruch-Riemann-Roch Theorem. Those years and also the early years in Bonn, when the core of Fritz's research was still in topology and its applications to algebraic geometry, will be discussed in detail in the contribution by Michael Atiyah.

Friedrich Hirzebruch ca. 1985 in Bonn.

This period also included three major events in Fritz's personal life: his marriage to Inge Spitzley in August 1952 just before taking the boat to Princeton, and the birth of his first two children, Ulrike (1953) and Barbara (1956). His third child, Michael, was born a little later, in 1958. Inge, known to and loved by countless mathematicians, was a big part of everything he built up during his life. Both of his daughters later studied mathematics and eventually worked in related areas (Ulrike in mathematical publishing and Barbara as a schoolteacher), while Michael was to become a doctor. Ulrike's contribution to this article gives us a vivid picture of Fritz as a father.

When Fritz returned to Germany in 1956 to take up his duties at his new chair in Bonn, he had a clear ambition and a mission: to establish a center that would attract mathematicians from all over the world. After the First World War, German mathematics had been ostracized by the international community, led by France. This lasted for many years and embittered relations. Fortunately, the 1945 generation of French mathematicians, led by Henri Cartan, was more enlightened, and prewar mathematical friendships were rapidly renewed. The Münster school members under Heinrich Behnke were welcomed back into the field by Cartan, while Fritz, part of the Behnke team,

Karl Stein, Reinhold Remmert, Friedrich Hirzebruch, and Henri Cartan in the 1950s.

Friedrich Hirzebruch with Gerd Faltings in the MPIM Library ca. 2000.

played a full role in this rapprochement. So with his Princeton contacts, including Kodaira from Japan and the new talent emerging from Paris (Serre, Borel, Grothendieck, …), Fritz was well placed to reintegrate German mathematics into the world community. Contacts with Britain came initially via the Cambridge geometry school of Hodge and Todd and later the younger generation (Atiyah, Adams, Wall, …). The division of Germany and, more generally, the cold war partition of Europe were particularly challenging, but Fritz spent many years of his life forging links between East and West, including notably the German Democratic Republic and the Soviet Union.

He achieved his goals remarkably quickly. At Bonn University he built up the mathematics department to a high level, doubling the number of full professors and attracting people such as Klingenberg, Tits, Brieskorn, and Harder. The *Arbeitstagung*, which he established in 1957, soon served as a worldwide meeting point and attracted many who would never otherwise have returned to Germany. But Fritz's main goal stemmed from his experience in Princeton: to set up a visitors' center modeled after the IAS. A first attempt to create this as a Max Planck Institute failed because of the opinions of various referees (including Courant and Siegel) that, at least at that time, there were better ways to use both Fritz's talents and the taxpayers' money to further mathematical research in Germany. But some ten years later, when the German Research Council (DFG) set up a new research program for German universities whose units (called *Sonderforschungsbereich* or "Special Research Domains", abbreviated SFB) would be supported for a limited period of time, Fritz presented his ideas of a visitor center to the decision committee and came back with two SFBs: one (SFB 40, with himself as *Sprecher* or chairman) for theoretical mathematics and one (SFB 72, with Rolf Leis and Stefan Hildebrandt) in a more applied direction. With his Sonderforschungsbereich, he started the envisaged visitor program on a limited basis. This turned out to be so successful that when the support ended and Fritz applied for a takeover from the Max Planck Society, his project no longer met with the former reservations, and a permanent Max Planck Institute for Mathematics was founded in Bonn in 1981 and has been flourishing ever since. Through the Arbeitstagung, the Sonderforschungsbereich, and finally the Max Planck Institute, Fritz created an extensive visitor program that he guided with his many outstanding qualities: his personal tastes in mathematics were broad and generous—he was no narrow specialist; his international contacts were extensive; his efficiency became legendary; and above all, he encouraged an informal and friendly atmosphere, far removed from the traditional rigidity of German academia.

After about 1970 the main thrust of Fritz's mathematical work slowly moved from pure topology and algebraic geometry to the connections of these domains with number theory. They will be discussed in more detail in the contribution by Don Zagier. During these years he also became more and more active and influential in the development of mathematics, both nationally and internationally. These activities, which will be described in more detail later, included most notably his unflagging efforts to build up relations with the countries of the Eastern Bloc, his many contributions to rehabilitating Germany's image after the years of the Third Reich and to creating new scientific and human bonds with Israel, his two presidencies of the German Mathematical Union, and his roles as first president of the European Mathematical Society (described by Bourguignon) and as honorary president of the International Congress of Mathematicians in Berlin in 1998.

During all the years before the Iron Curtain fell, Fritz indefatigably kept up contacts with mathematicians in the Eastern Bloc, no matter how much effort this required and how unavailing it seemed. Russian mathematicians were always invited to the Arbeitstagung, though only once—perhaps because of an oversight by the Russian bureaucracy?—were some of them allowed to come: in 1967, Anosov, Manin, Postnikov, Shafarevich, and Venkov took part, and all of them gave a talk. But these efforts were not in vain, because, as we learned later, the yearly invitations to come to Germany, even when they had to remain unanswered, often helped their recipients by demonstrating to the authorities their visibility in the West. Fritz himself was seen quite positively by those same authorities and in 1988 was elected as a foreign member of the Academy of Sciences of the USSR. After 1990, of course, many more

possibilities of exchange opened up, and the MPIM today is never without some Russian conversation in its corridors. Another Eastern country that he became deeply involved with was Poland. His contributions here, in particular in connection with the Stefan Banach International Mathematical Center in Warsaw, are recounted by Stanisław Janeczko.

By a coincidence that seemed willed by fate, Fritz was elected twice to the presidency of the DMV (German Mathematical Society) at key moments in the history of postwar Germany and postwar German mathematicians: in 1961 when the Berlin Wall was built, and again in 1989–90 when it fell. The separation of Germany into two blocks fell in the middle of his first term, and he solved the problem of the inability of the East German mathematicians to cross into West Berlin by repeating in its entirety the first DMV meeting that he chaired after the separation. But of course such makeshift measures could not last, and soon the DMV was split into a new East German branch (MGDDR = Mathematische Gesellschaft der DDR) that for almost three decades was no longer officially connected with the West German one. When the political world changed again and the two halves of Germany were reunited, Fritz was able to preside over the reunification also of the Mathematiker-Vereinigung and to ensure that the transition took place in a spirit of reconstruction rather than of recrimination or retaliation.

For several years after the wall fell, he traveled nearly every week to Berlin, where he had the task of helping the nearly two hundred mathematicians of the previous Karl Weierstrass Institute of the East German Academy of Science to find new positions. The individual cases were very dissimilar, and the solutions he came up with were varied. The cases where no adequate solution could be found haunted him, and he sometimes spoke to his friends at the institute of the sorrow he felt, but in the vast majority of cases provisional or permanent positions could be set up, whether in temporary Max Planck Working Groups, in permanent new institutes that he helped establish, or in schools or universities in Germany or abroad. His contacts with the GDR during its years of isolation and the respect in which he was held on both sides of the previous dividing line made him effective in this role in a way that no one else could have been, and his achievements, though little known to outsiders, were received with enormous gratitude by the people involved.

Of the many other countries with which Fritz built up or maintained intensive contacts, two must be mentioned individually. One is Japan, which Fritz visited many times, starting in 1972, and from which a huge number of visitors came, first to the Sonderforschungsbereich and later to the Max Planck Institute, at a period when the possibilities of scientific interchange between Japan and Europe were still severely limited. His contributions are described in detail by Kenji Ueno. The other is Israel, which is dealt with by Mina Teicher. Fritz almost never mentioned overtly, but very clearly also never forgot, what Germany had done in the years of the Third Reich, and a leitmotif of much of what he did in his life was to help reestablish an image of the country that would be characterized by decency and tolerance.

Not surprisingly, Fritz was showered with many distinctions of every imaginable kind. His first half dozen honorary doctorates came roughly at the same times and with the same frequency as his grandchildren, and he used to make jokes about this ongoing race, but with only three children, the competition was an unequal one and the doctorates finally won 15:6. He was a full or associate member of more than twenty academies, in several of which he was scientifically active, and also of the order "Pour le Mérite", which has as its members Germany's most distinguished scientists, writers, and artists and to which he was particularly attached. Among the many prizes that he received the most notable were the Japanese Seki Prize, usually given to institutions and which he received for his role in developing the contact between Japanese and non-Japanese mathematicians; the Lobachevsky Prize and the Lomonosov Medal from the USSR; the Polish Stefan Banach Medal; the German Krupp Prize and Georg Cantor Medal; and, most important of all, the Israeli Wolf Prize, which he received in 1998 and which, quite apart from its immense prestige, had a huge symbolic significance. At one point the honors were arriving so thick and fast that his secretary once famously remarked, after checking his morning's mail, "Wir haben heute keine Ehrungen bekommen!" ("We didn't get any honors today!")

That "we" somehow characterizes in two letters what was so exceptional about Fritz and the way he made those around him feel. We hope that the articles collected here will convey to those who did not know him some feeling for this extraordinary personality.

The Hirzebruch signature dish being admired by Lily Atiyah and Fritz, Edinburgh, 2010.

Michael Atiyah

Fritz Hirzebruch played a major part in my life, particularly over the early formative period. He became a close personal friend, a long-term collaborator, and, through the Arbeitstagung, my introduction to the mathematical world. I learned a good deal from him on how to write papers, how to present talks, and, most importantly, how to handle people. In short, he was an ideal role model.

I first met Fritz in 1954 when I was a young graduate student and he visited Cambridge at the invitation of Hodge, my supervisor. Hodge and Todd had been much impressed by what Fritz had been doing at Princeton and were keen to be briefed on the Riemann-Roch Theorem and Chern classes. What I remember about the occasion is how friendly and informal Fritz was. Although he was already an assistant professor at Princeton and I was merely a graduate student, there were no barriers between us, and we quickly established a friendship which blossomed over the subsequent years. We met again at the Amsterdam ICM of 1954 and then, for a longer period, when I went on a postdoctoral fellowship to the Institute for Advanced Study in Princeton.

The Princeton Years

Those Princeton years were, for me, for Fritz, and for many others the "golden years". Algebraic geometry and topology were being transformed by the new ideas of the French School. Sheaves and spectral sequences from Leray combined with complex analysis by Henri Cartan produced powerful machinery to tackle classical problems. This was taken up by Kodaira and Spencer, while Serre burst on the scene with spectacular applications to both algebraic topology and algebraic geometry. When I arrived in September 1955, brilliant young mathematicians were absorbing the new ideas and carving out new routes for the future. I remember in particular the gang who regularly attended Kodaira's lectures: Fritz, Serre, Bott, Singer.

This had been for Fritz the experience that transformed him from a promising novice to a world figure capable of competing with the greatest talents of the time. Within a short period of time he came up with two great triumphs. Both were based on the innovative way of associating multiplicative classes to formal power series in one variable. First there was his formula

$$\mathrm{Sign}(M) = \int_M \mathcal{L}(M) = \int_M \prod_{i=1}^{n} \frac{x_i}{\tanh x_i},$$

$$\text{where (formally)} \quad p(M) = \prod_{i=1}^{n} (1 + x_i^2)$$

for the signature of a $4n$-dimensional manifold in terms of the Pontrjagin classes $p_j(M)$. This was a beautiful application of Thom's new cobordism theory. But Fritz's second triumph, his generalization (now known as "HRR" or Hirzebruch-Riemann-Roch)

$$\chi(X, V) = \int_X \mathrm{ch}(V)\,\mathrm{Td}(X)$$

of the Riemann-Roch Theorem, was even more impressive. Here $\chi(X, V) = \sigma$ (from $q = 1$ to $q = m$) of $(-1)^q \dim H^q(X, V)$ is the holomorphic Euler characteristic $\sum_{q=0}^{m} \dim H^q(X, V)$ of the sheaf cohomology groups of a holomorphic vector bundle V (of dimension d) over a complex projective algebraic manifold X of dimension m. The Chern character is defined in terms of the total Chern class $c(V)$ by

$$\mathrm{ch}(V) = \sum_{i=1}^{d} e^{x_i},$$

$$\text{where (formally)} \quad c(V) = \prod_{i=1}^{d} (1 + x_i),$$

and the Todd class $Td(X)$ is defined similarly in terms of the total Chern class $c(X)$ of the tangent bundle of X by

$$\mathrm{Td}(X) = \prod_{j=1}^{m} \frac{y_j}{1 - e^{-y_j}},$$

$$\text{where (formally)} \quad c(X) = \prod_{j=1}^{m} (1 + y_j).$$

Of course HRR built on fundamental work by Kodaira, Spencer, and Serre, but the proof was a tour de force that had the hallmark of Fritz's own mathematical style.

Characteristic classes had been developing for many years, from the algebraic geometry of the Italian School through significant advances by Todd and the later topological approach of Steenrod and Chern. But all this emphasized their geometrical origin and significance. It was Fritz, in collaboration with Borel, who took the dual route of cohomology and, connecting it to the theory of Lie groups, gave Chern classes their formal algebraic setting, which has now become standard. With his command of this algebra and with his insight into the right algebraic framework, Fritz had developed his theory of multiplicative sequences, which provided the right tools to tame the horrendous-looking formulae.

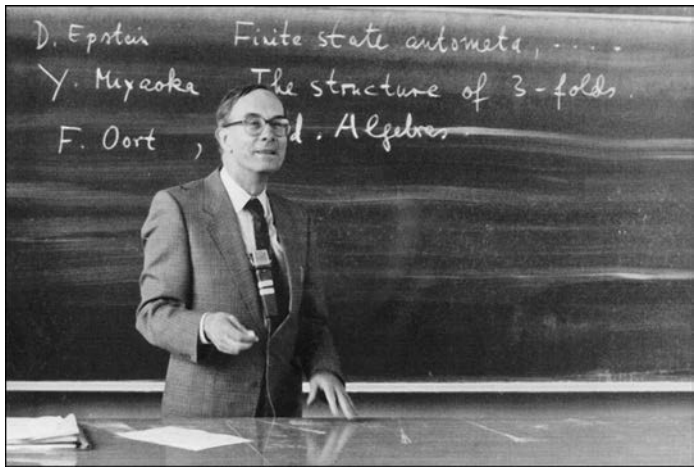
When Todd, no slouch at algebraic computations, had computed the first half dozen "Todd polynomials", it had been a matter of brute force. In the hands of Fritz as "magician" the calculations became elegant and transparent. After seeing this, Todd remarked that he now had to reverse the earlier view he had held of the "Princeton School" that, while they might be good at general theory, they were not adept at calculations. The old maestro conceded defeat to the young contender.

It was fortunate for the new generation like me, eager to learn about the great advances in algebraic geometry, that Fritz was also a brilliant expositor. His book *Neue Topologische Methoden in der Algebraischen Geometrie* (Springer, 1956) gave an impeccably clear account of sheaf theory, Chern classes, and all the new machinery that culminated in the Hirzebruch-Riemann-Roch Theorem. The book and its subsequent English edition *Topological Methods in Algebraic Geometry* (with appendices by R. L. E. Schwarzenberger, one of my early students) has remained the standard work for over fifty years.

The Early Arbeitstagungs

When Fritz returned to Germany as a full professor at the University of Bonn, a new day dawned for German mathematics. With his enthusiasm, ability, efficiency and drive, Fritz soon transformed Bonn into a major center of the mathematical world. Modelled on Princeton, it aimed to introduce into Europe the features that had so attracted Fritz and others across the Atlantic.

Because of the friendship I had forged with Fritz in Princeton and because of the proximity of Cambridge to Bonn, I was fortunate to have been invited to the very first of the annual meetings that became the famous Arbeitstagung. I went on attending these meetings for almost thirty years. It became an obligatory part of the academic calendar where new results were announced, many famous mathematicians regularly attended, and the whole event was under the careful but loving care of the "maestro". Fritz's talents were fully exploited, but not exposed, in these annual gatherings. With their relaxed atmosphere, the Rhine cruises and the skillful selection of speakers by what has been described as "guided democracy", the Arbeitstagungs were unique. Happy family gatherings they may have been, but much serious mathematics was always being presented and fostered. Ideas flowed, collaborations emerged, and successive years reflected the latest movements.

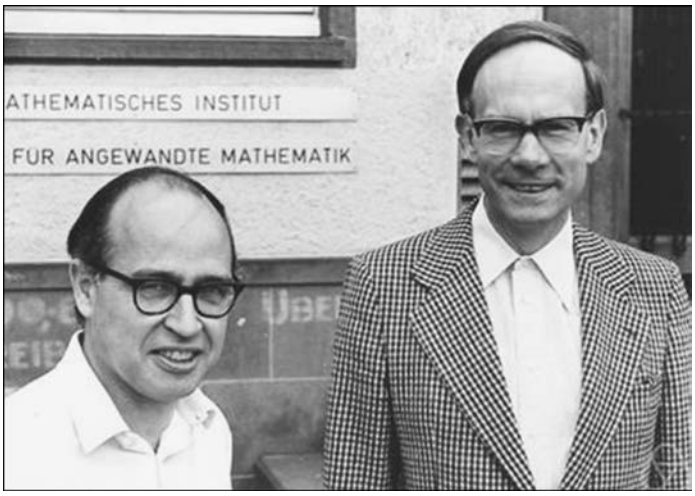


Program discussion at the Arbeitstagung, 1987.

Moreover, as the years passed, Fritz was always keen to attract new talent, and he encouraged me to send promising graduate students to attend. I was happy to respond, and, over the years, my students were introduced to the international scene through the Arbeitstagung. Graeme Segal, Nigel Hitchin, Simon Donaldson, Frances Kirwan, and many others came and became, in their turn, regular participants.

But if the entire series of Arbeitstagungs became highpoints of the academic calendar, the initial one (in 1957) on a very modest scale was particularly noteworthy for launching Grothendieck. He had just developed his brilliant new approach to the Hirzebruch-Riemann-Roch Theorem, based on K-theory. I remember him lecturing for many hours on his ideas. In fact he seemed almost to monopolize the timetable, but the novelty and importance of his work fully justified the time devoted to it. The fact that the program was sufficiently generous and flexible to allow this to happen was an early indication of the way Fritz wanted the Arbeitstagungs to work. No set plans, and full steam ahead for novel and exciting mathematics.

Grothendieck's explosive entry on the scene was a hard act to follow, but the Arbeitstagungs in those early years saw a succession of new and exciting results, including Milnor's discovery of exotic spheres and their subsequent realization



Michael Atiyah and Friedrich Hirzebruch in front of Mathematisches Institut Bonn, 1977.

by Brieskorn (a student of Fritz) via isolated singularities of algebraic varieties (a study initiated by Fritz). In fact, so many new ideas filled the Arbeitstagung air that most of my own work (and probably that of many others) emerged from this background. We learned many new things from disparate fields, and cross-fertilization became the norm. I will elaborate on this in the next section.

My Collaboration with Fritz

In the three years 1959 to 1962 Fritz and I wrote eight joint papers, all concerned with topological K-theory and its applications. This had emerged naturally from the early Arbeitstagungs and in particular from Grothendieck's K-theory in algebraic geometry, as expounded in the very first Arbeitstagung. But there were many other ingredients in the background, notably the Bott periodicity theorem.

Topological K-theory was mainly developed by Fritz and me in 1959 when we both had a sabbatical term at the IAS in Princeton. A preliminary account appears in [1], and we planned to write an expanded version in book form. In fact, we never had time for this project, but a book [4] did eventually appear under my name based on a Harvard course of lectures.

These joint papers are a mixture of general theory and concrete problems. For example, [3] showed that the famous Hodge conjectures were false for integer cohomology (still leaving the case of rational cohomology as one of the Clay Institute Millennium Prize problems). Other papers were related to some of Fritz's earlier Princeton period, such as his discovery of a relation between Steenrod squares and the Todd polynomials [2]. Some of our joint papers appeared in German (written by Fritz), while others appeared in English (written by either of us), but one appeared in French (written by neither of us!). That one gave bounds on the smallest dimension in which various manifolds could be embedded. While a primitive version was an idea of mine, the final very polished version was an exquisite illustration of Fritz's elegance with algebraic formulae. But my mathematical interaction with Fritz extended far beyond these joint publications and the three years they cover. Much of my work was influenced in one way or another by Fritz, and a later publication [5] is one of my favorites. Here we proved that a spin manifold that admits a nontrivial circle action has vanishing $\hat{A}$-genus. This emerged as a new application of index theory, which first appeared in the Arbeitstagung program of 1962. Fritz took great interest in the development of index theory, which owes so much to his pioneering work.

While our later mathematical paths may appear to have diverged, this is only superficially true. We met frequently in Bonn and elsewhere, and we followed each other's work with great interest. One notable example is Fritz's beautiful results on the resolution of the cusp singularities of Hilbert modular surfaces (as explained by Don Zagier). His key result gave the signature defect of such a cusp singularity as the value of a suitable L-function of the number field. He then conjectured that this result would continue to hold in higher dimensions for arbitrary real number fields. This was one of the main sources of inspiration that eventually led to the index theorem for manifolds with boundary [6] and its application [7] to prove Fritz's conjecture.

Fritz also followed with great interest the exciting interaction between geometry and physics of recent decades. He organized several meetings of mathematicians and physicists (in Bad Honnef in 1980 and in Schloss Ringberg in 1988, 1989, and 1993). He also extended [8] the work of Witten and others on the elliptic genus, a subject close to his heart.

Final Comments

I knew Fritz and was a close friend for nearly sixty years. We were mathematical brothers and shared a common love of geometry in the broadest sense. We had very similar tastes, even if I could never match Fritz's algebraic virtuosity. I was a great admirer of his lecturing style, and, with my limited German, I found he was the only German lecturer I could understand. He was also a magician who carefully crafted his lecture so as to produce a surprise at the end. Alluding to this skill of his, I once said that "rabbits do not appear out of hats unless they are put there!"

A close mathematical partnership leads to a close personal friendship and also evolves from it. This extends to families on both sides. Lily and I got

to know Fritz and Inge in Princeton when we both had small children, and we have remained close friends ever since, meeting occasionally in Bonn, Oxford, Edinburgh, Barcelona, and elsewhere. In Bonn, at all the Arbeitstagungs, Inge was always a welcoming hostess, and the friendly atmosphere of the Hirzebruch family was an important ingredient in the success of both the Arbeitstagungs and the MPI.

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Don Zagier

Entering Fritz's Orbit

My first meeting with Fritz Hirzebruch was a never-to-be-forgotten moment in my life (not least because I also met Egbert Brieskorn and Silke Suter, my future wife, on the same day). It was May 1970 and I was not yet nineteen. I had been a precocious but incompetent topology graduate student in Oxford for two years, the first under the supervision of Michael Atiyah, who tried to teach me the basics I should have learned as an undergraduate, and the second with no real supervision, because Atiyah had left for Princeton in 1969. I had been studying Professor Hirzebruch's books and papers on applications of the signature theorem to constructing exotic spheres and the like and had found some amusing formulas relating these to cotangent sums and other elementary number theory, which I had sent to him, inquiring on the same occasion about the possibility of coming to Bonn to complete my D.Phil. studies under his supervision (an idea supported by Atiyah). He had responded with an invitation for a short visit to meet both him and Professor Brieskorn,

Thirty-two years later at the eightieth birthday of Sir Michael Atiyah, Edinburgh, April 20–22, 2009.

who would be in Bonn for a few days, and now received me with all the friendliness and interest in my work that he would have shown if I had been an established mathematician and which as a beginner I had certainly not expected.

That first meeting lasted several hours (in the evening Hirzebruch had to go home, but Brieskorn invited me to a Chinese restaurant to continue the discussion) and resulted in new research projects for me and invitations to come to Bonn a month later for my first Arbeitstagung (also memorable!) and again in the fall as Hirzebruch's doctoral student. (I remained immatriculated in Oxford, and Hirzebruch received a salary of £5 a year for his work.) As my advisor, he met me frequently, listened to my reports with great attention, and made such minimalistic comments that I always felt the new ideas that emerged were my own, although I did sometimes wonder why everything was working out so much better than it ever had before.

My actual thesis was on a somewhat different subject from the cotangent sums that had provided the initial contact with Hirzebruch, but during the two years that I spent in Bonn as his student and *Studentische Hilfskraft*, we also had many more discussions about those things, and he gave a course on the subject which turned into our joint book [2] on relations between index theorems and elementary number theory. One of the topics treated in that book, the calculation of invariants of torus bundles over the circle, was to lead him later to his beautiful discoveries, discussed below, on the geometry of Hilbert modular surfaces. Some of this work and of Hirzebruch's own work in this area is beautifully told in his article [1], whose introduction ends with the words

> In the second half of this lecture we shall point out some rather elementary

Silke Suter, Friedrich Hirzebruch, and Don Zagier, 1982 in Bonn at the MPI.

> connections to number theory obtained by studying the equivariant signature theorem for four-dimensional manifolds. Perhaps these connections still belong to recreational mathematics because no deeper explanation, for example of the occurrence of Dedekind sums both in the theory of modular forms and in the study of four-dimensional manifolds, is known. As a theme (familiar to most topologists) under the general title "Prospects of mathematics" we propose "More and more number theory in topology."

As we will see, these last words were to be prophetic in his own case.

I had intended to come to Bonn only for the time needed to complete my thesis, but ended up staying there for my whole life. This development, which I could never have imagined (not only because I knew no German when I came and had no relationship with the country, but also because I am half Jewish and much of my father's family had perished in the concentration camps), was due exclusively to Hirzebruch's tremendous personality and to the atmosphere that he created. In the first period after my thesis, I began working more and more intensively with him, first on cotangent sum-related topics and then on Hilbert modular surfaces. Part of this collaboration took place on long train trips to Zürich, where he was giving a course on the latter subject and where I regularly accompanied him because it was the only chance to get him to myself for long periods at a time. In the evenings we often ate together at the elegant *Zunfthäuser* (guild halls turned into restaurants) of Zürich, gradually becoming better friends and increasing our alcohol consumption from a modest single glass each at the beginning to a full bottle. On one occasion this was increased to one and a half bottles, and Professor Hirzebruch formally proposed the use of "Du" and first names. Henceforth he was always "Fritz" to me, and so he shall remain for the rest of this article. During these years I also got to know his family well, and this too made Bonn become a true home. His daughters, Barbara and Ulrike, also attended my course on elementary number theory. Both had real mathematical talent, but in the end neither one opted for a research career, though Ulrike wrote a master's thesis on elliptic surfaces with three exceptional fibers that is still quoted regularly today.

Fritz's Work in Number Theory

Fritz had already done earlier work that is important in the theory of algebraic and arithmetic groups, most notably his fundamental papers with Armand Borel about homogeneous spaces (in particular, the determination of their characteristic classes) and his proportionality principle, which has proved enormously important in the theory of automorphic forms. But starting around 1970 his interest in the relations between topology and number theory became much more intense and led to what one might call a second spring in his mathematical research career. The high point of this was his work on Hilbert modular surfaces, which I now briefly describe.

In the classical theory of modular forms a crucial role is played by the modular curve $\mathfrak{H}/\mathrm{SL}(2,\mathbb{Z})$ ($\mathfrak{H}$ = complex upper half-plane) and its cousins. The higher-dimensional generalization of this curve is the Hilbert modular variety $\mathfrak{H}^n/\mathrm{SL}(2,\mathcal{O}_K)$ associated to a totally real number field K. Here $\mathcal{O}_K$ is the ring of integers of K and $\mathrm{SL}(2,\mathcal{O}_K)$ is the Hilbert modular group, embedded into $\mathrm{SL}(2,\mathbb{R})^n$ by the n different real embeddings of K and hence acting naturally (and discretely) on $\mathfrak{H}^n$. This variety can be compactified by adding "cusps" to give a projective algebraic variety X_K, but these cusps are highly singular points, with the boundary of a small neighborhood of each cusp being a T^n-bundle over T^{n-1} rather than a $(2n-1)$-dimensional sphere. In particular, for $n = 2$ these neighborhood boundaries are precisely the torus bundles over a circle that Fritz had already been studying in connection with the equivariant index theorem, and it was this that led him to the study of Hilbert modular surfaces.

He set himself three main goals:

(i) to describe the geometry of X_K and calculate its numerical invariants,

(ii) to give for $n = 2$ the resolution of the singularities at the cusps, and

(iii) to apply this to the classification of X_K in the sense of the theory of algebraic surfaces.

He achieved these goals in a series of papers published between 1970 and 1980, partially in collaboration with A. van de Ven and me in the case of part (iii). Each part was mathematics of the highest order. The calculations of the numerical invariants involved deep results from both differential geometry and number theory, including Günter Harder's extension of the classical Gauss-Bonnet theorem to noncompact manifolds like Hilbert varieties and classical results of Hecke, Siegel, and Curt Meyer about Dedekind zeta functions and class numbers of number fields and their relationship to cotangent sums. The resolution of the singularities in terms of periodic continued fractions was an amazingly beautiful result in itself and also spawned many generalizations, including the theory of toroidal compactifications (work of Mumford, Faltings, and many others) that now plays a central role in the theory of mirror symmetry. The results in part (iii), which culminated in the complete determination of the position of the Hilbert modular surfaces within the Kodaira classification, provided a beautiful collection of algebraic surfaces having particularly interesting properties because of the interplay between their transcendental aspects (description as quotients of $\mathfrak{H}^2$) and their algebraic aspects (description as projective varieties). This interplay leads to many insights that are not available for varieties possessing "merely" an algebraic description. All aspects of the theory are described in the masterful exposition [3].

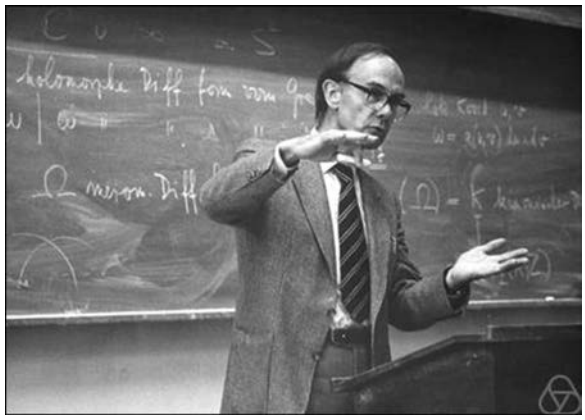
Fritz's investigation of the geometry of the Hilbert modular surfaces led him to an intensive study of the modular curves T_N ($N \in \mathbb{N}$) that are naturally embedded in these surfaces. This led to a joint paper with me [4] showing that the generating function $\sum_N [T_N]\, q^N$ of the classes of these curves in the second homology group of the surface is itself a modular form in one variable, a result that in turn has given rise to many later applications and generalizations (work of Kudla-Millson and many others). There is another amusing anecdote connected with this. Serre, who had studied Fritz's work on the topological invariants of Hilbert modular surfaces, wrote him a letter pointing out a coincidence between the numbers occurring here and the formulas for the dimensions of certain spaces of modular forms. His letter and Fritz's giving the explanation in terms of our modularity result crossed in the mail, a nice example of a question being answered before it is received. I should perhaps also mention that this collaboration was one of the most exciting mathematical events of my own life and, I think, meant a lot to Fritz too. On the day when we sent off the final manuscript, we celebrated with a dinner together with our families in a fancy restaurant at which Barbara famously reacted to the bill by computing how many portions of French fries she could buy with the same money.

Don Zagier and Friedrich Hirzebruch at the Leonhard Euler Congress, June 10–12, 2007, St. Petersburg.

In later years Fritz worked on many other topics at the interface between number theory and topology that for lack of space I will not describe in detail. A prime example arose in the late 1980s when Ochanine and Witten introduced elliptic genera, which attach modular forms to manifolds. Not surprisingly, Fritz was very interested in this development and wrote some beautiful papers and a book [6] (joint with his students Th. Berger and R. Jung) on this topic. Other topics included the study of Fuchsian differential equations (alone and in collaboration with Paula Cohen) alluded to above and his really beautiful work applying the Miyaoka-Yau inequality and other deep results about characteristic classes of surfaces to classical questions going back to Sylvester (1893) about configurations of points and lines in the plane [7].

Final Remarks

Fritz Hirzebruch was the most important person in my life outside my own family, and it is impossible for me to say everything he meant to me. It is he who taught me how to be a mathematician, but more important than this were his human qualities: his empathy, his gentleness with everybody, and his ability to correct without criticizing. His moral rectitude and the straightness of the path he followed made one wish to also act in a way he would approve of. In many almost invisible ways, he made the people around him slightly better people and the world around him a slightly better world.



Friedrich Hirzebruch giving a talk in Berlin, 1980.

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Yuri I. Manin

Friedrich Hirzebruch was eighteen years old in December 1945 when he started his study at Münster University. Reminiscing about this time in 2009 he wrote:

> Wenn ich damals einen kurzen Lebenslauf abgeben musste, dann enthielt er immer den Satz "Von Mitte Januar 1945 bis zum 1. Juli 1945 durchlief ich Arbeitsdienst, Militär und Kriegsgefangenschaft." (In those days, whenever I had to supply a short CV, it always contained the sentence: "Between mid-January 1945 and July 1, 1945, I served fatigue duty, military duty, and was detained as prisoner of war.")

This statement puts a double distance between the present day and painful youth of war years, defies any attempt to express this pain more eloquently, and does so by silence.

After settling in Bonn in 1956, Hirzebruch put great effort into the restoration of the European mathematical community, destroyed, like so many other institutions and lives, by the war. The brilliant idea of annual Arbeitstagungen and later the founding of the Max Planck Institute for Mathematics (MPIM) bore rich fruit. Hirzebruch struggled for the new Europe, like Henri Cartan in France, using all the influence that he possessed as an internationally renowned researcher.

My first close contact with Fritz and Inge Hirzebruch came in 1967. I spent six weeks at the Institut des Hautes Études Scientifiques in Bures–sur–Yvette, where Grothendieck taught me the "fresh-from-the-oven" project of motivic cohomology. After that I got permission and a German entry visa, which enabled me to visit Bonn and to participate in the Arbeitstagung on my way back to Moscow.

The blissful stress of study with Grothendieck and of Paris magic did something to my body, but in Bonn, Inge and Fritz treated me as their son and helped my healing. Their kindness and generosity forever remain in my memory.

In 1968 an abrupt end came to these budding direct contacts between mathematicians of Western Europe and their colleagues in the Soviet Union and Eastern Europe. The next generation, coming after Hirzebruch's and then mine, had different concerns. As one of those young men recalled recently, "We thought it highly likely we would be blown off the planet, and that, somehow, it was up to us—children after all—to prevent it." [1]

We were not blown off the planet. The existing order of things again started to seem stable—or stagnating. I had not the slightest premonition that this epoch would also pass during my life and that almost a quarter of a century afterwards I would meet Fritz again and become a colleague of his in the MPIM. After 1990 and the fall of the Berlin Wall, Friedrich Hirzebruch, through an immense effort, helped many mathematicians from East Germany find jobs and continue their scientific lives in a new environment.

Mathematics is a *travail de longue haleine*. Leonard Euler (born in Basel and working in St. Petersburg), inspired perhaps by the seven

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[1] *"It was about Cold War", letter by Geoffrey Wells, LRB, 5 April 2012.*

bridges of Königsberg (mostly destroyed by bombings in 1944 and 1945), discovered the notion of *Euler characteristic* of a graph. This notion had evolved during two centuries and by the time Friedrich Hirzebruch was maturing as a mathematician, found reincarnation as an alternating sum of dimensions of cohomology groups of (invertible) sheaves on an algebraic manifold. The celebrated *Riemann–Roch–Hirzebruch formula* of 1954 (described by Atiyah) expressed this number through geometric invariants of the base, crucially using the *Todd genus*, discovered by J. A. Todd from Liverpool. At the first Arbeitstagung in 1957, Alexander Grothendieck, son of a Russian anarchist and an eternal exile in France and everywhere else, presented its great generalization.

Perhaps the Riemann–Roch–Hirzebruch–Grothendieck Theorem, which fused and crowned efforts of a dozen great spirits from all corners of Europe, deserves to be put on the flag of the united Europe more than any other symbol.

Gerard van der Geer

The first time I saw Hirzebruch was when he visited my thesis advisor, Van de Ven, at Leiden University, where I was a Ph.D. student. I got to know him slightly better when Van de Ven took me to Bonn, where we visited Hirzebruch for a few days in 1974 to discuss Hilbert modular surfaces. At the time I was quite surprised to see how seemingly relaxed he was, though he must have been extremely busy at the time. He took ample time to talk to us, and the same happened about a year later when I visited him alone.

He invited me as a postdoc in 1977 to the Sonderforschungsbereich Theoretische Mathematik, the predecessor of the present Max-Planck-Institut. Shortly after my arrival there we celebrated his fiftieth birthday, the beginning of a long series of similar celebrations.

What struck me when we discussed mathematics was his instinct for the beauty of mathematics, and in fact all that he did bore the hallmark of elegance. The charming way he could lead the program discussion for the Arbeitstagung was another instance of this.

During my time in Bonn he would often invite me to his office and ask my opinion or even advice. In the beginning this surprised me, though I found out that weighing opinions of various people was part of his way of forming an opinion or coming to a decision. This applied especially to his preparation for the Arbeitstagung, where in the month before he was collecting suggestions for speakers and titles. It was surprising to see how he managed, seemingly without effort, to have the outcome of the public program discussions be guided by the ideas he had assembled.

The Fine Hall faculty in 1956. First row: Wigner, Tucker, Bargmann. Middle: Hirzebruch, Fox, Moore, Steenrod, Feller. Back: Spencer, Church, Artin, Wilks, Milnor, Tukey.

In 1981 he invited me to join him for a Summer Academy of the Studienstiftung in Alpbach in the Tirolean Alps in Austria. This was a two-week seminar where we would work with twenty-five very bright German students on a topic, studying in the morning, hiking in the afternoon. This was the first of seven such summer schools, the last one held in 1997. That was a fantastic experience, and during these seven summer schools I got to know Hirzebruch very well. From an awe-inspiring and paternal mathematician he became a very good friend. Professor Hirzebruch became Fritz. How difficult it was in the beginning to use "Du" instead of "Sie"! He enjoyed these days enormously and often in the later years would recall the happy days in Alpbach.

The charming way in which he would lead the summer school and discourse with students only fed my admiration for him. We would have lectures by students and ourselves in the morning and go hiking the whole afternoon. After dinner there would be interdisciplinary talks, because the Sommerakademie comprised groups from various disciplines, ranging from astronomy, say, to linguistics. After those talks we would gather in the Roter Salon of the Böglerhof Hotel for a beer and discussions with the students. Around 11 p.m. we would change location with our group to the disco, where we would dance—yes, Fritz too!—and continue to discuss as far as the noise admitted, and where we awarded drinks for prize-winning solutions to the exercises and problems. In the early hours of the morning we would return to

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At the third Arbeitstagung in 1959: Thom, Grothendieck, von Viereck, Milnor, and Dombrowski.

our rooms and decide whether quick preparation for the lecture the next morning was better done then or after sunrise. To do things efficiently was another lesson he taught by example.

In the later years, besides recalling Alpbach, he would often refer to the "golden fifties", the years he spent in Princeton, where he proved his landmark Riemann-Roch Theorem. For somebody who lived as a young man in the horrible Nazi time, those years must have been paradise. Inspired by this and his desire to rebuild mathematics in his own country, he formed the idea to have such an institute in Germany. That he succeeded in creating in Bonn one of the world's best mathematical research institutes is just one proof of his many talents. That it possesses such a pleasant atmosphere is another.

I often noted how he exerted a positive influence on other people just by being there. Or, even without him being there: I often noticed that faced with a difficult situation or decision, I asked myself how Fritz would have acted in such a case, and how much it helped. He was a wonderful person.

John Milnor

In 1955–56 Fritz and I were fellow assistant professors at Princeton. I don't believe that I really got to know him that year. However, I was certainly very much impressed by his mathematics. His *Neue topologische Methoden in der algebraischen Geometrie* had just appeared and was extremely exciting.

This was a time when many radically new ideas were beginning to completely transform the field of topology. Both Norman Steenrod's theory of cohomology operations and Jean-Pierre Serre's thesis, which brought the previously intractable study of homotopy groups under control, provided powerful new algebraic tools for studying homotopy theory. René Thom's ingenious geometric arguments exploited the work of both Serre and Steenrod to provide a completely new way of studying smooth manifolds. Hirzebruch's book added a whole new dimension, grounded in algebraic geometry and the study of complex manifolds. His theory of multiplicative sequences provided an important complement to Thom's work. For the first time, this brought Bernoulli numbers into topology, where they are related not only to groups of differentiable spheres but also to stable homotopy groups of spheres and the Adams conjecture.

I certainly got to know Hirzebruch well in the following years. He jumped from an assistant professorship in Princeton to a full professorship in Bonn and almost immediately established the annual Arbeitstagung, a true stroke of genius: It provided an annual get-together for mathematicians from all over Europe and from the US who wanted to follow the latest developments in topology and geometry. The relaxed atmosphere and low-keyed organization were a marvel of benevolently supervised democracy. The annual excursion on the Rhine provided a special opportunity for interaction. Visits to Bonn in the following years were always a pleasure, and Fritz and Inge's hospitality was much appreciated.

Mina Teicher

I want to start with the day that Hirzebruch received the Wolf Prize. It was on May 12, 1988, in the Knesset (the parliament) of Israel in Jerusalem—a very structured ceremony in the presence of the president of the country and five hundred guests.

Hirzebruch was sixty years old at the time he was awarded the Wolf Prize. He was the youngest person and only the second German to have received it.

Two prizes in mathematics were awarded, and Hirzebruch was chosen to respond on behalf of himself and the other laureate. He came to the podium to deliver his speech. With his strong and direct voice, he expressed his gratitude to the Wolf Foundation for awarding them the prize.

He then added a few sentences on behalf of himself only. When he completed his speech, the audience was dead silent for a few seconds, and then with tears in their eyes they started to clap in a fashion that is usually not seen in the academic world. They clapped and clapped more and more. He had spoken from his heart and had exposed his soul:

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> …As a professor at the University of Bonn, I am one of the successors of the famous mathematicians Felix Hausdorff and Otto Toeplitz. Hausdorff committed suicide in 1942, together with his wife, when deportation to a concentration camp was imminent; Toeplitz emigrated to Israel in 1939 and died there the following year. The memory of these mathematicians is with me always on this trip.

In these three sentences he managed to create continuity between the mathematical community in Bonn before and after the Nazis, to establish links between the Jews in Germany and the Israeli society, and to penetrate the hearts of the listeners.

Hirzebruch's first visit to Israel was in 1981 by the invitation of Piatetski-Shapiro, my Ph.D. advisor at the time. He was widely welcomed for being the great mathematician he was, as well as for his leadership role in reestablishing mathematics in Europe after WWII. But it was only in the late 1980s that he started to be actively involved in the mathematical research infrastructure in Israel.

Hirzebruch had a fundamental role in the Emmy Noether Institute of Bar-Ilan University. Following his advice, we prepared an application for a joint German-Israeli Minerva center in mathematics. We named the center after one of the greatest scientists of the twentieth century and one of the first female mathematicians, the German-Jewish mathematician (who fled to the USA in the early 1930s) Emmy Noether. The application was submitted to the Minerva Foundation (a subsidiary of the Max Planck Society), and in 1991 it was approved.

The inauguration ceremony of the Emmy Noether Institute took place in the house of the Israeli ambassador in Bonn in July 1992. A binational Beirat was appointed by the Bar-Ilan University and the BMBF. Hirzebruch was appointed by the deputy minister of the BMBF as the chairman of the Beirat. He served as chairman for twelve years, a role he took on with great commitment. He contributed his valuable time (when appointed he was still the director of MPIM in Bonn), his endless energy, his deep wisdom, and his vast experience to the success of the center. In 2000 he received an honorary degree from BIU for his contributions.

Two major conferences in algebraic geometry were held in the center in his honor. "Hirz 65" was held in May 1993 and attracted an international audience, including Fields medalists, directors of research institutes worldwide, collaborators, former students—all came to pay respect. "Hirz 80" was held in May 2008 and was one of the last big conferences he attended. Again, five Fields medalists attended, four Wolf Prize winners, and more. Fritz came, accompanied by his wife, Inge, and his son, Michael. He was very pleased to meet old friends, attended ALL the talks, and enjoyed the celebrations and the tours to the Golan Heights and Jerusalem. Unfortunately, on the day before the last, during a tour in the Western Wall caves, he fell and broke his leg, but then was most concerned that the conference was continuing as planned and kept apologizing for disturbing the agenda!

At the award of the Stefan Banach Medal in Warsaw, October 26, 1999.

I was reflecting on the times (circa 1975) when, for me, the name Hirzebruch was the title of a yellow book *Topological Methods in Algebraic Geometry*, which, as part of my M.Sc. studies, I had to read and then give a shorter proof of the Hirzebruch-Riemann-Roch Theorem in the special case $n = 3$. In spring 1988 I participated in a special semester in Bonn on algebraic surfaces, coorganized by Hirzebruch. Ten years later, in summer 1998, we organized together a special semester in the MPI, "Topology of Algebraic Varieties". He gave brilliant lectures, presenting complex geometrical structures in a simple and natural way, demonstrating beautiful examples. I learned more about the skills that helped him reestablish the mathematical community in Europe after the war. He never forgot that mathematics is made of—and by—mathematicians. Listening and attending to everybody's needs, "combining" people, making his own friends into friends of one another. A man who followed his values with no exception. A noble man.

Kenji Ueno

When I was a graduate student of the University of Tokyo, Professor Kodaira often told us his memories of his time in the US. The most unforgettable one is the following.

> A young German mathematician came to the Institute for Advanced Study. He calculated the Todd genus of several algebraic manifolds. I wondered what he was really trying to prove. But suddenly he proved the Riemann-Roch theorem for all algebraic manifolds. In that summer I wrote a letter to J-P. Serre that Hirzebruch proved the Riemann-Roch theorem, while I could only prove that the Hodge manifolds were algebraic.

Kodaira had proved the Riemann-Roch Theorem for algebraic threefolds by using the theory of harmonic integrals. He was trying to prove the theorem step-by-step as he could not foresee that one could prove it in a single step. Hirzebruch used cobordism theory to prove it. This was a completely new approach and paved the way for the Atiyah-Singer index theorem.

In December 1971 Kodaira told us that Hirzebruch would visit Japan the following February and deliver a series of talks at the University of Tokyo. So many times we had heard the name of Hirzebruch from Kodaira and also consulted his famous book *Topological Methods in Algebraic Geometry*, but we had never expected that we would have a chance to meet him in Japan. His lectures were the IMU lectures, which means that the IMU supported his visit to Japan. At that time the Japanese economy was growing but still not strong enough, so that the Japanese government supported universities very little. We had the research grants of the Ministry of Education, but strangely enough it was forbidden to use them for either inviting foreign scholars or for visiting foreign institutes. For that we had to apply for another grant, which was quite difficult to get. This restriction was continued for a long period and only removed around fifteen years ago. Therefore, at that time it was almost impossible to invite foreign scholars with Japanese funds.

In January 1972 the title of his talks was announced. To my surprise his talks were on the resolution of cusp singularities and Hilbert modular surfaces. In February Hirzebruch came to Japan. The lecture room was full of people. His talk was so clear and beautiful that I thought I understood every detail. Of course, this was his magic, and later I realized that I had missed many important points. In his lectures he posed several exercises and problems related to the subject. Since the classification theory of algebraic and analytic surfaces was popular among us, some of his problems were not difficult. After the lecture Kodaira introduced us to Hirzebruch. Before his next talk I visited him and showed him answers to some of his problems. He was pleased and encouraged me to study further. At that time I was invited to Mannheim University, and Hirzebruch was kind enough to give me suggestions. He asked me to attend the Arbeitstagung in Bonn and promised to send an invitation letter.

After Tokyo he visited Kyoto and gave several lectures. Many young active Japanese mathematicians attended his lectures and solved several problems posed by him. He asked them to apply to the SFB 40 in Bonn University. Soon some of them got invitations to Bonn. At that time in Japan there were several programs to visit foreign universities as graduate students but very few possibilities to visit foreign countries as researchers, so that his advice was very helpful for young Japanese mathematicians.

At the beginning of that March I went to Mannheim University. In June I received an invitation letter to the Arbeitstagung from Hirzebruch. He never forgot his promise. The Arbeitstagung was very interesting. I met there many mathematicians whose names I knew only from their papers. In October 1972 I was invited to the SFB 40 and stayed there half a year. Then I came back to Tokyo to get my Ph.D. and went back to Bonn the following spring.

At Bonn University I got a room in the same building where Hirzebruch had his office. Almost every day I saw him working hard not only on administrative works but also discussing mathematics with students and many mathematicians. He was busy enough, but he always attended important seminars and colloquium talks. Also, at teatime he came down to the tearoom and discussed mathematics with us. He was very kind to answer our questions and always encouraged us to do mathematics. If the questions were not in his fields, he introduced us to the appropriate mathematicians.

In the 1970s the only possible way to invite foreign scholars to Japan was to use the JSPS (Japan Society for the Promotion of Science) program. Hirzebruch's second visit to Japan was under this program. He stayed mainly in Kyoto and had discussions with many young Japanese mathematicians. After that he visited Japan several times. He always advised young mathematicians to apply to the SFB 40 and later the Max Planck Institute for Mathematics. Following his advice,

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many young Japanese mathematicians applied to Bonn and many of them had chances to visit Bonn. They could not only concentrate on their research but also collaborate with foreign mathematicians, often in different fields. During the mid-1990s more than one hundred Japanese mathematicians visited Bonn.

In 1997 the Mathematical Society of Japan (MSJ) awarded the Seki-Kowa Prize to Hirzebruch for his outstanding contribution to the Japanese mathematical community in giving many young Japanese mathematicians the opportunity to study and collaborate with mathematicians from all over the world. At the same time the MSJ had applied for the Order for Hirzebruch through the Ministry of Education. The Japanese government awarded him the Order of the Sacred Treasure, Gold and Silver Star, which was the highest order for foreigners except politicians and diplomats. In November 1997 the ceremony was held at the Ministry of Education, and the vice minister awarded him the order. In the ceremony Hirzebruch answered that he would accept the order on behalf of all the Japanese and German mathematicians who had once stayed in Bonn and collaborated together, the secretaries and staff of the SFB 40 and the Max Planck Institute for Mathematics who helped their activities, and the Deutsche Forschungsgemeinschaft and Max Planck Gesellschaft for supporting them financially. His speech deeply impressed officials of the Ministry of Education who were present at the ceremony.

Hirzebruch loved mathematical talks, and his talks were always clear. Once when he visited Kyoto, I asked him to give a lecture for high school students. At that time every two weeks I organized a mathematics lecture for high school students at the Kyoto University. He gave a beautiful lecture on the regular icosahedron. The high school students enjoyed his talk and were impressed by how deeply he loved mathematics.

It is really sad that I cannot talk with him anymore. He always talked with a gentle smile and never failed to encourage us to do mathematics. I am quite sure that his warm memory and his encouragement to do mathematics will survive in all mathematicians who once met him.

Graeme Segal

The month I spent in Bonn as a second-year graduate student in the autumn of 1964, when I first encountered Fritz Hirzebruch, remains one of my most vivid memories. When I think of all he must have been involved in I am humbled to think of his kindness in spending so much time, not just

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Shiing-Shen Chern, Samuel Eilenberg, and Friedrich Hirzebruch, 1956 in Mexico.

in talking to me about my work but in making sure that my wife, Desley, and I were at home and happy in what was for us a strange new world.

For a young Australian, Germany then was an overwhelmingly formal place. After two years I had just about become accustomed to the increased formality of England, but in Germany it attained another level. In retrospect I see that the country was poised on the brink of a great change in social style, and I think this was essential to Fritz's magic. On one side he was the perfect German professor of the old school: although only thirty-eight, he had already served a term as dean of the Faculty of Sciences and was a figure of manifest authority. (My status rocketed with the very genteel elderly lady in whose house we were lodging when one day the Herr Professor arrived in person to pick me up.) He gave wonderful lectures, but what I most remember about them was his use of the German language—his long, elegant, articulated sentences in which every clause clicked faultlessly into place. Mathematicians had long since ceased to lecture like that in English; I wonder whether it still happens in Germany?

But there was another side, as Fritz had become part of the Princeton mathematical world with its very different manners. He had attracted Jacques Tits to Bonn as his closest colleague, and they called each other "Fritz" and "Jacques" in public, which was constantly remarked upon to me—sometimes with a definite hint of disapproval—by the *Assistenten* in the department. (Peter Pears and Julian Bream came and gave a recital in Bonn at the time, and the informality of their dress and demeanor on stage also caused a flutter.) I had no idea then of Fritz's great achievement

in rebuilding German mathematics from the late 1950s on, but it seems to me that a big part of his success must have come from his ability to shine in two, at least, very different styles at once, with always just the tiniest suggestion of ironical detachment from each. He evidently had a remarkable ability to see what was needed and what was possible for the mathematical world and a perfectly pragmatic way of pursuing it, with almost nothing showing of amour propre. Foreign mathematical visitors like me saw little of his "Germanic" style beyond the legendary clockwork perfection of the arrangements for the annual Arbeitstagung, but, looking back, I marvel at how, in gathering together such an outstanding panoply of diverse mathematicians from all over the world in his institute, he managed to seem—and indeed to be—so uniformly benevolent, sometimes in the face of much that was surely alien and even offensive to his own nature. I sometimes felt he had a special affinity with the Japanese visitors, whose reserved manners had something in common with his own.

I shall not try to talk about Fritz's mathematical work, as I don't feel the best-placed person to do that. I always admired his taste for beautiful concrete geometric examples and all he could extract from them, though I never myself worked quite in his area. But I cannot resist mentioning one of his earliest achievements. When I became a graduate student in 1962 the first suggestion made to me by my first supervisor, Sir William Hodge, was to try to read Hirzebruch's *Neue topologische Methoden in der algebraischen Geometrie*, which had just appeared. It was far above my head then, but it begins with the piece of algebra whereby a formal power series gives rise to a multiplicative characteristic class for vector bundles. I was bewildered but tremendously intrigued by this, and I remember struggling with the proof that the only series $f(x)$ such that the coefficient of x^m in $f(x)^{m+1}$ is 1 for all m is the famous one

$$f(x) = x/(1 - e^{-x})$$

which defines the Todd genus. I can only say that almost everything I have ever thought about in mathematics, in K-theory, index theory, elliptic cohomology, deformation quantization, or whatever has involved what I learned then.

Stanisław Janeczko

The political changes in Poland in 1990 (Eastern Europe) caused many necessary reorganizational efforts. One of the institutions in trouble was the Stefan Banach International Mathematical Center (BC) in Warsaw. It needed a new basis and structure for a secure and prosperous existence. Friedrich Hirzebruch, being at that time president of the European Mathematical Society, offered his help and great involvement to reconstruct the BC and to form new conditions for European cooperation. During the meeting of the Executive Committee of the EMS in Budapest, the letter of Intent on Cooperation between the Institute of Mathematics of the Polish Academy of Sciences and the EMS was discussed and signed *in order to secure the fruitful continuation of the activity of the Stefan Banach International Mathematical Center*. It was President Friedrich Hirzebruch's personal effort, made with care and concern, for the fruitful future activity of the BC. We found him enormously friendly and deeply involved in any possible undertakings. His pragmatism, careful attitude, and firm support allowed all the good working elements of the former activity of the BC to be maintained.

The agreement was signed on 30 March 1993, and the first meeting of the new Banach Center Council, with three representatives of the Executive Committee of the EMS, four representatives from Poland, and three representatives from the founding countries, was organized on 25 October 1993. Friedrich Hirzebruch agreed to serve as its chairman. The council and mainly the chairman started to work very hard to adapt the BC to the new but still unstable reality. As a master and friend of all of us, Hirzebruch visited the Banach Center every year and taught us how to be supportive and really helpful to other colleagues; how to be honest, objective, constructive and not discouraging to other applicants, how to improve the atmosphere for successful research, how not to be "divisive" and troublemaking, and how to be gentle and responsible in formulating opinions about others. He taught us that mathematics is unity, that there are no better or worse branches of mathematics, but that it is engagement in research and striving for perfection that are of key importance. He was always supportive of the director of the institute in the latter's difficult fights and efforts. He was an excellent advisor during my period of directorship, always patient and understanding, friendly, with impeccable manners. He made an enormous effort to help the institute in its fight to maintain the basic properties. Under his chairmanship the first eight years, despite the material difficulties which we all suffered in Poland, the Banach Center was very successful and prosperous.

In 1997 Friedrich Hirzebruch became a member of the Polish Academy of Sciences. The next year an Algebraic Geometry Conference in Honor of F. Hirzebruch's Seventieth Birthday was organized in the Banach Center in Warsaw. It was an unusual event with extreme importance also for Polish

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mathematicians. Then in 1999 he got a prestigious award of the Polish Academy of Sciences—the Stefan Banach Medal.

Since my first visit to the Max Planck Institute for Mathematics in Bonn in 1984, through our daily meetings and walks along the paths in the pleasant neighborhood of the institute to my last visit there in November 2011, I experienced Fritz's generous, warm, and extremely eager ideas and advice on mathematics as well as on everyday life. He was always so pleased with mathematicians' new achievements and at the same time deeply worried about his colleagues' material status and the financial conditions of mathematics in general. He showed us that we have to be extremely careful not to lower the value of mathematics and not to isolate it from the global efforts of mankind.

It was an extreme pleasure and satisfaction for me when he agreed to come to Warsaw in May 2012 to celebrate his birthday, to meet with all the Polish friends and former scholars of MPI. We were very happy to prepare this event to thank him for all that he had done for the Banach Center, the Institute of Mathematics, and Polish mathematicians. Unfortunately, a few days before the symposium started, Fritz had an accident at home and was not able to come. The letter, perhaps his last letter (which can be found on the website of the Banach Center) was brought to us by his son, Michael, and his daughter-in-law, Anne Hirzebruch. It was the most meaningful gift which we never expected to get—to be in Friedrich Hirzebruch's great mind and soul till the last days of his life.

Jean-Pierre Bourguignon

Some Personal Recollections

Personally, over the last forty years, I owe a lot to Friedrich Hirzebruch for his unfailing support and continuous inspiration. I met him in Bonn in 1970 while I was visiting Wilhelm Klingenberg as a very young researcher in differential geometry. It was really during the academic year 1976–77, spent in Bonn with my family as guest of the Sonderforschungsbereich 40, that I got to know him better.

The Arbeitstagung, a major mathematical event that he organized with his Bonn colleagues for more than thirty years, offered each year in June a broad overview of the most exciting mathematics of the time. It was an exceptional place to meet mathematicians of all sorts, famous and less famous, senior or just beginning. Like many young mathematicians, I benefited a lot from it, directly through the new perspectives gained by listening to the lectures and indirectly through the great number of encounters, some of which had a great impact on my professional life.

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Friedrich Hirzebruch lecturing on Chern classes at IHÉS, November 17, 2011.

He was always curious to know what kind of mathematics was on your mind and showed special interest in young mathematicians. Also worthy of remark was his determinedly proactive attitude towards women mathematicians at a time when gender equality was not given much priority. Several women colleagues consider that they owe him a lot because of his continued support.

The numerous encounters with him that followed the wonderful year in Bonn gave me ample opportunity to witness his many talents: as an outstanding mathematician of course, but also as a remarkably clear lecturer, an efficient communicator, and an exceptionally talented manager. Some of them were quite unexpected for me, such as accompanying him to a press conference with German journalists to discuss the development of mathematics in his country.

He was a great supporter of the collaboration between the Institut des Hautes Études Scientifiques (IHÉS) and the Max-Planck-Gesellschaft (MPG). He represented the MPG on the board of directors of IHÉS for several years. Both he, as director of the Max-Planck-Institut für Mathematik, and Sir Michael Atiyah, as founding director of the Isaac Newton Institute in the Mathematical Sciences, endorsed immediately the idea of the European Post-Doctoral Institute (EPDI) which I proposed in the fall of 1994 shortly after becoming the director of IHÉS. Already in 1995 the three institutions could join forces to get young postdocs to move around Europe. For the inaugural ceremony in

Bures-sur-Yvette, Hirzebruch gave a very inspiring speech on the role of institutes in mathematics.

A Very Early and Critical Involvement in European Mathematical Affairs

All along his career, Friedrich Hirzebruch had a lot of interactions with Henri Cartan, a dedicated European very early on: his first interaction was in relation to Cartan's efforts to renew contact between German and French mathematicians after the Second World War. Indeed, as early as November 1946, Henri Cartan lectured in the Lorenzenhof in Oberwolfach.

In this connection, Friedrich Hirzebruch wrote the following: "The 'Association Européenne des Enseignants' (European Association of Teachers) was founded in Paris in 1956. Henri Cartan was president of the French section. As such he took the initiative to invite participants from eight European countries to a meeting in Paris in October 1960. Emil Artin, Heinrich Behnke and I were the German members. The second meeting of this committee was in Düsseldorf in March 1962. As a result, the 'Livret Européen de l'Etudiant' (European Student's Record) was published and distributed by the Association. The booklet contained a description of minimal requirements for basic courses. It was supposed to increase the mobility of students from one country to another. The professor of one university would mark in the booklet the contents of courses attended by the student. The professor at the next university would then be able to advise the student in which courses to enroll. The booklet was not used very much." This was indeed the early form of the by now well-established "Erasmus Program".

A lot about their relationship can be learned from reading the letter that Friedrich Hirzebruch wrote in 1994 to Henri Cartan on the occasion of his ninetieth birthday.

The European Council of Mathematics (EMC) opened the way to the European Mathematical Society (EMS). The foundational meeting of the EMS was held in October 1990 in Madralin and was not an easy affair, as opposite views on the structure of the EMS were presented by some delegations: should it be a federation of societies or a society with individual members? Friedrich Hirzebruch, who had agreed to be considered as the first EMS president, led to success the rather tense meeting behind closed doors between supporters of the conflicting positions. The next day the new society could be created with statutes ensuring a good balance between individual members and member societies, a feature that still remains operational to this day.

Under Friedrich Hirzebruch's leadership, the EMS developed successfully. A lot had to be achieved in a short time to take advantage of the dynamics that accompanied the creation of the society. Among milestones of his mandate, one can single out the setting up of the first European Congress of Mathematics in Paris in 1992 and laying the groundwork for the *Journal of the European Mathematical Society* (JEMS) that was finally created in 1999.

To my great surprise, he asked me to become his successor as EMS president in 1994 to serve for the second term, 1995–98, another great honor that he bestowed on me.

Final Visit to Paris

In November 2011 Hirzebruch came to IHÉS on the occasion of a conference in honor of the centenary of Shiing-Shen Chern, a close friend of his since 1953, whom he described as "one of the greatest mathematicians of the 20th century [and] for me a fatherly friend whom I owe very much." He lectured brilliantly on Chern classes and was able to meet Chern's daughter, Mae Chern. At the end of his lecture, he told me, "I am afraid that this will be my last visit to Paris." It is very sad to remark that he was indeed right.

Matthias Kreck

After my oral *Vordiplom* examination in the summer of 1968, I asked Hirzebruch whether I could attend his seminar. "Of course, but it is rather difficult," was his reaction. He was right; I was not prepared to follow that seminar. But it gave me the chance to become familiar with some of the other students and assistants in his group, such as Klaus Jänich, Erich Ossa, and Walter Neumann. A year later I asked Hirzebruch whether I could write my diploma thesis with him and the answer was the same: "Of course." Often when he supervised a diploma thesis, he asked one of his assistants to help him, which meant that he gave the assistant the major part of the responsibility, but he followed what was going on. In my case he asked Klaus Jänich to supervise me and that was wonderful. At that time Jänich had started to systematically investigate invariants which share a fundamental property with the most important manifold invariants, such as the Euler characteristic and the signature, namely, that they are invariant under cutting and pasting. In this way I became a friend of two of Hirzebruch's best friends: the signature and the Euler characteristic. This has been a lifelong friendship, with the signature in particular playing a role in many of my papers.

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Around 1969 Jänich received an offer from Regensburg and asked me to join him there with the aim of becoming his assistant and to write a Ph.D. with him. I felt very honored and agreed. Soon after my arrival in Regensburg both Jänich and I discovered that we had almost opposite political opinions. This was a great pain for Jänich, so that he felt unable to continue working with me. To resolve the situation he wrote a letter to Hirzebruch asking him whether he would be willing to take me back: "Perhaps you can deal with this young man." The answer: "Of course." In this way I came back to Bonn and became Hirzebruch's Ph.D. student (in parallel with Don Zagier).

My Ph.D. time was difficult. Hirzebruch had started his fundamental work on Hilbert modular surfaces and gave a course about it. He asked me to take notes (which he used to write his beautiful Enseignement survey article). He didn't give me a specific problem to work on. Instead he pointed at certain invariants occurring in connection with the resolution of singularities, which are some sort of signature defects, and suggested that I investigate them further. He had proven some relations to L-functions and had a rather general conjecture which he mentioned. This was all too hard for me and I became rather frustrated. After about a year, I decided to give up and to study Protestant theology. When I told this to Hirzebruch, he looked unhappy but said, "Of course, I understand," at the same time clearly thinking what would be the best for me in this situation. He suggested that we should meet in the near future again and look at what I had done so far. "Perhaps what you have proven so far is already enough for a Ph.D.," he said. This was extremely kind, since I had not done very much. We met, and he suggested certain things which I could realistically work out, and we agreed on a plan which would lead to my Ph.D. within a year.

I defended my Ph.D. in July 1972 and immediately started an intensive three-month course in Hebrew, which is a prerequisite to study theology. After this course I went to Hirzebruch to finally say good-bye and thank him for all his support. He was very friendly and asked how the Hebrew course was going and whether I was looking forward to starting my theological education. Then he continued: "I have just lost another assistant who became a professor at another university. Would you be willing to be my assistant? Of course, I know that you need most of your time for theology, but I will give you enough free time. I also know that you don't want to do mathematical research; this is not necessary. I need your help with supervising seminars, other students, courses, examinations, etc. Do you agree?"

Princeton, 1967, in the house of Louise and Marston Morse. Inge and Fritz Hirzebruch with their children, Ulrike, Barbara, and Michael.

I found this extremely generous and agreed. Whether he had an ulterior motive I really don't know. But in any case, his offer bore fruit. After more than two years of not thinking about mathematical research, I found myself thinking about a mathematical problem in my theology courses. I did not tell this to Hirzebruch; this was just for my own personal fun. I did not even consult the literature to find out what was known. Within a few weeks I could solve half of the cases and told this to Hirzebruch. He looked rather skeptical and asked, "Do you know that this is a well-known problem which had been attacked by mathematicians like Thom, Browder, and Sullivan?" I had no idea and immediately said that my solution must be wrong. "Why? Let me hear," was his answer. I explained the idea to him, and he said, "This has a chance; write it up in detail. And if you can do the (much harder) remaining cases, this is your Habilitationsschrift."

Based on this result, in 1976 I received an offer as professor at Wuppertal University, even before my Habilitation was formally finished. This was also the time when I had to begin my final examinations in theology. I asked my friends:,"What should I do? The devil is tempting me." Their reaction was, "If you have not learned more about the devil, you better go back to mathematics."

When I told Hirzebruch that I would accept the offer from Wuppertal, I could see from his face that he was pleased. But his reaction also made it clear that if I had decided to stay in theology, he would have respected this equally.

Whenever I think about mathematics I am influenced by my teacher, Friedrich Hirzebruch. My strongest impression is of the enthusiasm

Inge and Fritz Hirzebruch on the boat trip to Remagen, Mathematische Arbeitstagung, 2007.

for mathematics he lived; this was a relaxed and friendly enthusiasm. He was always open for discussions with me, either about questions I had or to share his mathematical ideas. I was impressed by his clear thinking and writing, his ability to bring different mathematical areas together, and his deep insights. And also by his always visible humanism, both within and outside mathematics. I am so grateful that I had the chance to have close contact with Hirzebruch and that he always treated me like his friend. I will never forget him.

Ulrike Schmickler-Hirzebruch

Since my childhood I have always been convinced that I had a very special father. I am the eldest of three children and was born in 1953 (my father was twenty-five years old) in Princeton, New Jersey, where my father spent a productive time at the Institute for Advanced Study from 1952 to 1954. These were the formative years of his mathematical career but also of his family life. My father met my mother, Inge, also a mathematics student, for the first time in Münster in 1947. After a few occasions where they saw each other again, it became clear that they should get married, which they decided on in 1952 before my father left Germany for Princeton. He arrived in Hoboken, NJ, in August 1952 with the Holland-America oceanliner *Ryndam*; my mother came over in November on the *Maasdam*, and a few days later they married. With a settled married life, my father could be "free" to concentrate on his scientific work.

There are a lot of letters from my parents to their parents in Germany—in those days it was the only way to communicate. I was amused when I recently read in a birthday letter from my father to his father (Dec. 12, 1953):

> …The last days were mathematically very exciting, so exciting that I almost did not eat anything. I worked during the night until 4:30, once until 6:30. Results came out that I had already wanted to prove for quite some time, but that had seemed to be very difficult.…(I assume that Ulrike gets the credit. They say here that babies, as long as they are less than 6 months old, know everything about mathematics, but they can't tell it.)

Starting from 1956, my father was a professor in Bonn. In 1957 he organized the first annual international meeting Mathematische Arbeitstagung. My siblings and I got to know this group of mathematicians in our early childhood on the boat trips and at the parties held in our apartment. The Arbeitstagung was a special event also for us. My father's enthusiasm was contagious, and his love for mathematics included his mathematical friends.

We were "infected" at an early age by mathematical problems: for example, on our Sunday walks in the forest: "Just think of a number, multiply it by 4, add 10…and so forth. And what is your result?" Then he told every one of us the individual chosen number. Also at lunch he often surprised us with beautiful simple problems, for example, with the trick of how to quickly multiply two numbers between 10 and 20 (he had learned this trick from his father, a math teacher and director of a secondary school) and easy ways to construct magic squares. This and much more happened without any prior planning.

My father generally accepted what we did and how we did it. Without much consideration, I decided to study mathematics, and later so did my sister, Barbara. Because of the pleasure it gave me, I accepted the challenge, all the more so since at that time there were only a few female students in the mathematics diploma program in Bonn. My sister, Barbara, wanted to be a math teacher. My brother, Michael, wanted to study medicine, which in later years would be very helpful for my father.

As a father he had authority through his reliability, personal credibility, and his familiar smile as a sign of his helpfulness and warmth towards us. My father gave us cautious advice; sometimes, maybe, he was a bit too cautious. He was extremely balanced.

From my student days, I remember that my father lent me some books that I saw on the bookshelves of his study. I could take them to my home to work with them. There was discipline: he

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would keep track accurately, and his name was written in the book; but from the expression in his face I knew if I liked the book, I would own it someday. An arrow from his name to "Ulrike" then indicated this transfer. For my father, books also had been important in his youth when he was lucky to learn from the math books his father owned.

I also remember some Sundays when I came to my parents' home an hour before lunchtime. I extremely enjoyed this hour with my father in his study. With a light hand he could show me the relationship between mathematical objects and beautiful concrete examples. A small hint was enough; I immediately understood his explanations—the combination of teacher and father was wonderful.

Later, in my professional life, I met my father a couple of times at mathematics meetings. In a few of his lectures, he deliberately included—just for me, and unnoticeable to others—a phrase or an expression with which he wanted to tease me a little.

My father had three children and six grandchildren. He took each of us seriously. We miss his loving nature and how he could clearly express individual good wishes for us. His nice simple words, enriched with caring humor, always hit the nail on the head.

My parents were a good team for almost sixty years. They complemented each other well. My mother encouraged my father in his organizational efforts, and she joined him on his ways, especially, whenever she could, on trips and visits to mathematical places.

My mother sometimes refers to the statement by Mephistopheles in Goethe's *Faust* II: "How are merit and luck linked together." His personal actions and a few good coincidences (for instance, being at the right time at the right place) shaped my father's life. We are very grateful that my father had the good fortune to bring his life to a full end and that, shortly before his death, he was still able to give two mathematical lectures, which had always been such a great pleasure for him.

Note: All photos are courtesy of either the Hirzebruch family or the Max Planck Institute.

Friedrich Hirzebruch's grave on Poppeldorfer Friedhof in Bonn.

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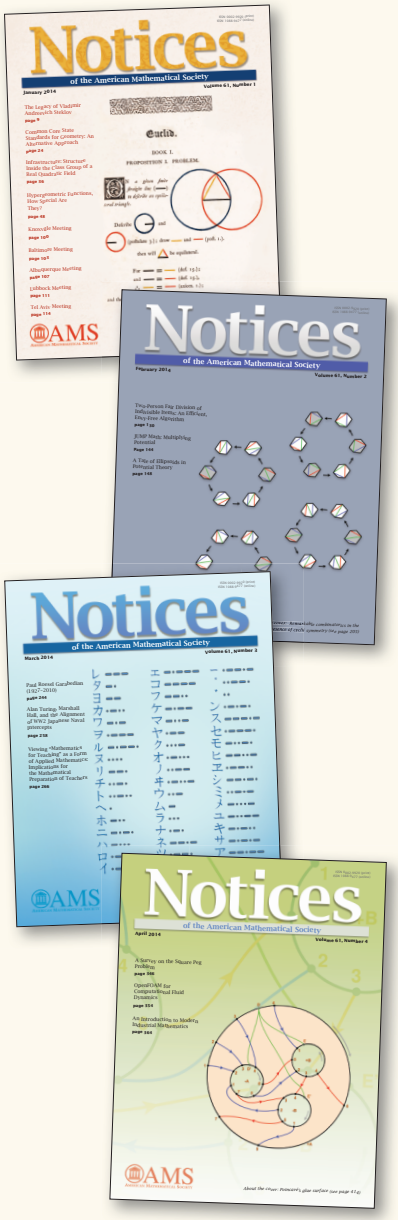

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Is There a Spectral Theory for All Bounded Linear Operators?

Longyun Ding and Su Gao

The answer is not known. But results from recent (and some not so recent) research suggest that there might be one, and in fact there *likely* is one. We will explain below what has been achieved and why it promises some more exciting research ahead.

What Is Spectral Theory?

By spectral theory we mean the theory of structure of certain bounded linear operators on a Hilbert space. In a broader sense, the history of spectral theory goes way back to the nineteenth century, when the objects of study used to be infinite systems of linear equations and integral equations. The subject was revolutionized in the late 1920s by von Neumann, when he defined the notion of an abstract Hilbert space and considered bounded linear operators on it. In this modern sense a successful spectral theory was soon obtained by Riesz for all compact operators as a direct extension of the theory of finite square matrices. By the early 1930s, von Neumann had obtained a satisfactory spectral theory for all normal operators, with self adjoint (or Hermitian) operators and unitary operators as important special cases.

Spectral theory has evolved further since then; a vast amount of work was done on extending spectral theory to various Banach algebras. However, efforts to extend spectral theory to all bounded linear operators on a Hilbert space have met with resistance so far. This will be the problem we concentrate on in this article. To be explicit, the problem we consider is the existence of a satisfactory spectral theory for all bounded linear operators.

At this point we have to include a disclaimer: neither of the authors considers himself a functional analyst; in fact, both of us work in *descriptive set theory*, which is the study of definable sets of real numbers. So what does descriptive set theory have to do with this important problem in functional analysis? The answer is, we hope, that it provides some new perspectives on this old problem.

We employ some notation before continuing our discussion. Let $\mathcal{H}$ denote a separable infinite-dimensional complex Hilbert space and let $B(\mathcal{H})$ denote the space of all bounded linear operators on $\mathcal{H}$. Let $N(\mathcal{H})$, $S(\mathcal{H})$, and $U(\mathcal{H})$ denote, respectively, the spaces of all normal, self adjoint, and unitary operators on $\mathcal{H}$. In notation,

$$N(\mathcal{H}) = \{T \in B(\mathcal{H}) : TT^* = T^*T\},$$
$$S(\mathcal{H}) = \{T \in B(\mathcal{H}) : T = T^*\},$$
$$U(\mathcal{H}) = \{T \in B(\mathcal{H}) : TT^* = T^*T = I\}.$$

Obviously, $S(\mathcal{H})$ and $U(\mathcal{H})$ are subspaces of $N(\mathcal{H})$.

In a nutshell, here is how spectral theory works for a normal operator T. The *spectrum* of T, denoted by $\sigma(T)$, is the set of $\alpha \in \mathbb{C}$ such that $T - \alpha I$ is not invertible. If $\mathcal{B}$ is the σ-algebra of all Borel subsets of $\sigma(T)$, a *spectral measure* for $\sigma(T)$ is a function $E : \mathcal{B} \to B(\mathcal{H})$ such that

(a) $E(X)$ is a projection of $\mathcal{H}$ for every $X \in \mathcal{B}$;
(b) $E(\emptyset) = 0$ and $E(\sigma(T)) = 1$;
(c) $E(X \cap Y) = E(X)E(Y)$ for $X, Y \in \mathcal{B}$;
(d) if $\{X_n\}_{n=1}^{\infty}$ is a collection of pairwise disjoint Borel sets from $\mathcal{B}$, then

$$E\left(\bigcup_{n=1}^{\infty} X_n\right) = \sum_{n=1}^{\infty} E(X_n).$$

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Then the spectral theorem states that for any normal operator T there is a unique spectral measure E^T on the Borel subsets of $\sigma(T)$ such that

$$T = \int z dE^T(z).$$

This, at least in theory, completely describes the structure of a normal operator.

As an important consequence, it is now possible to completely classify normal operators up to unitary equivalence. Recall that two operators T, $S \in B(\mathcal{H})$ are *unitarily equivalent* if there exists $U \in U(\mathcal{H})$ such that $T = USU^{-1} = USU^*$. From results of multiplicity theory, developed based on the spectral theorem, for each normal operator T there is a canonical sequence $x_0, x_1, \ldots \in \mathcal{H}$ such that the sequence of measures

$$\mu_n^T = \langle E^T(\cdot)x_n, x_n\rangle,$$

considered up to *measure equivalence*, gives a complete invariant for T up to unitary equivalence. In other words, two normal operators T and S are unitarily equivalent if and only if, for all $n \in \mathbb{N}$, μ_n^T and μ_n^S are absolutely continuous with respect to each other.

The spectral theorem is usually considered the centerpiece of spectral theory, with the classification as one of the most important applications. For the purpose of generalizing the spectral theory, we will see that there is no obvious candidate for the spectral theorem, and so the classification becomes a natural subject of study. In particular, we do not want to hint that the spectral theory is equivalent to the classification, but our discussions will concentrate on the classification problem since the question appears natural to us.

Difficulties arise quickly when one tries to extend the above spectral theory to all bounded linear operators. The spectral theorem is obviously false since an integral with respect to a spectral measure always gives a normal operator.

The classification up to unitary equivalence, however, is *not* obviously false for all bounded linear operators. Imagine a statement saying that two bounded linear operators T and S are unitarily equivalent if and only if some sequences of measures obtained from T and S, respectively, by some canonical means are absolutely continuous with respect to each other. In other words, some sequence of measures would completely determine the unitary equivalence type of the operator. This would be consistent in spirit with what a spectral theory is expected to achieve.

Still, this has not been done and the question is somewhat vague. We are now ready to consider some rigorous mathematical statements and give some results. To do this, we take advantage of the descriptive set theory of equivalence relations developed in the last two decades.

Spectral Theory from the Point of View of Descriptive Set Theory

Our first task is to turn the collection of our objects of study into a Polish space, that is, a separable, completely metrizable topological space. For this, let $B_1(\mathcal{H})$ be the space of all bounded linear operators on $\mathcal{H}$ with norm ≤ 1. The operators in $B_1(\mathcal{H})$ are also called *contractive*. There are several Polish topologies on $B_1(\mathcal{H})$, the most well known being the *strong operator topology* (SOT) and the *weak operator topology* (WOT). For $T_n, T \in B_1(\mathcal{H})$, $T_n \to T$ in the SOT if $T_n x \to Tx$ for all $x \in \mathcal{H}$, and $T_n \to T$ in the WOT if $\langle T_n x, y\rangle \to \langle Tx, y\rangle$ for all $x, y \in \mathcal{H}$. Both topologies generate the same Borel structure. It is not obvious which topology is more advantageous since the multiplication (composition) operation on $B_1(\mathcal{H})$ is continuous in the SOT but not in the WOT and, on the other hand, the adjoint operation is continuous in the WOT but not in the SOT. For both the multiplication and the adjoint operations to be continuous, we consider the *strong-star topology*. For T_n, $T \in B_1(\mathcal{H})$, $T_n \to T$ in the strong-star topology if both $T_n \to T$ and $T_n^* \to T^*$ in the SOT. For our purposes we regard the strong-star topology to be the default Polish topology on $B_1(\mathcal{H})$.

Let $S_1(\mathcal{H}) = S(\mathcal{H}) \cap B_1(\mathcal{H})$. Then obviously the strong-star topology coincides with the SOT on $S_1(\mathcal{H})$. $S_1(\mathcal{H})$ is a closed subspace of $B_1(\mathcal{H})$ in the strong-star topology (in fact in either of the Polish topologies); hence it is itself a Polish space.

The WOT, the SOT, and the strong-star topology all coincide on $U(\mathcal{H})$, which is a closed subspace of $B_1(\mathcal{H})$ with the strong-star topology. Moreover, $U(\mathcal{H})$ is a topological group with multiplication as the group operation, and we refer to $U(\mathcal{H})$ as a *Polish group* since its underlying topology is Polish. $U(\mathcal{H})$ acts on $B_1(\mathcal{H})$ by conjugation, with the orbit equivalence relation representing the unitary equivalence. $S_1(\mathcal{H})$ is a closed invariant subspace for this action.

Finally, let $N_1(\mathcal{H}) = N(\mathcal{H}) \cap B_1(\mathcal{H})$. Then the strong-star topology on $N_1(\mathcal{H})$ is again Polish. $N_1(\mathcal{H})$ is an invariant subspace for the conjugacy action of $U(\mathcal{H})$ on $B_1(\mathcal{H})$.

As noted above, understanding the unitary equivalence for all bounded linear operators comes fairly close to establishing a spectral theory for these operators. This unitary equivalence is in turn *represented* by the orbit equivalence relation of the conjugacy action of $U(\mathcal{H})$ on $B_1(\mathcal{H})$, which is now a continuous action of a Polish group on a Polish space.

Next we take a closer look at what the spectral theory of normal operators entails. This will help us identify some mathematical statements for investigation about all bounded linear operators.

We claim that what the spectral theory of normal operators achieves is a *reduction*.

Let $\mathcal{E}, \mathcal{F}$ be equivalence relations on Polish spaces $\mathcal{X}, \mathcal{Y}$, respectively. A *reduction* from $\mathcal{E}$ to $\mathcal{F}$ is a function $f : \mathcal{X} \to \mathcal{Y}$ such that, for all $x_1, x_2 \in \mathcal{X}$,

$$x_1 \mathcal{E} x_2 \iff f(x_1) \mathcal{F} f(x_2).$$

f is called a *Borel reduction* if it is a Borel measurable function from $\mathcal{X}$ to $\mathcal{Y}$. We say that $\mathcal{E}$ is *Borel reducible* to $\mathcal{F}$, and denote it by $\mathcal{E} \leq_B \mathcal{F}$, if there exists a Borel reduction from $\mathcal{E}$ to $\mathcal{F}$.

With this definition, the classification of all normal operators up to unitary equivalence can be restated as one equivalence relation being reducible to another. On the left-hand side is the unitary equivalence for all normal operators, which is in turn represented by the orbit equivalence relation of the conjugacy action of $U(\mathcal{H})$ on $N_1(\mathcal{H})$. On the right-hand side is the equivalence of measures. To put this latter equivalence in perspective, we have to come up with a Polish space of measures.

Let S be a compact metric space and let $\mathcal{B}$ be the collection of all Borel sets of S. Recall that a function $\mu : \mathcal{B} \to \mathbb{C}$ is a *complex Borel measure* on S if $\mu(\emptyset) = 0$ and for any collection $\{B_n\}_{n=1}^{\infty}$ of pairwise disjoint Borel sets,

$$\mu\left(\bigcup_{n=1}^{\infty} B_n\right) = \sum_{n=1}^{\infty} \mu(B_n),$$

where the series on the right converges absolutely. Let $M(S)$ be the space of all complex Borel measures on S, equipped with the topology generated by functions $\mu \mapsto \int f d\mu$, where $f \in C(X, \mathbb{C})$. Let

$$M_1(S) = \left\{ \mu \in M(S) : \left| \int f d\mu \right| \leq 1 \right. \\ \left. \text{for all } f \in C(X, \mathbb{C}) \text{ with } \|f\|_\infty \leq 1 \right\}.$$

Then $M_1(S)$ is a closed subspace of $M(S)$, and moreover, $M_1(S)$ is a compact metric space. Hence $M_1(S)$ is Polish.

The relations $\mu \ll \nu$ (μ is absolutely continuous with respect to ν) and $\mu \sim \nu$ (μ and ν are equivalent) are Borel on $M_1(S)$ (meaning they are Borel subsets of $M_1(S) \times M_1(S)$). Moreover, it is easy to code a countable sequence of measures in $M_1(S)$ by a single measure in $M_1(S)$.

Putting all these together, the main theorem of multiplicity theory can be restated as:

> *The orbit equivalence relation of the conjugacy action of $U(\mathcal{H})$ on $N_1(\mathcal{H})$ is Borel reducible to the measure equivalence relation $\sim$ on $M_1(D)$, where D is the unit disc on $\mathbb{C}$.*

The main addition in this restatement is the Borelness of the reduction function, which is not a trivial matter, but is straightforward to recover from the proofs of the theorems in spectral theory.

An obvious corollary of this statement is that the unitary equivalence of normal operators is a *Borel* equivalence relation because the measure equivalence relation is known to be Borel. Without spectral theory and multiplicity theory, this corollary would be by no means obvious.

Now to test the water with the possibility of a spectral theory for all bounded linear operators, it is natural to ask:

> *Is the orbit equivalence relation of the conjugacy action of $U(\mathcal{H})$ on $B_1(\mathcal{H})$ Borel?*

If the answer turned out to be no, then it would explain why a spectral theory had not been developed, and one could even argue that this was enough evidence to conclude that there would *never* be a spectral theory.

The reason we stated at the beginning of this article that there *might* be a spectral theory, therefore, is that the answer to the above question is yes.

What Does It Take to Prove This?

We give a sketch of the proof below.

First note that every bounded linear operator $T \in B(\mathcal{H})$ can be written in the form $T = A^T + iB^T$, where $A^T, B^T \in S(\mathcal{H})$; in fact

$$A^T = \frac{1}{2}(T + T^*), \quad B^T = \frac{1}{2i}(T - T^*).$$

Moreover, if $S = UTU^{-1}$ for some $U \in U(\mathcal{H})$, then $A^S = UA^TU^{-1}$ and $B^S = UB^TU^{-1}$. This simple observation implies that the mapping $T \mapsto (A^T, B^T)$ is a reduction from the orbit equivalence relation of the conjugacy action of $U(\mathcal{H})$ on $B_1(\mathcal{H})$ to the orbit equivalence relation of the conjugacy action of $U(\mathcal{H})$ on the product space $S_1(\mathcal{H}) \times S_1(\mathcal{H})$. The reduction map is actually continuous. Thus, to see that the former equivalence relation is Borel, it suffices to investigate the *diagonal* action of $U(\mathcal{H})$ on $S_1(\mathcal{H}) \times S_1(\mathcal{H})$ and show that its orbit equivalence relation is Borel.

The diagonal actions of Polish groups on product Polish spaces and the Borelness of the orbit equivalence relation are the main objects of study in [2]. The next step of the proof is to cite one of the main results of [2]. Before doing this, we will need to recall some definitions. For any Polish space $\mathcal{X}$ the *Effros Borel space* $\mathcal{F}(\mathcal{X})$ is the space of all nonempty closed subsets of $\mathcal{X}$, equipped with the Borel structure generated by basic Borel sets of the form

$$\{F \in \mathcal{F}(\mathcal{X}) : F \cap O \neq \emptyset\}$$

where O is an open subset of $\mathcal{X}$. This space was first defined by Effros in 1965 in [3]. He proved that $\mathcal{F}(\mathcal{X})$ is a *standard* Borel space, that is, there is an underlying Polish topology generating the Borel structure.

Suppose G is a Polish group, Z is a Polish space, and $a : G \times Z \to Z$ is a Borel measurable action of G on Z. For any $z \in Z$, the *stabilizer* of z is

$$G_z = \{g \in G : a(g, z) = z\}.$$

G_z is always a closed subgroup of G. We also refer to the map $z \mapsto G_z$ as the *stabilizer map*. The stabilizer map is therefore a map from Z into $\mathcal{F}(G)$. Let E_a denote the orbit equivalence relation of the action a. A well-known theorem of Becker and Kechris [1] states that E_a is Borel if and only if the stabilizer map is Borel.

The main theorem we cite from [2], Theorem 4.4, is a refinement of the above theorem of Becker and Kechris. The following is a simplified version tailored for our purpose.

> *Let G be a Polish group and let S be a Borel subset of $\mathcal{F}(G)$ that is closed under conjugation. Then the following are equivalent:*
>
> (i) *The intersection operation $(X, Y) \mapsto X \cap Y$ from $S \times S$ to $\mathcal{F}(G)$ is Borel.*
>
> (ii) *Given any Polish space Z and Borel measurable action $a : G \times Z \to Z$ of G on Z, let E_a be the orbit equivalence relation of the action a. Let $b : G \times (Z \times Z) \to (Z \times Z)$ be the diagonal action:*
>
> $$b(g, (u, v)) = (a(g, u), a(g, v)),$$
>
> *for $g \in G$, $u, v \in Z$. Let E_b be the orbit equivalence relation of the action b. Assume $G_z \in S$ for every $z \in Z$. If E_a is Borel, then E_b is Borel.*

To apply the theorem in our context, let $G = U(\mathcal{H})$, $Z = S_1(\mathcal{H})$, and we have yet to suitably define the collection S. Note that the Borelness assumption on E_a is given by the spectral theory for self adjoint operators, which is a special case of the spectral theory for normal operators.

To define the collection S we need the notion of von Neumann algebras. A subspace of $B(\mathcal{H})$ is called a $*$-*subalgebra* if it is closed under multiplication and the adjoint operations. A $*$-subalgebra of $B(\mathcal{H})$ is called a *von Neumann algebra* if it is closed in the WOT (or equivalently, closed in the SOT). If $C \subseteq S(\mathcal{H})$ is any subset, the *commutant*

$$C' = \{T \in B(\mathcal{H}) : TS = ST \text{ for any } S \in C\}$$

is a von Neumann algebra. It is easy to see that, if $S \in S_1(\mathcal{H})$, then

$$\{S\}' \cap U(\mathcal{H}) = \{U \in U(\mathcal{H}) : S = USU^{-1}\},$$

which is the stabilizer $U(\mathcal{H})_S$ for the conjugacy action of $U(\mathcal{H})$ on $S_1(\mathcal{H})$.

We now define the collection S to be $\mathrm{vNA}(U(\mathcal{H}))$, the collection of all sets of the form $\mathcal{A} \cap U(\mathcal{H})$, where $\mathcal{A}$ is a von Neumann algebra. We will prove the Borelness of $\mathrm{vNA}(U(\mathcal{H}))$ (as a subset of $\mathcal{F}(U(\mathcal{H}))$) as well as that of the intersection operation in the final step below.

Let $\mathcal{F}^*$ denote the Effros Borel space of all nonempty subsets of $B_1(\mathcal{H})$ that are closed in the strong-star topology. We will also consider $B_1(\mathcal{H})$ with the WOT, which makes $B_1(\mathcal{H})$ a compact space. Let $\mathcal{F}^w$ denote the Effros Borel space of all nonempty subsets of $B_1(\mathcal{H})$ that are closed in the WOT. Since all strong-star open sets are WOT K_σ on $B_1(\mathcal{H})$, the identity map $\mathrm{Id} : \mathcal{F}^w \to \mathcal{F}^*$ is a Borel injection. We will use this tacitly in the computations below.

Let $\mathrm{vNA}(B_1(\mathcal{H}))$ be the collection of all sets of the form $\mathcal{A} \cap B_1(\mathcal{H})$, where $\mathcal{A}$ is a von Neumann algebra. We claim that $\mathrm{vNA}(B_1(\mathcal{H}))$ is a Borel subset of $\mathcal{F}^w$. To see this, let $\{\xi_m : m \in \mathbb{N}\}$ be a dense subset of the unit ball B of $\mathcal{H}$. Fix a sequence of Borel selector maps $s_n : \mathcal{F}^* \to B_1(\mathcal{H})$ such that, for each nonempty $F \in \mathcal{F}^*$, $\{s_n(F) : n \in \mathbb{N}\}$ is dense in F in the strong-star topology. Such maps exist by the Borel selection theorem of Kuratowski and Ryll-Nardzewski (cf. Theorem 12.13 of [6]). Keep in mind that both multiplication and the adjoint operations are continuous on $B_1(\mathcal{H})$ with the strong-star topology. We can now calculate, for any $F \in \mathcal{F}^w$, that $F \in \mathrm{vNA}(B_1(\mathcal{H}))$ if and only if

$$\begin{aligned}
&\forall n \forall q \in \mathbb{Q}[\,\forall m(q \| s_n(F)\xi_m\| \le 1) \Rightarrow q s_n(F) \in F] \\
&\&\,\forall k \forall l[\,\tfrac{1}{2}(s_k(F) + s_l(F)) \in F \,\&\, s_k(F)s_l(F) \in F] \\
&\&\,\forall n\,[\,s_n(F)^* \in F\,].
\end{aligned}$$

Since $B_1(\mathcal{H})$ is compact in the WOT, the intersection operation on $\mathcal{F}^w$ is Borel. It follows that the intersection operation on $\mathrm{vNA}(B_1(\mathcal{H}))$ is Borel. To prove the Borelness of the intersection operation on $\mathrm{vNA}(U(\mathcal{H}))$, as well as to show that $\mathrm{vNA}(U(\mathcal{H}))$ itself is a Borel subset of $\mathcal{F}(U(\mathcal{H}))$, we only need to note that there is a Borel bijection between $\mathrm{vNA}(B_1(\mathcal{H}))$ and $\mathrm{vNA}(U(\mathcal{H}))$ that preserves the intersection operation. The obvious candidate $F \mapsto F \cap U(\mathcal{H})$ works. In fact, since the map $T \mapsto \exp(2\pi i B^T)$ from $B_1(\mathcal{H})$ to $U(\mathcal{H})$ is continuous with respect to the strong-star topology, we have that if $F \in \mathrm{vNA}(B_1(\mathcal{H}))$, then $F \cap U(\mathcal{H})$ is the closure of

$$\{\exp(2\pi i B^{s_n(F)}) : n \in \mathbb{N}\}.$$

This finishes the proof of our main claim of this article, which is that the unitary equivalence for all bounded linear operators is a Borel equivalence relation.

A Better Theorem

Descriptive set theory can be viewed as a complexity theory for sets of real numbers. By coding objects as elements of Polish spaces, this complexity theory can be extended to sets which occur on higher levels in the cumulative hierarchy of sets

(the cumulative hierarchy is another important contribution of von Neumann to mathematics). The notion of Borel reducibility gives rise to a complexity theory of equivalence relations on Polish spaces. If $\mathcal{E}$ is Borel reducible to $\mathcal{F}$, then intuitively we regard $\mathcal{E}$ as being no more complex than $\mathcal{F}$ because questions about $\mathcal{E}$ can be answered by resolving questions about $\mathcal{F}$ via the reduction map. By Borel reducibility one can also speak of the *essential* complexity of a Borel equivalence relation in the usual Borel hierarchy, as follows.

First recall that the σ-algebra of all Borel sets on a Polish space can be stratified into classes Σ^0_α, Π^0_α, and Δ^0_α for countable ordinals $\alpha \geq 1$. On each Polish space $\mathcal{X}$, these classes are defined by a transfinite induction:

(i) Σ^0_1 is the collection of all open subsets of $\mathcal{X}$,
(ii) for each countable ordinal $\alpha \geq 1$, Π^0_α is the collection of all subsets of $\mathcal{X}$ whose complement is in Σ^0_α,
(iii) for each $\alpha > 1$, Σ^0_α is the collection of all subsets of $\mathcal{X}$ of the form $\bigcup_{n=1}^{\infty} S_n$, where each S_n is in $\Pi^0_{\beta_n}$ for some $\beta_n < \alpha$,
(iv) for each $\alpha \geq 1$, $\Delta^0_\alpha = \Sigma^0_\alpha \cap \Pi^0_\alpha$.

For an uncountable Polish space $\mathcal{X}$, the Borel hierarchy does not collapse; that is, if $\alpha > \beta$, then each of the classes on the β-th level is a proper subset of any of the classes on the α-th level.

Let $\mathcal{E}$ be a Borel equivalence relation on a Polish space $\mathcal{X}$. Let $\alpha \geq 1$ be a countable ordinal. We say that $\mathcal{E}$ is *essentially* Π^0_α if there is a Π^0_α equivalence relation $\mathcal{F}$ on a Polish space $\mathcal{Y}$ so that $\mathcal{E}$ is Borel reducible to $\mathcal{F}$. In a similar fashion one can define the notion of essential Σ^0_α and essential Δ^0_α. Of course, if the equivalence relation $\mathcal{E}$ itself is Π^0_α, then it is essentially Π^0_α.

With this notion in hand let us take a closer look at the unitary equivalence of bounded linear operators. Again we start from the normal operators. As we noted before, spectral theory and multiplicity theory give that the unitary equivalence of normal operators is Borel reducible to the measure equivalence. By a straightforward computation, one can see that the measure equivalence is a Π^0_3 equivalence relation on $M_1(D)$. Thus we conclude that the unitary equivalence of normal operators is essentially Π^0_3.

If the unitary equivalence for all bounded linear operators turns out to be an essentially Π^0_3 equivalence relation, then we would be more confident about the existence of a new spectral theory.

The proof we demonstrated above for the Borelness of the unitary equivalence of all bounded linear operators, however, does not give an essential class for the equivalence relation. It does not even allow us to compute the Borel rank of the equivalence relation because there is no level-by-level correspondence of the Borelness of the intersection operation with that of the orbit equivalence relation of the diagonal action.

The punch line, as the reader may have suspected, is that, yes, the unitary equivalence for all bounded linear operators is essentially Π^0_3, and this is the reason we stated at the beginning of the article that a new spectral theory is *likely* to exist.

Strangely enough, the story of this result goes back to another paper [4] of Effros published in 1965. The main result of that paper is that the commutant, join, and intersection operations on the space $\mathrm{vNA}(B(\mathcal{H}))$ are Borel. But the relevance of the paper in recent research comes from a problem that Effros stated on unitary representations.

Let Γ be a countable discrete group. A *unitary representation* of Γ is a homomorphism $\rho : \Gamma \to U(\mathcal{H})$. Let $\mathrm{Rep}(\Gamma, \mathcal{H})$ be the space of all unitary representations of Γ. Since each unitary representation can be viewed as an element of $U(\mathcal{H})^\Gamma$, the space $\mathrm{Rep}(\Gamma, \mathcal{H})$ can be viewed as a subspace of $U(\mathcal{H})^\Gamma$. Equipping $U(\mathcal{H})^\Gamma$ with the product topology, $\mathrm{Rep}(\Gamma, \mathcal{H})$ is a closed subspace, hence is Polish. Two representations ρ and π of Γ are *unitarily equivalent* if there exists $U \in U(\mathcal{H})$ such that for all $g \in \Gamma$,

$$\rho(g) = U\pi(g)U^{-1}.$$

Effros asked if the unitary equivalence of all unitary representations of Γ is a Borel equivalence relation.

This was recently given a positive answer by Hjorth and Törnquist [5]. In fact, they were able to determine the Borel rank of these equivalence relations:

> *For any countable discrete group* Γ*, the unitary equivalence relation on* $\mathrm{Rep}(\Gamma, \mathcal{H})$ *is* Π^0_3.

As a direct corollary, the orbit equivalence relation of the diagonal conjugacy action of $U(\mathcal{H})$ on $U(\mathcal{H}) \times U(\mathcal{H})$ is also Π^0_3. To see this, consider the reduction map from $U(\mathcal{H}) \times U(\mathcal{H})$ to $\mathrm{Rep}(\mathbb{F}_2, \mathcal{H})$, where $\mathbb{F}_2 = \langle a, b \rangle$ is the free group with two generators a and b, given by $(S, T) \mapsto \rho$, where

$$\rho(w(a, b)) = w(S, T)$$

for any group word $w(a, b) \in \mathbb{F}_2$. Note that this map is continuous.

Finally, it suffices to see that the unitary equivalence of all bounded linear operators is Borel reducible to the above diagonal orbit equivalence relation. Earlier in this article we mentioned that it is Borel reducible to the orbit equivalence relation of the diagonal conjugacy action of $U(\mathcal{H})$ on $S_1(\mathcal{H}) \times S_1(\mathcal{H})$. Now it suffices to note that this reduction can be composed with another reduction from $S_1(\mathcal{H})$ to $U(\mathcal{H})$ via the map $T \mapsto \exp(2\pi i T)$.

It is easy to see that all the reductions used in the composition above are continuous, which implies that the unitary equivalence of all bounded linear operators is itself a Π^0_3 equivalence relation.

With this result we are one step closer to reaching a spectral theory. One can extract from [5] the functional analytical machinery that is needed to effectively decide when a pair of bounded linear operators are unitarily equivalent. However, what is expected from a spectral theory is a method to extract all important structural information from a *single* operator, so that a classification can be performed by comparing this information extracted separately from different operators.

What's Next?

The next rigorous question that can be asked from the point of view of descriptive set theory is the following:

> *Is the unitary equivalence of all bounded linear operators Borel reducible to the measure equivalence?*

As we speculated before, if the answer turns out to be positive, then it should be possible to extract a new spectral theory from its proof.

Of course, the ultimate solution to the problem is likely to need all the techniques of functional analysis, especially operator theory. The story told in this article confirms again that all of mathematics is deeply connected, and we hope the reader is as excited as we are by these connections.

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Solving Rota's Conjecture

Jim Geelen, Bert Gerards, and Geoff Whittle

In 1970, Gian-Carlo Rota posed a conjecture predicting a beautiful combinatorial characterization of linear dependence in vector spaces over any given finite field. We have recently completed a fifteen-year research program that culminated in a solution of Rota's Conjecture. In this article we discuss the conjecture and give an overview of the proof.

Matroids are a combinatorial abstraction of linear independence among vectors; given a finite collection of vectors in a vector space, each subset is either dependent or independent. A matroid consists of a finite *ground set* together with a collection of subsets that we call *independent*; the independent sets satisfy natural combinatorial axioms coming from linear algebra. Not all matroids can be represented by a collection of vectors and, ever since their introduction by Hassler Whitney [26] in 1935, mathematicians have sought ways to characterize those matroids that are. Rota's Conjecture asserts that representability over any given *finite field* is characterized by a finite list of obstructions. We will formalize these notions, and the conjecture, in the next section. In the remainder of this introduction, we will describe the journey that led us to a solution.

In the late 1990s, Rota's Conjecture was already known to hold for fields of size two, three, and four. Geelen, Gerards, and Kapoor [4] had recently announced that there are seven obstructions for representability over the four element field. As far back as 1958, Tutte had already proved that there is one obstruction for the class of binary matroids [22], and in the 1970s Bixby [1] and Seymour [20] had independently proved that there are four obstructions for the class of ternary matroids, verifying a result that was announced earlier by Ralph Reid.

It was a promising time for matroid theory; a number of useful new techniques had emerged in the previous decade, and it looked like there was real potential for major progress. Nevertheless, there is a significant difference between the concrete problem of finding the full set of obstructions for some particular field and the abstract problem of showing that there are finitely many obstructions for an arbitrary finite field. The techniques available at that time did not offer any realistic hope of solving Rota's Conjecture in general.

Our hopes were raised in 1999, at a workshop on graph theory in Oberwolfach, Germany, when Neil Robertson and Paul Seymour proposed ideas for extending their Graph Minors Project to matroids. We eagerly took up the challenge; the Graph Minors Theory had exactly the kind of general purpose tools that we lacked. Their results were published in a series of twenty-three journal papers totalling more than 700 pages, and we spent the next year learning how the machinery worked.

Then we set about the daunting task of extending the Graph Minors Theory to matroids. That was a major undertaking which took a decade to complete. The first three years were the hardest, and during that time it was not at all clear that we would succeed. The relief was palpable when we made our first major breakthrough in November of 2002. That marked a massive turning point in the project: from that point on we had no doubt that we would get to the end, despite the enormity

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of the task that lay ahead. We even maintained our optimism through two bleak years, 2006 and 2007, when we made almost no discernible progress despite considerable effort.

In early 2011 we had extended the main part of the Graph Minors Project to matroids. The techniques that we had developed were general and powerful, however, there were still many issues that were particular to Rota's Conjecture that had to be addressed. In fact, at that time we did not have a concrete approach in mind, and our first serious attempt to prove Rota's Conjecture, later in 2011, failed. In early 2012 we hatched a new plan of attack and spent the rest of that year developing the required machinery. When we met together in January 2013, we were confident that we had the right method and all of the required tools; after three weeks of joint work we had thrashed out the remaining details.

We are now immersed in the lengthy task of writing up our results. Since that process will take a few years, we have written this article offering a high-level preview of the proof.

What Is a Matroid?

A *matroid* consists of a pair $(E, \mathcal{I})$ where E is a finite set, called the *ground set*, and $\mathcal{I}$ is a collection of subsets of E, called *independent sets*, such that

1. the empty set is independent,
2. subsets of independent sets are independent, and
3. for each set $X \subseteq E$, the maximal independent subsets of X all have the same size.

The canonical example of a matroid comes from a collection of vectors in a vector space or, equivalently, the columns of a matrix. Let A be a matrix over a field $\mathbb{F}$, and let E be the set of column-indices of A. The *column matroid* of A, denoted by $M(A)$, is the pair $(E, \mathcal{I})$ where $\mathcal{I}$ is the collection of subsets of E that index linearly independent sets of columns. A matroid is called *$\mathbb{F}$-representable* if it is the column matroid of a matrix over the field $\mathbb{F}$.

The matroid axioms allow us to extend notions such as *bases* and *rank* from linear algebra to matroids; a *basis* being a maximal independent set and the *rank* of a set X in a matroid $M = (E, \mathcal{I})$, denoted $r_M(X)$, being the size of a maximal independent subset of X.

There are matroids that are not representable over any field; indeed, it is believed, but not yet proven, that the proportion of n-element matroids that are representable is vanishingly small as n tends to infinity. It was Whitney himself, in the introductory paper on matroid theory [26] in 1935, who posed the problem of characterizing the class of representable matroids.

Whitney's problem is open to interpretation in that there are many different types of characterizations that one might consider and that one can consider representability over a specified or unspecified field. With two notable exceptions, most interpretations of Whitney's problem have been met with negative answers; see [11], [12], [13], [21]. The first exception is the algorithmic problem of determining when a given matroid is representable over an unspecified field, which was proved to be decidable by Vámos [28]. The second exception is, of course, Rota's Conjecture.

Matroid Duality

Matroids come in dual pairs; the *dual* of M, denoted M^*, is the matroid on E whose bases are the complements of the bases of M. While it is not immediately clear from this definition, M^* is indeed always a matroid. More surprising, perhaps, is the fact that $\mathbb{F}$-representability is preserved under duality. Indeed, if $M = M(A)$, then $M(A)^* = M(A')$, where A' is a matrix whose row space is the orthogonal space of the row space of A.

Minors of Matroids

Let C and D be sets of elements in a matroid $M = (E, \mathcal{I})$. The matroid obtained from M by *deleting* D is defined as $(E - D, \{I \subseteq E - D : I \in \mathcal{I}\})$. Note that $M \setminus D$ is clearly always a matroid. The dual operation of deletion is *contraction* which is defined by $M/C = (M^* \setminus C)^*$. This definition of contraction is not particularly illuminating; geometrically it corresponds to *projection* from C, which is more readily seen via the rank function

$$r_{M/C}(X) = r_M(X \cup C) - r_M(C).$$

A *minor* of M is a matroid of the form $M \setminus D/C$, where D and C are disjoint subsets of E; when $D \cup C$ is nonempty, we call the minor *proper*. Note that the class of $\mathbb{F}$-representable matroids is closed under both deletion and duality and, hence, also under taking minors. For any minor-closed class of matroids, it is natural to consider characterizing the class by describing the *excluded minors*, that is, the matroids outside the class whose proper minors are all in the class—which brings us to Rota's Conjecture [19].

Conjecture 1 (Rota)**.** *For each finite field $\mathbb{F}$, there are, up to isomorphism, only finitely many excluded minors for the class of $\mathbb{F}$-representable matroids.*

Since a minor-closed class is determined by its list of excluded minors, Rota's Conjecture provides a succinct characterization for the class of $\mathbb{F}$-representable matroids.

Figure 1. The 4-point line, $U_{2,4}$; the 5-point line, $U_{2,5}$; and the Fano plane, F_7.

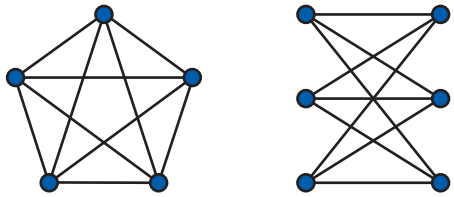

Figure 2. The Kuratowski graphs: K_5 and $K_{3,3}$.

Combinatorial Geometry

Consider a representable matroid $M = M(A)$. If A' is a matrix that is obtained from A by elementary row operations and column scaling, then A' is also a representation. Observe that, in obtaining A' from A in this way, we have simply applied a projective transformation to the column space of A, and, hence, we say that A and A' are *projectively equivalent*.

Now, instead of considering the elements in a representable matroid as vectors in a vector space, we could equally well regard them as points in a projective geometry. While this is a relatively small shift in perspective, it is surprisingly useful for intuition, and a lot of matroid terminology comes from geometry. For example, a *rank-k flat* is a maximal set of rank k. A *point* is a rank-1 flat, a *line* is a rank-2 flat, a *plane* is a rank-3 flat, and a *hyperplane* is a flat of rank $r_M(E) - 1$.

This geometric approach has the additional feature that it provides a succinct method for describing matroids of low rank. For example, Figure 1 depicts three important matroids $U_{2,4}$, $U_{2,5}$, and F_7. The 4-point line, $U_{2,4}$, is the only excluded minor for the class of binary matroids, and the excluded minors for the class of ternary matroids are $U_{2,5}$, F_7, and their duals.

Graph Minors Project

A *minor* of a graph G is a graph that is obtained from a subgraph of G by *contracting* some edges. To contract an edge, one identifies the ends of the edge into a single vertex and then deletes the edge.

Note that the class of planar graphs is closed under taking minors. As we will see, this class turns out to be particularly fundamental in the study of graph minors. It is therefore fitting to begin with Kuratowski's characterization of the class of planar graphs [10], which is one of the gems of mathematics.

Theorem 2 (Kuratowski's Theorem)**.** *A graph is not planar if and only if it has a minor isomorphic to $K_{3,3}$ or K_5.*

We can restate Kuratowski's Theorem as: the excluded minors for the class of planar graphs are $K_{3,3}$ and K_5; see Figure 2.

Robertson and Seymour generalized this result from the plane to arbitrary surfaces in [16].

Theorem 3 (Generalized Kuratowski's Theorem)**.** *For any given surface, there are only finitely many excluded minors for the class of graphs that embed in the surface.*

Later Robertson and Seymour further generalized the result to arbitrary minor-closed classes [18]. Diestel, in his book on graph theory [2], says that this theorem "dwarfs any other result in graph theory and may doubtless be counted among the deepest theorems that mathematics has to offer".

Theorem 4 (Well-Quasi-Ordering Theorem)**.** *Each minor-closed class of graphs has only finitely many excluded minors.*

The following two statements are reformulations of the WQO Theorem:

- In each infinite set of graphs there are two graphs, one isomorphic to a minor of the other.
- There are only countably many distinct minor-closed classes of graphs.

How then does one go about proving such a result? The first step is obvious. Suppose that the result is false and, hence, there exists an infinite sequence $(H_1, H_2, \ldots)$ of graphs such that none is isomorphic to a minor of another. In particular, none of the graphs $(H_2, H_3, \ldots)$ contains a minor isomorphic to H_1. The next step is to ask what a graph looks like if it does not contain a minor isomorphic to H_1. This question is answered by the Graph Minors Structure Theorem [17], which is the workhorse of the Graph Minors Project.

Let $\mathrm{EX}(H_1)$ denote the set of graphs that do not contain a minor isomorphic to H_1. If S is a surface into which H_1 does not embed, then every graph that embeds in S is clearly in $\mathrm{EX}(H_1)$. Let $\mathcal{G}$ denote the set of graphs that embed into a surface that does not embed H_1. Thus $\mathcal{G} \subseteq \mathrm{EX}(H_1)$. The gist of the Graph Minors Structure Theorem is that each graph in $\mathrm{EX}(H_1)$ can be constructed from graphs in $\mathcal{G}$ in a specified way.

Note that, if H_1 is planar, then it embeds in every surface and, hence, the class $\mathcal{G}$ is empty. Therefore graphs omitting H_1 have a particularly simple structure; see [15]. The extension of that result to matroids over finite fields [5] was our first major breakthrough.

The Graph Minors Structure Theorem gives considerable traction with the WQO Theorem, but completing the proof still requires more than 100 pages of careful argument.

From Graphs to Matroids

A *circuit* in a graph $G = (V, E)$ is a connected subgraph of G whose vertices all have degree 2, and a *forest* of G is a subgraph of G that does not contain a circuit. The *cycle matroid* of G, denoted $M(G)$, is defined as $(E, \mathcal{F})$ where $\mathcal{F}$ is the collection of all edge-sets of forests of G. It is easy to show that $M(G)$ is always a matroid. A matroid is called *graphic* if it is the cycle matroid of a graph.

The class of graphic matroids turns out to be surprisingly fundamental, in much the same way that the class of planar graphs is fundamental in the Graph Minors Project. Substantial parts of matroid theory have their roots in graph theory, which, given what we now know, is not at all surprising. This link to graph theory has also shaped the terminology. Note that the minimal dependent sets of $M(G)$ are the edge-sets of circuits of G. This terminology is carried over to general matroids: a minimal dependent set in a matroid is called a *circuit*.

Minors and Duality

The class of graphic matroids is minor-closed. Moreover, if D and C are disjoint edge-sets in a graph G, then $M(G \setminus D/C) = M(G) \setminus D/C$. The class of graphic matroids is not, however, closed under duality. In fact, a graph G is planar if and only if $M(G)^*$ is graphic. This beautiful geometric characterization of planarity was observed by Whitney [25] and is the first glimpse of a deep connection between matroid theory and topological graph theory.

By the discussion above, any characterization of the class of graphic matroids gives a characterization for the class of planar graphs. In particular, the following excluded-minor characterization for the class of graphic matroids, due to Tutte [23], implies Kuratowski's Theorem.

Theorem 5. *The excluded minors for the class of graphic matroids are $U_{2,4}$, F_7, $(F_7)^*$, $M(K_{3,3})^*$, and $M(K_5)^*$.*

Representability

Graphic matroids are representable; in fact, they are representable over every field. The *signed-incidence* matrix of a graph $G = (V, E)$ is a matrix $A \in \{0, \pm 1\}^{V \times E}$ such that, for each edge e with ends u and v, if $u = v$, then the column indexed by e is identically zero, and if $u \neq v$, then the column indexed by e has exactly one 1 and exactly one -1, and these are in the (u, e) and (v, e) positions, in no particular order; see Figure 3. It is a routine exercise to verify that A is a representation of $M(G)$ over any field.

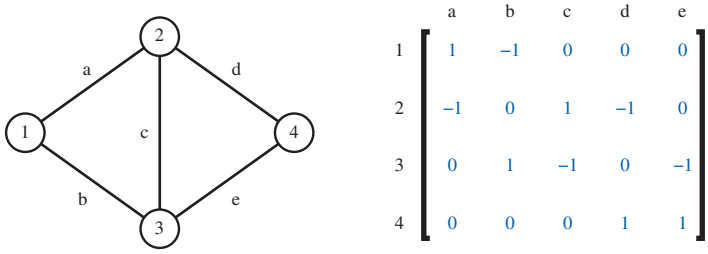

Figure 3. A graph and its signed-incidence matrix.

Frame Matroids

The class of graphic matroids is contained in a richer class of matroids, namely the class of "frame matroids". A *frame matrix* over $\mathbb{F}$ is a matrix with at most two nonzero entries per column, and a *frame matroid* over $\mathbb{F}$ is one that is represented by a frame matrix. As with the class of graphic matroids, the class of frame matroids is closed under taking minors. Moreover, there is a natural way to associate a graph with a frame matroid, although, to fully describe the matroid one needs to "decorate" the graph by orienting and labelling its edges.

Matroid Minors Project

Rota's Conjecture is reminiscent of the Generalized Kuratowski Theorem. Robertson and Seymour were able to further generalize the Generalized Kuratowski Theorem to obtain the WQO Theorem, so, perhaps, Rota's Conjecture is a special case of a much more general theorem. However, it is not true that the WQO Theorem extends to all matroids. An *antichain* of matroids is a set of matroids no one of which is isomorphic to a minor of another. It is surprisingly easy to construct infinite antichains; the matroids $\{M_3, M_4, M_5, \ldots\}$ in Figure 4, for example, form an infinite antichain of rank-3 matroids.

We were, however, able to prove the following significant generalization of the WQO Theorem.

Theorem 6 (Matroid WQO Theorem)**.** *For each finite field $\mathbb{F}$ and each minor-closed class of $\mathbb{F}$-representable matroids, there are only finitely many $\mathbb{F}$-representable excluded minors.*

This result is incomparable with Rota's Conjecture, in the sense that neither result implies the other, since, in Rota's Conjecture, the excluded minors are, by definition, not representable over $\mathbb{F}$.

Our proof of the Matroid WQO Theorem parallels the proof of the WQO Theorem for graphs. The

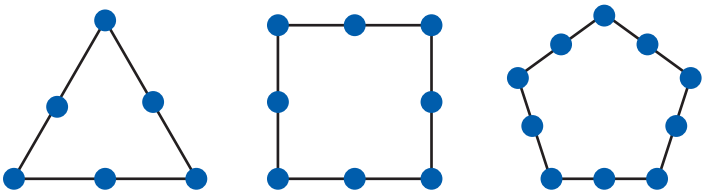

Figure 4. The first three matroids, M_3, M_4, and M_5, in an infinite antichain.

most significant ingredient is an analogue of the Graph Minors Structure Theorem. Recall that the Graph Minors Structure Theorem essentially says that, for any minor closed class of graphs, the graphs in the class can be constructed, in specified ways, from graphs that embed in surfaces of low genus.

For a finite field $\mathbb{F}$, what are the fundamental minor-closed classes of $\mathbb{F}$-representable matroids? It turns out that there are, up to duality, only two types. First, for each subfield $\mathbb{F}'$ of $\mathbb{F}$, the set of all $\mathbb{F}'$-representable matroids is minor-closed. The second is the class of frame matroids over $\mathbb{F}$.

The Matroid Minors Structure Theorem describes, for a finite field $\mathbb{F}$, how to construct, in a specified way, the members of an arbitrary fixed minor-closed class of $\mathbb{F}$-representable matroids from matroids represented over subfields, frame matroids, and the duals of frame matroids. It is this theorem that consumed most of our effort—it took more than a decade to prove.

Toward Rota's Conjecture

While we have been working together since 1999, it was not until 2012 that we finally formulated our strategy for attacking Rota's Conjecture. Prior to 2012 we were primarily immersed in the Matroid Minors Structure Theory. In this section we outline the machinery that we developed specifically for proving Rota's Conjecture. Significant parts of the machinery were developed with Tony Huynh and Stefan van Zwam who were postdoctoral fellows with Bert Gerards.

Connectivity

Connectivity plays a significant role in matroid theory in general and in the proof of Rota's Conjecture in particular. The following definitions are due to Tutte [24]. A *k-separation* in a matroid $M = (E, \mathcal{I})$ is a partition (X, Y) of E such that $r_M(X) + r_M(Y) - r_M(E) < k$ and $|X|, |Y| \geq k$. A matroid is *k-connected* if it has no l-separation for any $l < k$.

To motivate the definition, consider the case that M is represented by a matrix A. Let $\mathbb{V}$ denote the column space of A, and let $\langle X \rangle$ denote the subspace of $\mathbb{V}$ spanned by the columns indexed by X. The dimension theorem for subspaces shows that the dimension of $\langle X \rangle \cap \langle Y \rangle$ is equal to $r_M(X) + r_M(Y) - r_M(E)$. So when $r_M(X) + r_M(Y) - r_M(E)$ is small, X and Y are separated by a low-dimensional subspace of $\mathbb{V}$. The condition that $|X|, |Y| \geq k$ is a nondegeneracy condition that is needed since $r_M(X) + r_M(Y) - r_M(E) \leq \min(|X|, |Y|)$.

Problems concerning matroid representation typically reduce to the 3-connected case, and this is true of Rota's Conjecture.

Lemma 7. *For each field $\mathbb{F}$, each excluded minor for the class of $\mathbb{F}$-representable matroids is 3-connected.*

Unfortunately one cannot easily improve on Lemma 7; for each finite field of order at least 3, there is an excluded minor that is not 4-connected. The problem is that the nondegeneracy condition $|X|, |Y| \geq k$ is too weak. We were able to prove:

Theorem 8. *For each finite field $\mathbb{F}$ and integer k there is an integer $n = n(\mathbb{F}, k)$ such that, if (A, B) is a k-separation in an excluded minor for the class of $\mathbb{F}$-representable matroids, then $\min(|A|, |B|) \leq n$.*

We do not know an elementary proof of Theorem 8; our proof relies on several difficult results, including the Matroid WQO Theorem. As a consequence of applying well-quasi-ordering techniques in the proof, we do not have a computable bound on $n(\mathbb{F}, k)$, which, in turn, means that we do not obtain a computable bound on either the number or the size of the excluded minors for the class of $\mathbb{F}$-representable matroids.

Theorem 8 shows that the excluded minors are very highly connected in some sense. Henceforth we will focus on excluded minors that are very highly connected in Tutte's sense. While we lose some generality in doing so, we avoid a lot of technicalities without bypassing the main issues.

Inequivalent representations

Recall that, if A_1 and A_2 are projectively equivalent matrices, then they represent the same matroid. There are matroids that admit many projectively inequivalent representations over a given finite field; this is one of the major sources of difficulty in the area of matroid representation and is the focus of much attention [6], [8], [9], [14], [27]. This difficulty is tamed by considering matroids that have sufficiently high connectivity.

Theorem 9. *For each finite field $\mathbb{F}$, there exist integers k_1 and n_1 such that each k_1-connected matroid has at most n_1 projectively inequivalent representations over $\mathbb{F}$.*

Theorem 9 was proved in 2012 by Geelen, Gerards, Huynh, and Van Zwam [3]. That paper develops groundbreaking inductive tools for dealing with highly-connected matroids. The key is to

weaken the notion of connectivity in a manner compatible with Theorem 8. Those connectivity tools should find wider application in combinatorics, particularly in graph theory.

Bifurcation of Representations and Fixed Elements

Let $\mathbb{F}$ be a finite field, and let k_1 and n_1 be the integers given by Theorem 9. Suppose that e is an element of an $\mathbb{F}$-representable matroid and that M and $M \setminus e$ are both k_1-connected. While Theorem 9 shows that M and $M \setminus e$ both have at most n_1 inequivalent representations, it does not describe how the representations are related. Some representations of $M \setminus e$ may not extend to representations of M while others may bifurcate to two or more inequivalent representations of M; this bifurcation is a significant cause of difficulty for us. Fortunately we understand the root cause of bifurcation.

Suppose that A is a representation of $M \setminus e$ that extends to two projectively inequivalent representations $[A, u]$ and $[A, v]$ of M. Let

$$A' = \begin{array}{c} \\ A \end{array} \begin{array}{c} \begin{array}{cc} e & e' \end{array} \\ \left(\begin{array}{cc} u & v \end{array} \right) \end{array},$$

and let $M' = M(A')$. Note that swapping e and e' defines an automorphism of M'; we say that e and e' are *clones* in M'. Moreover, since $[A, u]$ and $[A, v]$ are projectively inequivalent, $\{e, e'\}$ is an independent set in M'. We say that an element e is *fixed* in M if it is not possible to get a matroid M' by extending M by an element e' so that $\{e, e'\}$ is an independent clonal pair. The next lemma follows directly from the discussion above.

Lemma 10. *If e is a fixed element in a matroid M, then no representation of $M \setminus e$ extends to two projectively inequivalent representations of M.*

The following result shows that highly connected $\mathbb{F}$-representable matroids contain few elements that are not fixed.

Theorem 11. *For each finite field $\mathbb{F}$, there exist integers k_2 and n_2 such that each k_2-connected $\mathbb{F}$-representable matroid has at most n_2 elements that are not fixed.*

Theorem 11 was proved by Geelen and Van Zwam [7]. The proof relies on the main result of [5], which describes the structure of an $\mathbb{F}$-representable matroid when we exclude the cycle matroid of a planar graph as a minor.

Theorems 9 and 11 provide us with a lot of control over the inequivalent representations of a matroid. However, as early as 1999, we already had much stronger results controlling the inequivalent representations of GF(5)-representable matroids [14], [27], and yet we still do not know the full set of excluded minors.

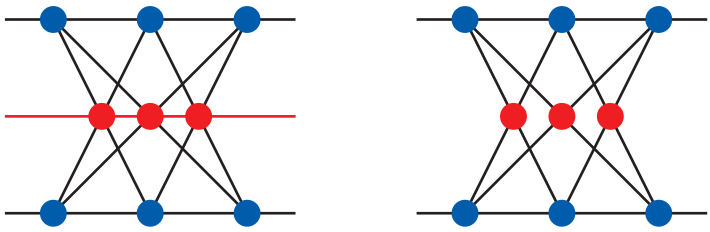

Figure 5. The Pappus matroid and the non-Pappus matroid.

Relaxing a Circuit-Hyperplane

Recall that a hyperplane in a matroid $M = (E, \mathcal{I})$ is a maximal set of rank $r_M(E) - 1$ and a circuit is a minimal dependent set. If C is both a circuit and a hyperplane, then we can construct a new matroid M' from M by *relaxing* C, that is $M' = (E, \mathcal{I} \cup \{C\})$.

This construction does not respect representability. Consider for example the matroids in Figure 5. The Pappus matroid is representable over the reals, which is evident by its straight-line drawing. The *non-Pappus* matroid, is obtained from the Pappus matroid by relaxing the circuit-hyperplane indicated in red. Pappus's *Collection* (circa 340 A.D.) already contained a proof that the non-Pappus matroid is not representable over the reals. In fact, the non-Pappus matroid is not representable over any field.

While the operation of relaxing a circuit-hyperplane does not behave well with respect to representation in general, it behaves particularly poorly with respect to representation over finite fields. By making this explicit, we obtain a method for certifying nonrepresentability in the proof of Rota's Conjecture. The following result shows that, if M is a sufficiently large and sufficiently connected matroid, and if M' is a matroid obtained from M by relaxing a circuit-hyperplane, then M and M' cannot both be representable over a given finite field.

Theorem 12. *For each finite field $\mathbb{F}$, there exist integers k_3 and n_3 such that, if M_1 and M_2 are $\mathbb{F}$-representable matroids on a common ground set E, where M_2 is obtained from M_1 by relaxing a circuit-hyperplane and M_1 is k_3-connected, then $|E| \leq n_3$.*

In fact, we proved a stronger result. Note that, if M_2 is obtained from M_1 by relaxing C, then $M_1 \setminus e = M_2 \setminus e$ for each $e \in C$.

Theorem 13. *For each finite field $\mathbb{F}$, there exist integers k_4 and n_4 such that, if M_1 and M_2 are distinct $\mathbb{F}$-representable matroids on a common ground set E and M_1 is k_4-connected, then there is a set $X \subseteq E$ such that $|X| \leq n_4$ and $M_1 \setminus e \neq M_2 \setminus e$ for each $e \in E - X$.*

This result is the hardest step in resolving Rota's Conjecture and relies on the full strength of the Matroid Minors Structure Theory that we had developed earlier. Much of the proof is graph theoretic, which is a little surprising given the statement of the result.

Highly Connected Excluded Minors

In this final section, we indicate how the machinery developed in the previous section can be combined to prove a weakening of Rota's Conjecture. In particular, we prove that, for each finite field $\mathbb{F}$, there are only finitely many highly connected excluded minors for the class of $\mathbb{F}$-representable matroids. This proof exemplifies all of the techniques needed to prove Rota's Conjecture in general other than one technical connectivity result which we discuss after the proof.

Theorem 14. *For each finite field $\mathbb{F}$, there exists an integer k such that the class of $\mathbb{F}$-representable matroids has no k-connected excluded minor with $2k$ or more elements.*

Proof. Let k_1, k_2, k_4, n_1, n_2, and n_4 be the integers given by Theorems 9, 11, and 13. Let

$$t = n_1(n_2+1)(n_4+1),$$

and let

$$k = \max(k_1 + n_1(n_4+1), k_2 + t, k_4 + 1).$$

Suppose that there is a k-connected excluded minor $M = (E, \mathcal{I})$ with $|E| > 2k$.

Throughout the proof we freely make use of the fact that, for any set $Z \subseteq E$, $M \setminus Z$ is $(k - |Z|)$-connected.

Let X_1 be a t-element subset of E, and let Π be a partition of X into $n_1(n_4+1)$ sets of size n_2+1. By Theorem 11, for each $Y \in \Pi$, there is an element $e \in Y$ that is fixed in $M \setminus (X_1 - Y)$. Let X_2 be a transversal of Π containing one such element from each set in Π; thus $|X_2| = n_1(n_4+1)$.

By Theorem 9, $M \setminus X_2$ has at most n_1 inequivalent representations. Since M is an excluded minor, $M \setminus e$ is representable for each $e \in X_2$. So there exists a representation A_0 of $M \setminus X_2$ and an (n_4+1)-element subset X_3 of X_2 such that A_0 extends to a representation of $M \setminus e$ for each $e \in X_3$. By construction, each element $e \in X_2$ is fixed in $M \setminus (X_2 - \{e\})$. So, by Lemma 10, the representation A_0 extends uniquely to a representation of $M \setminus (X_2 - \{e\})$. Thus we obtain a unique matrix A such that $A|(E - X_2) = A_0$ and, for each $e \in X_3$, $M(A) \setminus e = M \setminus e$.

Since M is not $\mathbb{F}$-representable, $M \neq M(A)$. Therefore there exists a set $B \subseteq E$ that is a basis in exactly one of M and $M(A)$. Note that $X_3 \subseteq B$. Choose $f \in E - B$. Now $M \setminus f$ and $M(A) \setminus f$ are distinct $\mathbb{F}$-representable matroids on the same ground set. Moreover $M \setminus f, e = M(A) \setminus f, e$ for each $e \in X_3$. This contradicts Theorem 13, and this contradiction completes the proof. □

To prove Rota's Conjecture in general, we start with an n-element excluded minor M, as in the proof above. By Theorem 8, M is "weakly" k-connected. Then, using the techniques developed in [3], we find a t-element set X_1 such that, after possibly replacing M with its dual, $M \setminus D$ remains weakly k-connected for each $D \subseteq X_1$. The rest of the proof continues as above.

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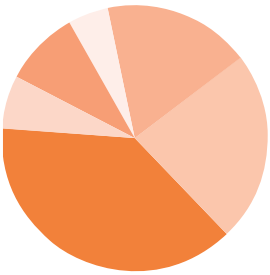
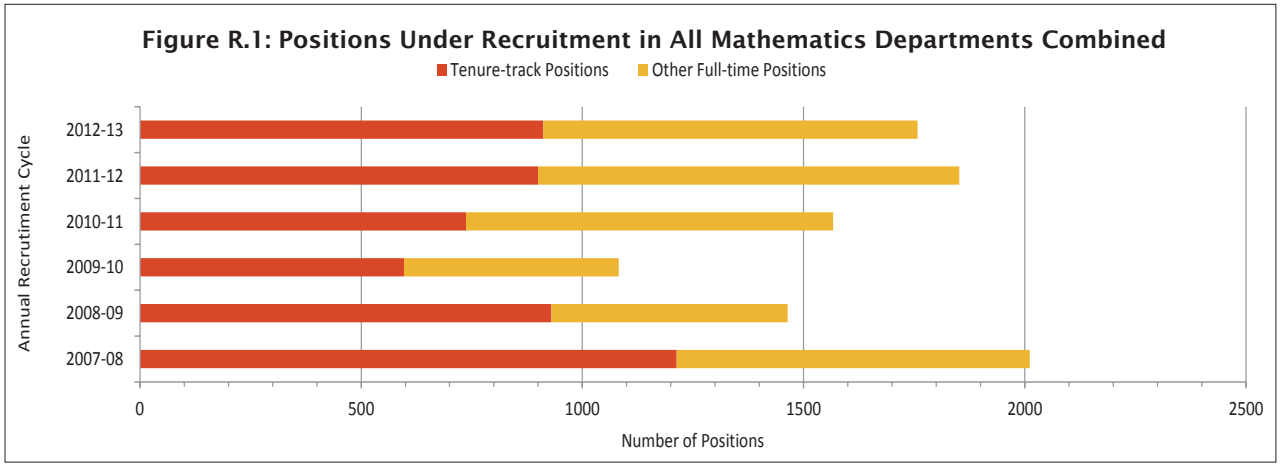
AIM seeks to promote diversity in the mathematics research community. We encourage proposals which include significant participation of women, underrepresented minorities, junior scientists, and researchers from primarily undergraduate institutions.



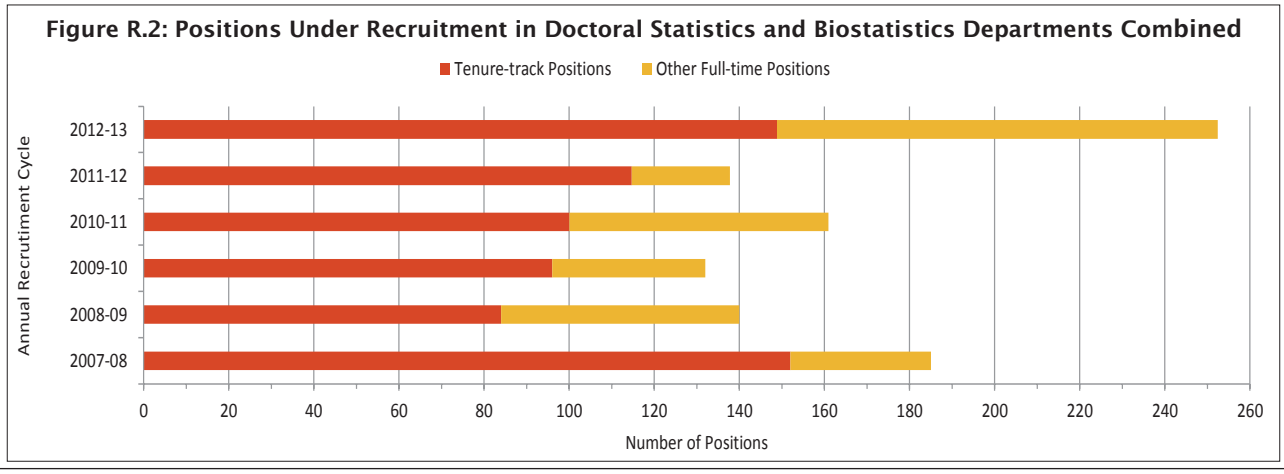
Report on 2012–2013 Academic Recruitment and Hiring

William Yslas Vélez, James W. Maxwell, and Colleen Rose

The number of full-time positions under recruitment in mathematics departments decreased during the 2012–2013 academic recruitment cycle (for employment beginning in fall 2013). The total number of positions under recruitment by all mathematics departments combined was 1,757[1]. This number is down 5% from the 2011–2012 total and up 12% from the 2010–2011 total. (Note: Throughout this report, the term tenure-track encompasses positions that come with tenure as well as those which provide the option of earning tenure at some point after appointment.)



The doctoral statistics and biostatistics department groupings each reported an 83% increase in the number of positions under recruitment over the numbers reported for the prior year, an (estimated[1]) combined total of 252 positions under recruitment for the 2012-2013 recruitment cycle. The increase (114) reported for the biostatistics departments was heavily affected by the recruitment in just two of the 24 responding departments which, combined, accounted for over half of the total recruitment reported. It will be interesting to see if this increase in recruitment continues next year.



[1] *All numbers reported are estimates made to account for non-responding departments. See page 749 for response rates.*

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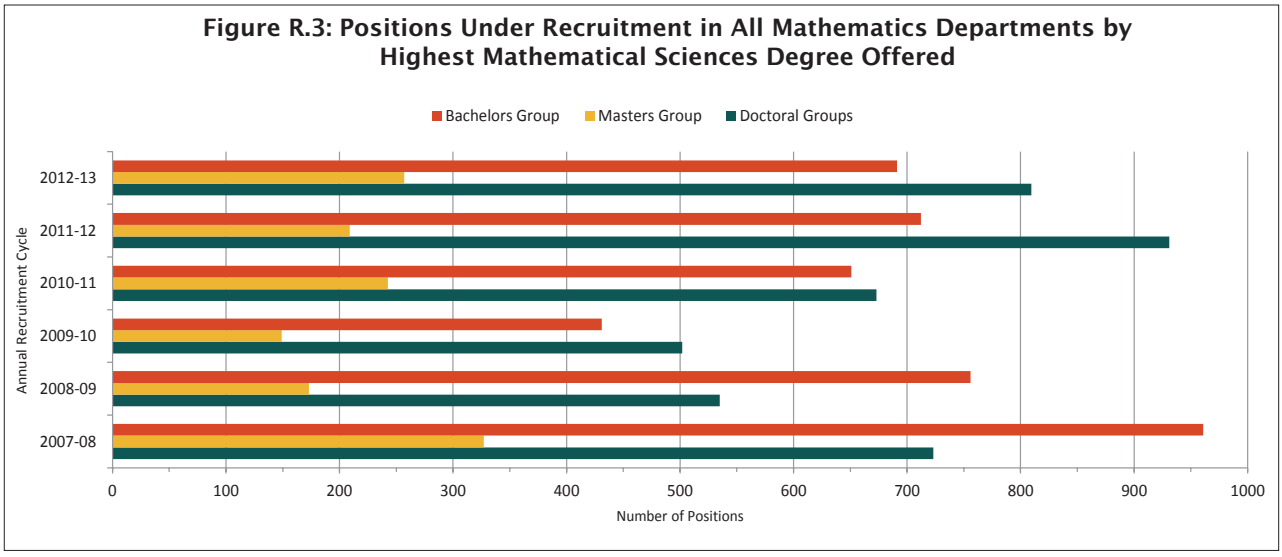
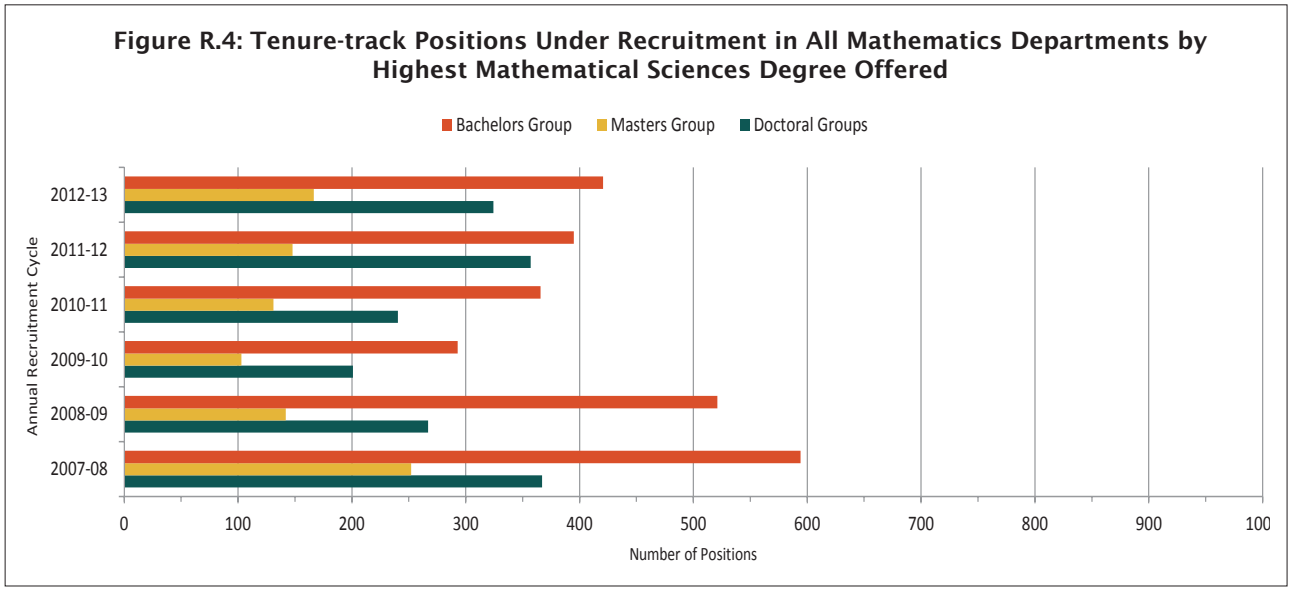
Positions Under Recruitment

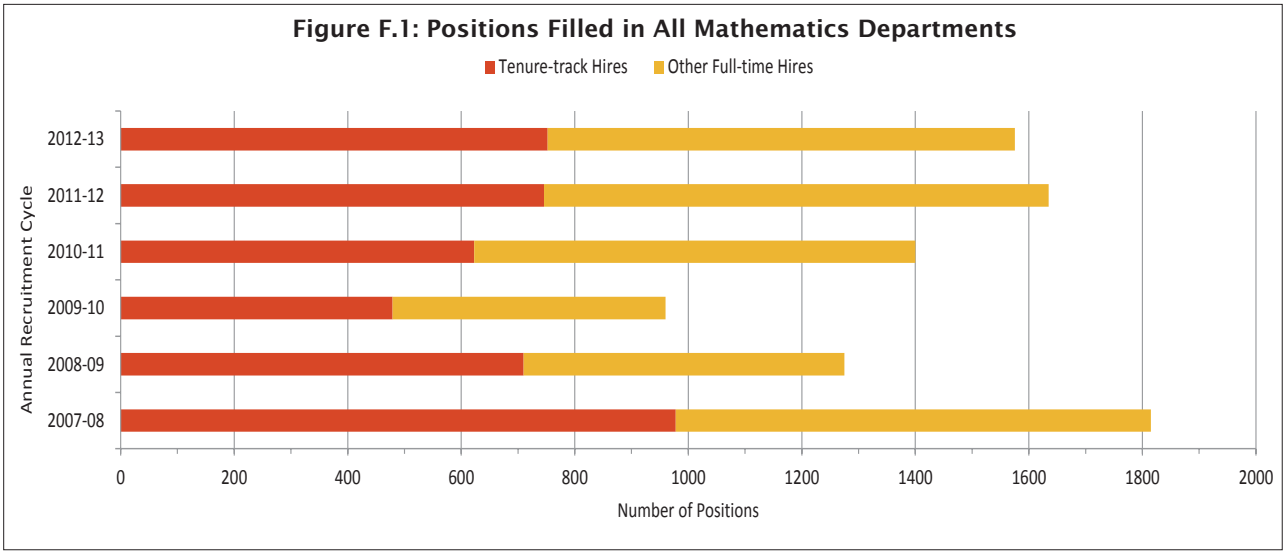
The overall number of positions under recruitment decreased among the mathematics departments. There was a 13% decrease for the doctoral mathematics groups combined, a 23% increase for the masters group and a 3% decrease for the bachelors group. Recruitment of tenure-track positions increased overall, but decreased 9% among the doctoral mathematics groups combined and increased in both the masters and bachelors groups by 13% and 7%, respectively.



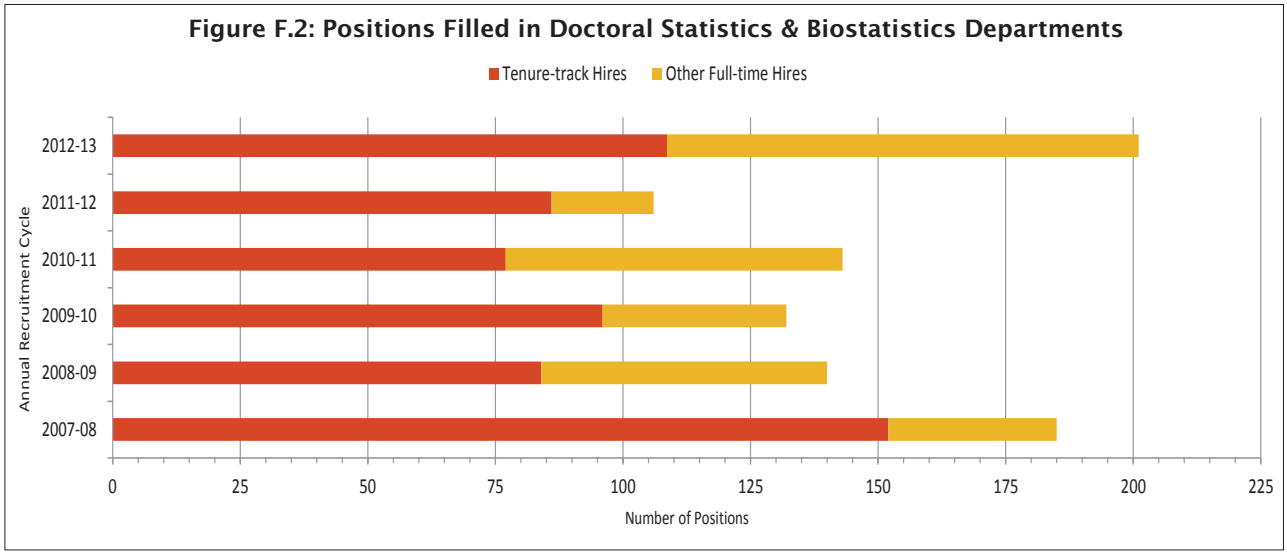


Positions Filled

A total of 1,576 positions were filled during the 2012–2013 academic cycle for employment beginning in fall 2013 by all mathematics groups combined. This total is down 4% from the 2011–2012 total and up 13% from the 2010–2011 total.

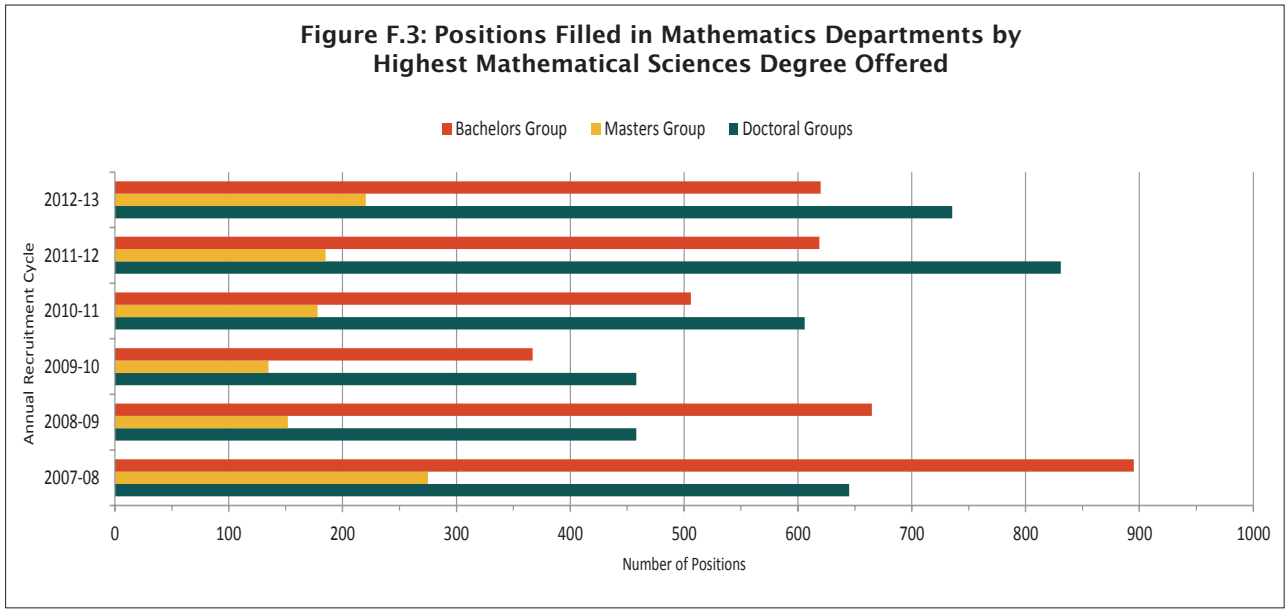


The situtation for doctoral statistics departments and biostatistics departments combined was somewhat different, as demonstrated by the accompanying figure. The total of filled positions is up 90% from the 2011–2012 total and up 41% from the 2010–2011 total. As was the case for recruitment, the increase in hiring by biostatistics departments was heavily affected by the recruitment in just two of the 24 responding departments which, combined, accounted for 60% of the total hiring reported by biostatistics.

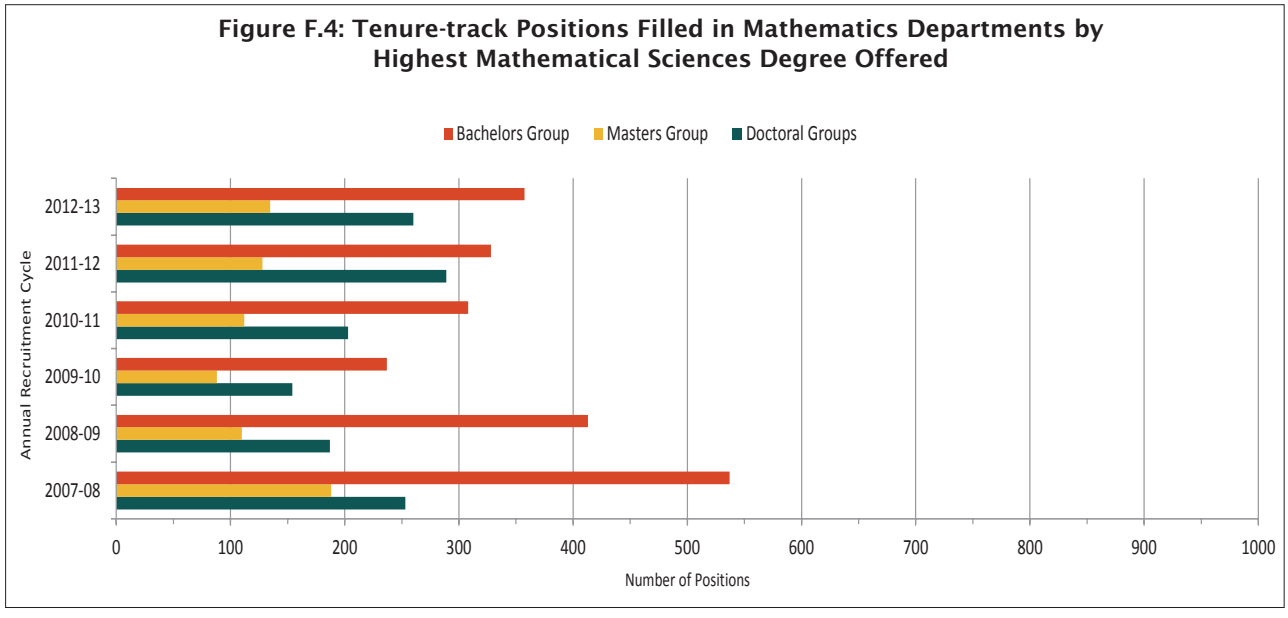


Positions Filled

The increase in positions filled for fall 2013 also varied widely among the various reporting groups. For the doctoral mathematics groups combined, the number of positions filled was 735, a decrease of 12% from the fall 2012 and up 21% from fall 2011 counts. For the masters group the count was 220, up 19% from fall 2012 and up 24% from the fall 2011 count. For the bachelors group the count remained essentially unchanged, 620 compared to 619 for fall 2012, and up 22% from fall 2011.

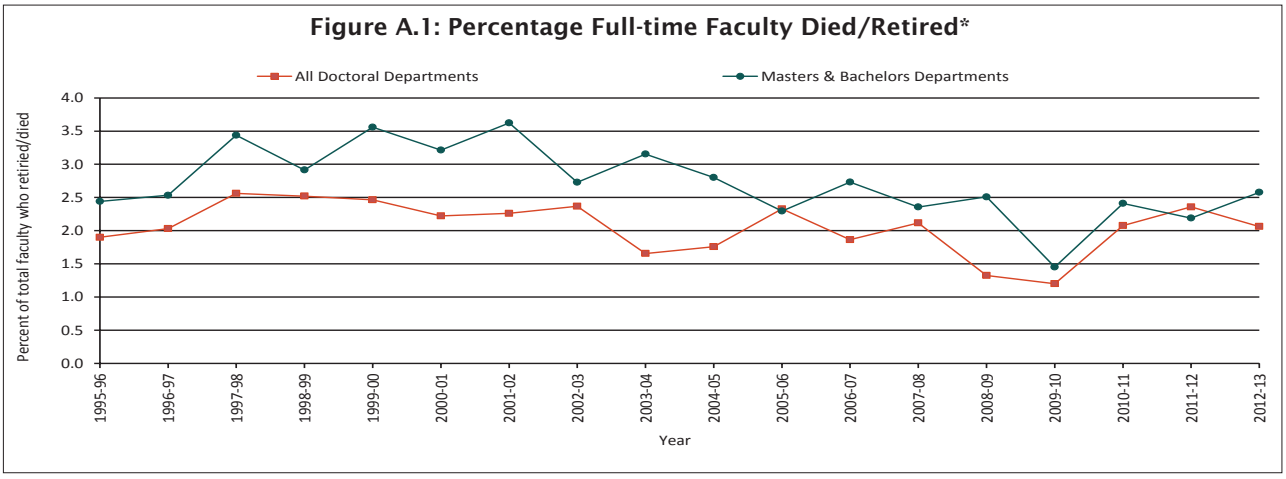


The total tenure-track positions filled for fall 2013 by all mathematics groups combined remained essentially unchanged, 752 compared to 746 for 2011–2012. This total is up 21% from the 2010–2011 figure of 623 and up 57% from the 2009–2010 total of 479.



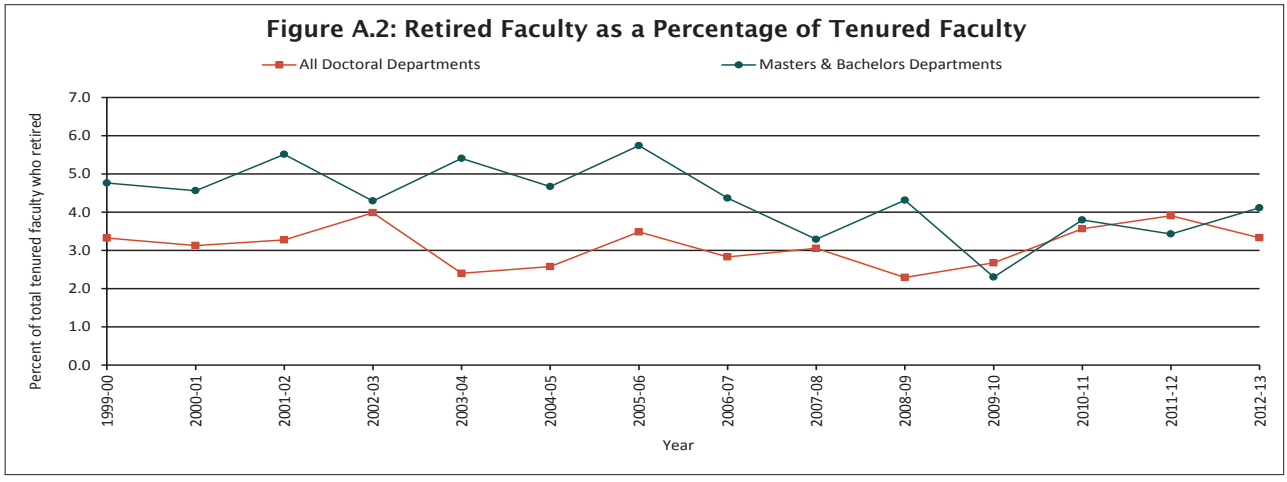
Faculty Attrition

Figure A.1 shows the trends in attrition from deaths and retirements among the full-time faculty for the academic years 1995–1996 through 2012–2013. In the late 1990s attrition leveled off, then began dropping after 2000, reaching the lowest rate of attrition in 2009–2010.



* The percentage of full-time faculty who died or retired is the number of faculty who died or retired at some point during the academic year (September 1 through August 31) divided by the number of full-time faculty at the start of the academic year.

Figure A.2 shows an alternative way of looking at the trends in annual faculty retirements compared to that offered in Figure A.1. It seems highly likely that the vast majority of individuals who are reported by their department as retiring are, in fact, members of the tenured faculty. Given that, it makes sense to look at the ratio of those retiring during an academic year to the total tenured faculty at the start of that year, as is done in A.2. Data collected this year show that approximately 85% of those retiring were tenured.



* Each percentage in this figure is the number of full-time faculty that retired at some point during the academic year (September 1 through August 31) divided by the number of full-time tenured faculty at the start of the academic year.

Survey Groups and Response Rates

Starting with reports on the 2012 AMS-ASA-IMS-MAA-SIAM Annual Survey of the Mathematical Sciences, the Joint Data Committee has implemented a new method for grouping the doctorate-granting mathematics departments. These departments are first grouped into those at public institutions and those at private institutions. These groups are further subdivided based on the size of their doctoral program as reflected in the average annual number of Ph.D.'s awarded between 2000 and 2010, based on their reports to the Annual Survey during this period. Furthermore, doctorate-granting departments which self-classify their Ph.D. program as being in applied mathematics will join with the other applied mathematics departments previously in Group Va to form their own group. The former Group IV is divided into two groups, one for departments in statistics and one for departments in biostatistics.

For further details on the change in the doctoral department groupings see the article in the October 2012 issue of *Notices of the AMS* at `http://www.ams.org/notices/201209/rtx120901262p.pdf`.

Survey Groups:

Math. Public Large consists of departments with the highest annual rate of production of Ph.D.'s, ranging between 7.0 and 24.2 per year.
Math. Public Medium consists of departments with an annual rate of production of Ph.D.'s, ranging between 3.9 and 6.9 per year.
Math. Public Small consists of departments with an annual rate of production of Ph.D.'s of 3.8 or less per year.
Math. Private Large consists of departments with an annual rate of production of Ph.D.'s, ranging between 3.9 and 19.8 per year.
Math. Private Small consists of departments with an annual rate of production of Ph.D.'s of 3.8 or less per year.
Applied Mathematics consists of doctoral-degree-granting applied mathematics departments.
Statistics consists of doctoral-degree-granting statistics departments.
Biostatistics consists of doctoral-degree-granting biostatistics departments.
Masters contains U.S. departments granting a masters degree as the highest graduate degree.
Bachelors contains U.S. departments granting a baccalaureate degree only.

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

Response Rates by Survey Groups

Faculty Recruitment & Hiring Response Rates

Group*	Received (%)
Math. Public Large	21 of 26 with 20 recruiting (81%)
Math. Public Medium	33 of 40 with 30 recruiting (83%)
Math. Public Small	44 of 64 with 32 recruiting (69%)
Math. Private Large	13 of 24 with 12 recruiting (54%)
Math. Private Small	25 of 28 with 23 recruiting (89%)
Applied Math.	19 of 24 with 18 recruiting (79%)
Statistics	40 of 59 with 35 recruiting (68%)
Biostatistics	24 of 43 with 15 recruiting (56%)
Masters	111 of 182with 72 recruiting (61%)
Bachelors	459 of 1002 with 200 recruiting (46%)
Total	789 of 1492 with 457 recruiting (53%)

* Doctoral programs that do not formally "house" faculty and their salaries are excluded from this survey.

Other Information

The interested reader may view additional details on the results of this survey and prior year trends by visiting the AMS website at `www.ams.org/annual-survey`. Survey results for the doctoral departments in statistics and biostatistics are available there.

Acknowledgements

The Annual Survey attempts to provide an accurate appraisal and analysis of various aspects of the academic mathematical sciences scene for the use and benefit of the community and for filling the information needs of the professional organizations. Every year, college and university departments in the United States are invited to respond. The Annual Survey relies heavily on the conscientious efforts of the dedicated staff members of these departments for the quality of its information. On behalf of the Data Committee and the Annual Survey Staff, we thank the many secretarial and administrative staff members in the mathematical sciences departments for their cooperation and assistance in responding to the survey questionnaires.

Optimizing Without Derivatives: What Does the No Free Lunch Theorem Actually Say?

Loris Serafino

One of the most important stages in many areas of engineering and applied sciences is modeling and the use of optimization techniques to increase the quality and performance of products or processes. Financial market operations, radiation therapy technologies, protein folding determination, material sciences, and power system facilities design: developments in these disparate scientific and technological areas, as well as many others, rely also on the help of some quiet, hidden workers called optimization methods. Beyond what seems to be just a machine-like application of some algorithm, there exists a world of challenges and developments. Generally in literature the term *optimization* is related to (the output of) a mathematical technique or algorithm used to identify the extreme value of an arbitrary objective function through the manipulation of a known set of variables and subject to a set of constraints. More technically, a maximization problem with an explicit objective can in general be expressed in the following mathematical form: Finding the value

$$\arg\max_{x\in\mathcal{H}} f(x),$$

where x is a given vector in a generic multidimensional space $\mathcal{H}$ and $f:\mathcal{H}\to\mathbb{R}$ is a function of the vector x and $\mathcal{H}\subset\mathbb{R}^n$ is a (discrete or continuous, but here the focus will be on continuous) subset of the multidimensional real Euclidean space. From now on we will refer to $\mathcal{H}$ as the *search space.*[1] In most real-world engineering optimization problems, no analytical expression exists for accurately evaluating the response of a candidate solution. Sometimes the objective function consists just in the possibility to observe different sets of pairs of input and output from a computational simulation or an experiment: $\mathcal{D}=\{(x_1,f(x_1)),\ldots,(x_n,f(x_n))\}$. This is the ***black-box scenario*** that will be considered here. In black-box optimization many issues are at stake. Some good reviews are [2, 3, 4]. Further, a number of engineering design tasks as well those in other contexts are modeled as multi-objective problems; this makes the optimization process even harder, but this case will not be considered here. Here the focus will be mainly on the following issues: the practical meaning of the ***No Free Lunch Theorem*** (NFLT) and on its natural connection with the Bayesian inference. This choice is due to the fact that they both represent a critical link between optimization theory and optimization practice.

Optimizing in the Black-Box Scenario

Black-box optimization is the reign of *metaheuristics*. A metaheuristic describes the way an optimization method decides which part of the search space to explore in the next step [1]. In general, every metaheuristic can be abstractly

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[1] *Even if there is no explicit mention of constraints here, the formulation is nonetheless general enough since they can be incorporated through an appropriate definition of the search space* $\mathcal{H}$.

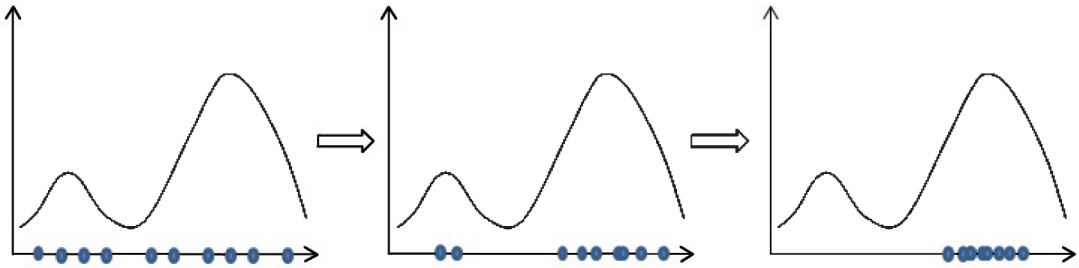

Figure 1. Genetic Algorithm: Generation after generation the population converges to a good solution.

considered as a sampling process acting on the search space. It starts with a set of values, and then step after step it generates new samples according to some specified mechanism based on current samples and the objective function values:

$$\left(x_1^{i+1},\ldots,x_m^{i+1}\right) = Alg\left(x_1^i,\ldots,x_n^i,f\left(x_1^i\right),\ldots,f\left(x_n^i\right),\Theta\right)$$

where Θ is a random variable and index i is the iteration counter.

So differences among different optimization methods come from the specific mechanism an algorithm uses to generate and accept new samples and in so doing alternating an exploration (global) phase with an exploitation (local) phase. For example, just to mention one class, *nature-inspired* algorithms, like the well-known genetic algorithm [5], are based on the idea of mimicking some natural phenomena that leads to the maximization of some defined quantity. Starting with a randomly generated population of candidate solutions (called chromosomes in usual terminology), a Genetic Algorithm (GA) carries out a process of fitness-based[2] selection and recombination to produce a successor population, the next generation. During recombination, *parent* solutions are selected and their genetic material is recombined to produce child chromosomes. After this step, in practical implementation, a mutation operator is applied. Mutation perturbs the recombined solutions slightly to explore their immediate neighborhood. These then pass into the successor population. As this process is iterated, a sequence of successive generations evolves and the average fitness of the chromosomes tends to increase until some stopping criterion is reached. In this way, a GA "evolves" a best solution to a given problem (see Figure 1). In the process of evolution, one population is replaced by another and so on.

GA represents just one tool in the hands of the practitioner. Other examples are: Particle Swarms, Ant Colonies, Simulated Annealing, and many other families [6]. In general, practice shows that any successful application depends on careful tuning of operators, parameters, and problem-dependent features.

Potentially there is an infinity of possible optimization problems, one for any possible function. At the same time there is an infinity of thinkable optimization methods, one for every possible exploration-exploitation trade-off combination. The choice of the correct metaheuristics for a given class of problem is a crucial theme that leads us to take into account the role played by the NFLT in terms of its theoretical and practical relevance.

The Practical Meaning of the No Free Lunch Theorem

We will start with the usual formal statement of the NFLT for optimization [9]. Wolpert and Macready's result considered a finite search space $\mathcal{X}$ and the space of all the possible objective functions $f:\mathcal{X}\mapsto\mathcal{Y}$ defined on it called $\mathcal{F}=\mathcal{Y}^{\mathcal{X}}$. They defined with $P(y_k|f,k,Alg)$ the conditional probability of finding a value $y_k\in\mathcal{Y}$ given a function f, after k iterations with algorithm Alg. This can be seen as a performance measure of the algorithm—its ability to locate a given function value after a given amount of iterations. Under some quite general conditions, the theorem states that, for any pair of algorithms Alg_1 and Alg_2:

$$\sum_f P(y_k|f,k,Alg_1)=\sum_f P(y_k|f,k,Alg_2).$$

Where the sum is carried out over the set of all the possible functions $\mathcal{F}$.

According to the most common understanding, the NFLT implies that there is no optimization method superior to others for all possible optimization problems. For some functions Alg_1 will be able to locate the maximum faster than Alg_2; for some other functions it will be the opposite. Averaging over the whole space $\mathcal{F}$, the performance will be the same. Equivalently, it is possible to say that, over $\mathcal{F}$, no algorithm will perform better

[2] *In GA literature the objective function is usually called* fitness.

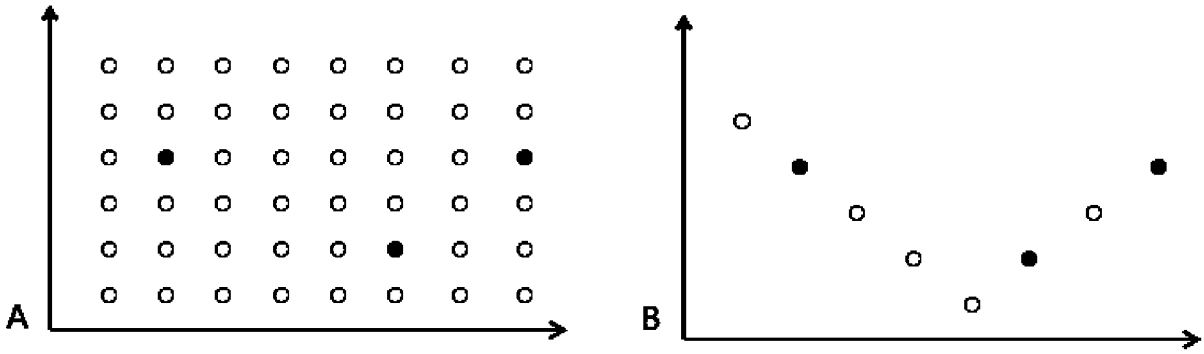

Figure 2. The No Free Lunch Theorem. The information collected so far will not say anything about the values of the function in other regions (case A). For a given subclass of functions, i.e., convex (case B), those algorithms that can take advantage of this structure will perform better than others.

than pure random search. Wolpert and Macready adopted a probabilistic framework. Their result holds if we assume a uniform distribution over $\mathcal{F}$, i.e., any functional form is uniformly admissible, and then they prove it by induction over the index k. To understand the practical implication of this theorem for black-box optimization problems, let's restate it while adopting a different perspective. Substantially the theorem states that:

With no prior knowledge about the function $f : \mathcal{X} \mapsto \mathcal{Y}$, in a situation where any functional form is uniformly admissible, the information provided by the value of the function in some points of the domain will not say anything about the values of the function in other regions of the domain.

This interpretation of the NFLT is pictured in Figure 2. So in this scenario the information collected with the data sample is not helpful in guiding the search as to which direction is better to explore next. In this sense, there is no optimization method superior to others for all possible optimization problems. Of course every function has its own structure; the problem is when prior knowledge about the functional form is not available because no rationale can guide an optimization strategy— i.e., to decide which optimization method to use, which set of parameters, and so on.

The lesson that has to be learned from NFLT is in the implications for a rational optimization strategy able to tackle black-box optimization problems. It is clear now that, for the practitioner the correct question is not *which algorithm I have to use* but first of all *what is the geometry of the objective function*: the optimization problem becomes an inferential problem as will be clear in the discussion below. Knowing the structure of the objective landscape makes it (theoretically) possible to properly tune an algorithm in terms of a trade-off between local search and global search. It is also true that, even if many studies are in progress, general results about which class of algorithms best suits which kind of problems are still far off. As we will see below, Bayesian probability theory will appear to be the natural foundational framework for metaheuristics.

In the NFLT scenario, where nothing is known in the literature about the structure of the problem at hand, practitioners tend to decide the optimization method according their background knowledge, practical availability of code, simulation software, and so on. In a different scenario where something is known about the function, like a lower bound on the function value or some information about the response landscape, this information must be used to tailor the algorithm and the optimization strategy accordingly. Knowledge of the objective function structure is a key to adjust effective algorithms in terms of a better trade-off between exploration and exploitation.

Summarizing, from the discussion of the NFLT, black-box optimization involves two main ingredients: input-output data and some prior knowledge. This leads naturally to the next section where the connection with the Bayesian framework will be explored.

NFLT and the Bayesian Philosophy: Two Sides of the Same Coin

Our interpretation of the NFLT in the context of black-box optimization shows a strong connection with the problem of *underdetermination* (see Figure 3). In the black-box context only a finite sample data set concerning the functional response is available: $\mathcal{D} = \{(x_1, f(x_1)), \ldots, (x_n, f(x_n))\}$. In this case locating a function value (the optimum) becomes a purely inferential problem that leads naturally to a Bayesian framework. The rationale of

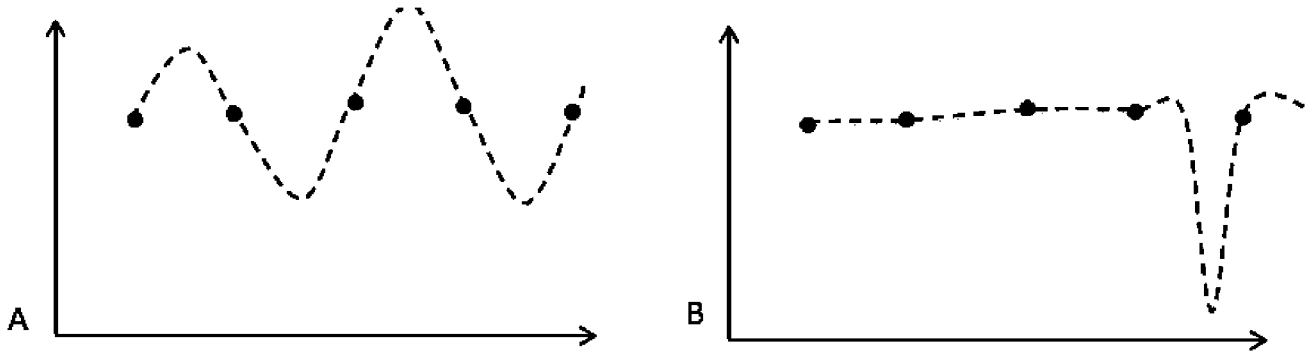

Figure 3. The problem of underdetermination: a sample of data can be described by quite different models (in this case function A and function B).

Bayesian probability theory is briefly summarized here in the context of optimization. The problem is to construct a model of the function that we need to optimize. In the Bayesian framework there are two ingredients: a data set and a prior. A prior distribution $P(f)$ over the space of functions is combined with the likelihood $P(\mathcal{D}|f)$ to generate a posterior

$$P(f|\mathcal{D}) \propto P(\mathcal{D}|f)P(f)$$

which takes into account the information given by the data set $\mathcal{D}$. In terms of modeling a function, if we assume as a prior every possible function (which is equivalent to saying that there is no prior) we are exactly in the NFLT case: no useful inferential information can be extracted from the data set. If the prior can be restricted to a proper class of functions, then the inference about the model realizing the data set will be more accurate. As we said about the implications of the NFLT, if it is possible to restrict the problem to a given subclass of functions, a proper optimization algorithm choice can produce good results. **For an optimization method, given $\mathcal{D}$, to have indications about where promising areas for the optimum can be located is equivalent to saying that a (posterior) refined model of the objective function has been inferred in Bayesian terms**. As is now clear, *there is a strong connection between the NFLT and the Bayesian framework* at the point where they can be considered two sides of the same coin. This situation is summarized in Table 1. The NFLT assumes a uniform distribution over the space of possible functions. In the Bayesian terminology this is equivalent to saying that there is no prior knowledge about the objective function: every functional form is admitted. According to the implication of the NFLT, it is essential to restrict the class of possible functions (in the NFLT terminology) to a proper subclass in order to tailor an effective optimization strategy. This restricted class of functions represents the prior that appears in the Bayesian formula. So the secret of a successful black-box optimization, assuming a *good* sample $\mathcal{D}$,[3] lies in the possibility of narrowing the prior.

Given a sample data set $\mathcal{D} = \{(x_1, f(x_1)), \ldots, (x_n, f(x_n))\}$			
NFLT terminology: optimum location		**Bayesian terminology: model generation**	
Uniform over $\mathcal{F}$	Nonuniform over $\mathcal{F}$	No prior	With prior
No *Alg* better than pure random search in locating $\arg\max f(x)$	Some *Alg* better than pure random search in locating $\arg\max f(x)$	No valid inference for the model realizing $\mathcal{D}$	Inference can be made about the model realizing $\mathcal{D}$

Table 1. NFLT vs. Bayesian theory

Some Implications

The discussion above about the interpretation of NFLT in terms of the Bayesian approach (and vice versa) can be useful in two ways: to use the NFLT for understanding surrogate-based optimization techniques and, on the other side, to use a Bayesian framework for understanding the metaheuristics working logic. In the context of black-box optimization there is a large amount of literature about methods for objective function approximation (also called *meta-models* or *surrogates*) as a way to generate functional models that are computationally efficient and that approximate the true function. All of them *assume*, often implicitly, a prior in terms of a restricted class of modeling functions. Functional surrogate models can be algebraic representations of the true problem functions. The most popular ones are polynomials, in a method often known in the statistical literature as *response surface methodology*. Several related methods are now commonly used for function approximation: neural networks, Kriging model, radial-basis-function networks and support vector machines (for a general reference, see [11, 12]). After the model has been developed, some classical derivative-based or derivative-free methods can

[3] *For Design of Experiments techniques see* [11].

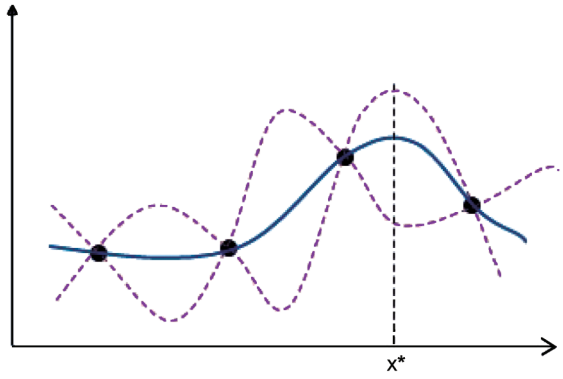

Figure 4. Bayesian optimization. Data points are shown as black dots. The GP modeled distribution has a mean shown by the blue line that fits the data, and a standard deviation represented here by the red dotted lines. Here x^* represents the next point to explore since maximum improvement is expected.

be applied [13]. *Bayesian optimization* is briefly discussed here as a tool that is getting relevance in optimization practice. This technique conceptually combines surrogate estimation with optimum localization (for a good introduction see [14, 15, 16]). It uses the Bayesian rationale to infer about a starting function model. The second step is to infill new points of the search space in those regions where a maximum improvement is expected according to the current best value and the predictive variance (Figure 4). Then the Bayesian procedure is updated. Usually in the literature, the prior is supposed to be a realization of a **Gaussian process**. This is a distribution over the space of functions modeled as a multivariate Gaussian distribution, so one can think of the Gaussian process as defining a distribution over the space of functions:

$$f(x) \sim \mathrm{GP}(m(x), k(x_i, x_j)),$$

meaning that the function f is distributed as a GP this means that function $m(x)$ and covariance function $k(x_i, x_j)$. A common choice for the covariance function is defined by:

$$k(x_i, x_j) = \exp\left(-\tfrac{1}{2}(x_i - x_j)^T \operatorname{diag}(\phi)^{-2}(x_i - x_j)\right),$$

where ϕ represents a family of hyper-parameters that have to be properly estimated.

The power of the Bayesian optimization philosophy briefly sketched out above lies in its ability to tackle optimization problems with a limited number of function calls, and this is very important for computationally expensive simulations. Again, the key point in the Bayesian rationale is given by the choice of the prior, i.e., the nonuniform distribution over $\mathcal{F}$ in the NFLT terminology. The choice of the prior as a *Gaussian process* implies that the function is supposed to be in the class of smooth well-behaved functions; this can be an arbitrary hypothesis. For objective functions with discontinuities or jumps this prior will not be able to provide very good results. Further, the construction of the surrogate model is essentially an exercise of design space exploration exactly in the same way any optimization algorithm result is. If the dimension of the search space is high (more than 100 variables), then the ability to sample promising regions becomes weaker and weaker. Bayesian optimization cannot avoid the *curse of dimensionality*: the number of candidate solutions grows exponentially with increasing dimensionality [7].

From the discussion above it is now clear how a Bayesian framework can be used to shed light on the main metaheuristics operating principles. All metaheuristics *assume* a model class (the Bayesian prior) of the objective function during the search and combine it with the sampled points at a given iteration to direct the search in the most promising directions. For example, genetic algorithms, as well as other optimizers, assume (and they work well if there is) *strong causality*: Small causes produce small effects. For functions with low causality they tend to suffer [2]. In metaheuristics the prior about the function is implicitly defined by the search operators used (*crossover*, *mutation*, etc.) and the set of internal working parameters. Many automated self-adapting strategies which are able to change the internal parameters values according to partial results obtained during the search process have been studied in recent years [8]. What these (so-called *smart*) optimization algorithms do is incorporate a more explicit Bayesian operating logic. They generate a posterior model using the sampled points collected at a given iteration and some assumptions about the function structure (prior). Iteration after iteration, they adjust the set of internal parameters to better tailor the function model and to foster the search in more promising regions (according to the *posterior* model).

Just to mention one, Covariance Matrix Adaptation Evolutionary Strategies (CMA-ES) is one of the most famous in the field of continuous global optimization. Again, the main idea of this algorithm is to use the information collected during the iterations in terms of sampled points to generate *on-the-fly* a model of the function to optimize by assuming a second-order functional structure [17]. This again shows the strong relationship between optimum location, model determination and the prior knowledge about the function geometry over which the optimization process is supposed to be carried out. The internal prior of a metaheuristic defines and constrains the exploration-exploitation trade-off and so the overall capabilities of the search process.

Summarizing, the ability of every optimization method is connected to the following points: a) how much the adopted internal prior model fits the geometry of the problem at hand and b) on the other side, the possibility of access to a *good* sample $\mathcal{D} = \{(x_1, f(x_1)), \ldots, (x_n, f(x_n))\}$ of $\mathcal{H} \times \mathrm{Im}(f)$. This can be a problem for computationally expensive functions and/or for high-dimensional search spaces. As we have said, the curse of dimensionality affects the ability to generate a valid posterior since, with increasing dimensions, the needed number of sampled points able to say something useful in the inferential process increases exponentially.

Conclusions

Summarizing the discussion above:

- Black-box optimization = prior function structure knowledge + sample data set + algorithm.
- In general, knowledge about the objective function landscape is the key for a better optimization in terms of the possibility to better tune the trade-off between local search (exploration) and global search (exploitation).
- The meaning of NFLT can be made clear if we reconsider it in terms of Bayesian logic. At an abstract level, the Bayesian approach is the natural framework on which to base an effective black-box optimization strategy.
- The choice of the ***prior*** is the critical point. The Gaussian process in Bayesian optimization is a valid choice whereas the fitness to be optimized is in the class of smooth functions.
- All metaheuristics more or less implicitly assume a functional model (prior). They work well if this model matches the geometry of the problem under optimization.
- The curse of dimensionality affects the ability to search every optimization method: In high-dimensional search spaces the number of sampled points needed for the inference process increases dramatically.

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Open Texts on the Web, Taking the Next Step

Michael Doob

Revolution to Evolution

As noted by Steven E. Barkan [3] in his *Notices* piece, there is a revolution underway. Books both new and old are migrating from being published primarily in print to being published primarily in an electronic format. Many of the advantages of electronic publication are correctly identified in that article, and, indeed, this revolution allowing for open textbooks is certainly to be encouraged and applauded.

If freely available books are desired, they can be found easily online at, for example, the Open Textbook Library [6] or the American Institute of Mathematics [1]. There is a shortcoming, however. Almost all books appearing in electronic format are, well, just books. The format is essentially linear: start at the beginning and proceed forward to the end, just as with the scrolls found in the great library at Alexandria two thousand years ago. Although some typographical elements break this pattern, cross-references and indexes being examples, there is a basic expectation of linear structure in mathematical texts: Once a certain level of mathematical sophistication is presented at the beginning, the same level will continue through to the end; all the necessary elements for a proof are given before or immediately after its statement; similar or near-identical proofs are not repeated; forward references appear rarely if at all. As we write our new open texts, we have the opportunity to free ourselves from the chains of this restrictive structure. We should promote this renewal! In this note I'll give some examples of different approaches in this direction based on the wiki that I use for a first-year linear algebra course.

The mathematical world is fortunate to have LaTeX as its *lingua franca* for typesetting mathematics. Although it was designed to produce traditional books, it has enough flexibility to adapt to more general formats. Most likely it will be our software of choice for the foreseeable future, and so its inclusion in any planning is important.

Almost all texts available in electronic form are in Portable Document Format (`pdf`). This format is a good first step, but most of these texts don't really exploit the full possibilities available.

What pdf Has to Offer

Putting books on the Web using a `pdf` file is easy, either by using pdfLaTeX directly or by converting the standard LaTeX output to a `pdf` file using intermediate software. While easy, we're still not using all the possibilities available.

Some `pdf` capabilities are really easy to use: first, the `pdf` file can be text-searchable, which will happen by default with most LaTeX software. Next, the `\label`-`\ref`, `\cite`-`\bibentry` and similar combinations can be live links. This is also easy to achieve: simply use the `hyperref` package. This can also give appropriate links in a table of contents and an index (one might ask what the role of the index should be, given that it is easy to search for the first occurrence of any given term). It's surprising that there are any `pdf` files without these capabilities.

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Members of the Editorial Board for Scripta Manent are: Jon Borwein, Thierry Bouche, John Ewing, Andrew Odlyzko, Ann Okerson.

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In addition, color is available using the standard `color` package, and it can be used (judiciously, one hopes). Although it is easy, several of the available `pdf` files are simple conversions from existing texts that don't use these straightforward possibilities. This is the really low-hanging fruit; we should pick it.

What about graphics? Fortunately, accurate and high-quality graphics are available using standard programs such as TikZ[8] or Asymptote[2], and they may be used in conjunction with LaTeX to create `pdf` files. There is a learning curve for either program that is a bit steep but nonetheless much easier than that for LaTeX itself. The effort is worthwhile.

Moving Beyond pdf

While the `pdf` format has much to offer, there are disadvantages:

- The original design first appeared in 1993. It always has been superb at replicating printed text but not as successful with other media.
- Existing `pdf` files require specialized software for editing.
- Files with multimedia entities usually do not work with all viewers.

In contrast, the newer specifications for Web browser formats will allow both more flexibility and some newer features. Here are some examples:

- It is possible to use the less common but perhaps more useful method of folding text instead of adding links. In this case, clicking on a "link" opens (that is, inserts) new text at that point within the document. Clicking again makes the text disappear. A list of topics (the forest) may be given; clicking on any one of them adds more details (the trees); this process may be repeated for even more detail (the branches and then the leaves). The data is tree-structured rather than linear, and, as such, allows the same material to be viewed from different perspectives.
- Problem sets have always been included within textbooks. They, too, follow a linear format. The easier ones appear first followed by slightly harder ones. The use of an asterisk to indicate harder problems is an attempt to add information (depth) to this structure and goes back at least sixty years (see [5]). More recent books have made this mesh even finer. There now exists software (see [9]) that will parcel out problems from large problem banks, and, when appropriate, grade the answers. The problems given can be customized to the individual student: ones who are successful are given harder problems while those who are struggling get to repeat the effort until successful.

There is a wonderful example of an electronic textbook that moves beyond the `pdf` format. Rob Beezer's new online version of his linear algebra textbook [4] incorporates many of these advantages. It's worth a good look.

So we can see the evolution of electronic books taking place at this very moment. In fact they won't be much like books for long; we should call them open texts. The result of this evolution will be creative and exciting. It surely will be interesting to see if the next generation of students acquires its mathematical skills with greater ease and understanding than has heretofore been possible.

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[7] Open Mathbook website: `http://www.openmathbook.org/`.

[8] TikZ website: `http://sourceforge.net/projects/pgf/`.

[9] The Mathematical Association of America has a problem bank and associated software available at `http://webwork.maa.org/`.

Some Graphic Examples

A Matrix Row-Reduces Itself

One of the first algorithms taught in linear algebra is the one that takes a matrix and puts it into reduced row echelon form. There is a forest-tree problem: show the details of the algorithm but keep the overview of what's happening. Having an animation that runs at full speed or single-steps solves this problem. (See `matrixanimation.gif`, *Notices* online.)

$$\begin{bmatrix} 1 & 0 & 5 & -20 & -15 & -4 & -3 \\ 0 & 1 & -3 & 12 & 9 & 3 & 2 \\ 0 & 0 & 1 & -\frac{29}{8} & -\frac{21}{8} & -\frac{7}{8} & -\frac{1}{2} \\ 0 & 0 & -6 & 36 & 29 & 7 & 9 \\ 0 & 0 & -22 & 94 & 71 & 21 & 17 \end{bmatrix} \quad R_3 \leftarrow \tfrac{1}{16} R_3$$

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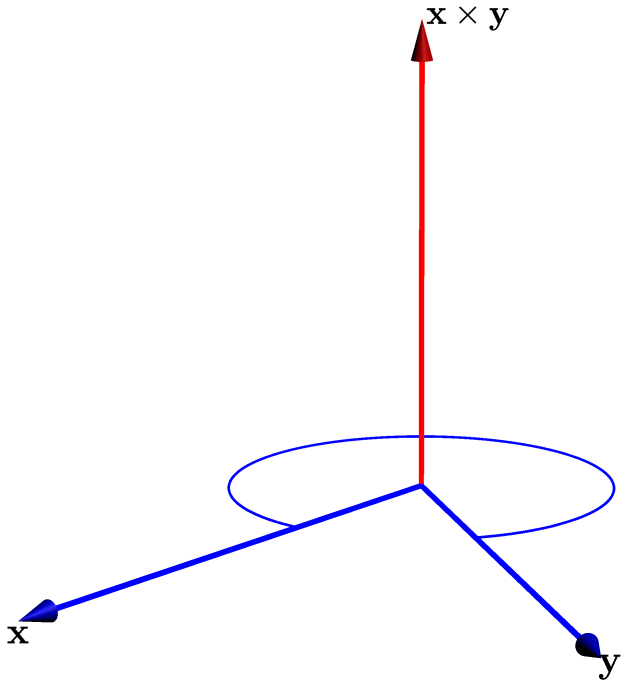
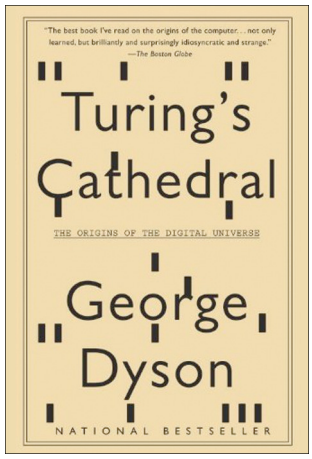
A Cross Product Defines Itself

The definition of the cross product is not very intuitive. I run the the following graphic telling the students that the red vector is the cross product of the blue vectors and ask for the properties. They get the orthogonality property immediately; with some prodding they get that the length is zero at 6:00 and 12:00 and maximum at 3:00 and 9:00. When I ask for a description of the length change as the hand rotates through 2π, someone always suggests $\sin(x)$. Using these properties, the definition of the cross product quickly emerges. (See `crossproduct.gif`, *Notices* online.)



Turing's Cathedral: The Origins of the Digital Universe



Reviewed by Brian E. Blank

Turing's Cathedral: The Origins of the Digital Universe
George Dyson
Vintage, 2012, 464 pp., US$16.95
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In 1936, Alan Turing, sparked by an interest in Hilbert's *Entscheidungsproblem*, introduced the notion of the stored-program Universal Machine. Nine years later, John von Neumann recruited a team of engineers to design and build a concrete realization of Turing's machine at the Institute for Advanced Study in Princeton. Von Neumann's machine, also known as the IAS or Princeton machine and, popularly but incorrectly, as the MANIAC (Mathematical Analyzer, Numerical Integrator, and Computer), was neither the first all-purpose, electronic, digital computer nor the first such machine to employ stored programs. Nevertheless, the IAS machine played an important role in shaping the digital revolution. It was, to borrow a modern phrase, open source. Not only were the design details enthusiastically shared, but teams of engineers from other institutions, national laboratories, and even commercial concerns regularly visited the construction site during the machine's six years of assembly to benefit first-hand from a difficult learning curve. For those unable to call in person, progress reports were disseminated. As a result, the logical architecture of the IAS computer was widely reproduced, and derivative machines were built around the world. By March 1953, the IAS computer and its eight completed offspring[1] held seventy percent of the world's fifty-three kilobytes of high-speed, random-access memory. To George Dyson, historian of technology, the Institute's Electronic Computer Project (ECP) was as close to a point source of the digital universe as any approximation can get. His *Turing's Cathedral* is an account of that enterprise.

If ever there were a book not to be judged by its cover, Dyson's is it. His title is more metaphorical than one might suppose. Turing's seminal 1936 paper, *On computable numbers, with an application to the Entscheidungsproblem*, contained a brilliant thought experiment but no blueprint for a practical implementation of a digital machine. Dyson's subtitle, *The Origins of the Digital Universe*, is out-and-out misleading. Before the IAS machine had its first run, more than a dozen digital computers were fully operational, but the ENIAC (Electronic Numerical Integrator and Computer) is the only one of them that receives more than a passing mention. Underneath the dust jacket, the front cover of *Turing's Cathedral* is devoted to an attractive portrait photograph of the book's namesake, taken in 1951 on the occasion of his election to a Fellowship of the Royal Society. Given the title and cover of Dyson's narrative, a reader might expect Turing to be an essential character for the story inside. Instead, Dyson largely confines his discussion of Turing to the thirteenth of eighteen chapters. In it, we learn that "Engineers avoided Turing's paper because it appeared entirely theoretical." Eleven years after its publication, during the development of von Neumann's machine, Turing *did* help design a practical, physical computer, but in a different style

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[1] *The machines that were based on the IAS computer are often referred to as copies or clones.*

than von Neumann. The question of whether Turing had any influence on von Neumann's contributions to computing has been much debated by historians, but there is no consensus. *Turing's Cathedral* offers no new information to change that.

Fortunately, we know better than to judge a book by its cover, and that must be especially true when the cover has little to do with the book's contents; in this case, those contents have no need of any exaggerated linkage to be of tremendous historical interest. Readers of the *Notices*, in particular, will appreciate Dyson's broad view of his subject. Many of us have visited the IAS and will welcome Dyson's concise, embedded history of its establishment and early years. He also manages to interweave a compact yet useful biography of John von Neumann. Whereas typical readers may find Dyson's life of von Neumann, whose star has waned with the general public,[2] a distraction from the main subject matter of *Turing's Cathedral*, mathematicians, for whom von Neumann remains a legend, will hail its inclusion. It should also be noted that Oswald Veblen, Marston Morse, and Stanislaw Ulam arise frequently in Dyson's treatment, while other mathematicians such as Raoul Bott and Martin Davis make interesting cameo appearances. The eight pages devoted to Kurt Gödel are patently tangential, but they are so absorbing that nobody should object to their presence.

Extensive biographical and institutional backgrounds are not the only unusual elements of Dyson's approach. Departing from the composition style of most historians of computing, who assume that the purpose of building computers is self-evident, Dyson takes a keen interest in the projects that von Neumann intended for the new machine. One paragraph will illustrate both the scope of Dyson's coverage and his knack for synthesis:

> By mid-1953, five distinct sets of problems were running on the MANIAC, characterized by different scales in time: (1) nuclear explosions, over in microseconds; (2) shock and blast waves, ranging from microseconds to minutes; (3) meteorology, ranging from minutes to years; (4) biological evolution, ranging from years to millions of years; and (5) stellar evolution, ranging from millions to billions of years. All this in 5 kilobytes—enough memory for about one-half second of audio, at the rate we now compress music into MP3s.

From Dyson's discussion of the Princeton machine's applications to nuclear weapons, we gain insights into the nation's mindset during the tense first decade of the Cold War. Von Neumann's hawkishness is a topic that Dyson does not neglect. As terrifying as the new atomic bombs were, a naive optimism about atoms for peace managed to coexist with the fear. In his chapter on weather prediction, Dyson quotes speculation in the *New York Times* that "Atomic energy might provide a means for diverting, by its explosive power, a hurricane before it could strike a populated place."

Another positive deviation from more technical histories of computing is the degree to which Dyson includes people in his story. He quotes extensively from many existing oral histories, and he secured access to several resources not generally available, including the archives of Julian Himely Bigelow, the first chief engineer of the ECP, and the remarkable writings of Klára von Neumann (née Dán), John von Neumann's second wife. Dyson also performed a timely service conducting many new interviews.[3]

The Institute for Advanced Study

The author, son of physicist Freeman Dyson, has a natural affinity for the Institute for Advanced Study: it is where he grew up. His childhood memories include visits to a barn on the Institute's grounds in which surplus electronic parts from the computer project, long since terminated, were still stored. As one might expect, he proves to be an enthusiastic guide to the IAS. His succinct account hits all the highlights, but, for those with more leisure, there is an alternative. Beatrice Stern's detailed history of the first twenty years of the Institute is now available online [8]. From her first sentence on, Stern's manner of expression offers considerable reading pleasure: "In the autumn of 1928 two elderly residents of South Orange, New Jersey, were quietly searching for a philanthropy worthy to be endowed with their ample fortunes." The benefactors were Louis Bamberger and his sister Carrie Fuld: the source of their wealth had been Bamberger's department store in Newark. Initially they intended the result of their generosity to be a medical college located in or near Newark. They were put in touch with Abraham Flexner, who, through his seat on the Rockefeller Foundation's General Education Board, had already disbursed

[2] *By contrast, Turing's star seems to be burning brightly in the popular press. Time's February 17, 2014, cover story asserts that "The modern computing era began in the 1930s with the work of Alan Turing."*

[3] *Not long after the author started his eight-year writing project, theoretical meteorologist Joseph Smagorinsky advised, "You're within about five years of not having a testifiable witness." Interviewees Smagorinsky, Bigelow, Bott, Benoît Mandelbrot, Atle Selberg, Françoise Ulam, and Nicholas Vonneumann died during the writing of* Turing's Cathedral. *Another interviewee, computer pioneer Willis H. Ware, an ECP engineer who also worked on the construction of the JOHNNIAC at RAND, died in 2013.*

$600,000,000 of excess prosperity. It was Flexner who persuaded the Bamberger siblings that there was a greater need for an institute for advanced study than for another medical college. In May 1930, a certificate of incorporation was signed for the establishment of an institute for advanced study at or in the vicinity of Newark. It was to be, as the Bambergers wrote the trustees, a place where scholars could devote themselves to serious research free from "the diversions inseparable from an institution the major interest of which is the teaching of undergraduates."

Having long been the recipient of requests for educational funds, Flexner had already become familiar with a proposal for a mathematics institute made some years earlier by Oswald Veblen, who, in 1930, was Henry Burchard Fine Professor of Mathematics at Princeton University. With diplomatic persistence, Flexner widened the Bambergers' horizons to include Princeton, arguing that "it might be difficult to get able lecturers to come to Newark." Flexner also had to campaign for an autonomous institute rather than one affiliated with an existing university. Quoting Veblen, he wrote the trustees in September 1931, "It is the multiplicity of its purposes that makes an American University such an unhappy place for a scholar."

In the context of a book about von Neumann's computer, a costly apparatus motivated by the immediacy of threatening geopolitical concerns, Flexner's reasons for proposing that a School of Mathematics be established as the first at the IAS will seem ironic. The indifference of mathematics to practical results, in Flexner's mind, epitomized his vision for the Institute. "Nothing is more likely to defeat itself, nothing is on the whole less productive in the long run than immediacy in the realm of research, reflection, and contemplation." He had a pragmatic argument as well: Mathematics "requires little—a few men, a few students, a few rooms, books, blackboard, chalk, paper, and pencils." The trustees were not easily won over. Dr. Charles Beard, a historian, insisted, "Mathematics can be taught 'safely' in Moscow, Berlin, Rome, and Washington …Chuck mathematics and take economics. Then you begin with the hardest subject." He continued with an appeal to the country's needs: "We have no good schools of higher economics in this land of business schools." A similar theme of urgency was argued by Felix Frankfurter, then a Harvard law professor, but in favor of mathematics: "Needless to say that mathematics is not a subject in which at present many American universities are eminent." Although the Bambergers preferred schools of economics and politics because of their potential for the advancement of social justice, Flexner prevailed. It will be noted that, in the end, the department store magnates paid a considerable sum, but what they bought did not exactly match what they wanted in any particular.

In 1932, Oswald Veblen became the first professor to be hired at the IAS. Albert Einstein joined him later that year. In 1933, John von Neumann received the third appointment. Twenty years later, Freeman Dyson observed that the long-term structure of the Institute had already been molded by these first three hires: "The School of Mathematics has a permanent establishment which is divided into three groups, one consisting of pure mathematics, one consisting of theoretical physicists, and one consisting of Professor von Neumann."

Dyson's readers will appreciate the insider's advantages on which he draws, but some shortcomings of his book can be frustrating. He often neglects to reestablish the timeline after his story has hopped forward or backward in time. Preferring to scatter his sources throughout the endnotes, Dyson does not provide a bibliography. And he does not always substantiate asserted facts with references. For example, with no citation, Dyson tells us that Flexner "deferred to Veblen as to candidates, explaining to the trustees that 'mathematicians, like cows in the dark, all look alike.' " When in Flexner's ten years of directing the IAS did he say this? In what way did he *defer* to Veblen? The picture Beatrice Stern paints is that Flexner struggled to resist Veblen's willfulness and clandestine maneuvering, which far exceeded his authority. In its first years, the Institute depended on Princeton University for its library and for offices in Fine Hall. After the acquisition of Veblen, Flexner did not want to be perceived by the Institute's host as a persistent faculty raider. Even as he repeatedly reassured the concerned and less remunerative university that he did not intend to drain the school of its best faculty, Veblen was in the process of luring away von Neumann and James W. Alexander[4] [8, pp. 148–151, 154–157, 162]. In 1934, Erwin Schrödinger turned down an offer of Princeton University's Jones Chair in Mathematical Physics, having been convinced by Veblen, abetted in this case by Weyl and Einstein, that a more lucrative appointment from the Institute would be forthcoming. Flexner, who had been unaware of any such representations, was forced to inform Schrödinger that there were no plans to increase the school's faculty [8, pp. 182–185]. Veblen's talent for getting what he wanted also fell short when he lobbied for more luxurious offices during the construction of the Institute's first building, Fuld Hall. Referring to the faculty's temporary digs in Fine Hall, Flexner retorted, "Weyl is happier in a room smaller than

[4] *Alexander followed by Marston Morse became the fifth and sixth permanent members. Hermann Weyl, who would have been the third but for his vacillation, was the fourth.*

yours, and Johnny is productive in a room smaller than Weyl's."

John von Neumann

John (János) von Neumann was born in 1903. He began his serious mathematical education at the age of thirteen with tutoring from Gabor Szegö, Michael (Mihály) Fekete, and their advisor, Leopold (Lipót) Fejér. To conform to his father's idea of a reasonable profession, he enrolled in the chemical engineering program of the ETH in Zurich, but continued his mathematical studies at the University of Berlin, returning periodically to the University of Budapest (Eötvös Loránd University) to take exams in classes he did not attend. He received a chemical engineering degree from the ETH in 1925 and a doctorate from Budapest in 1926. In the next few years he made fundamental contributions to operator theory, quantum mechanics, and game theory (at the rate of nearly one paper per month), but his mathematical work does not feature in *Turing's Cathedral*. Von Neumann's previous biographer, the late Norman Macrae, had more to say about von Neumann's contributions to mathematics, physics, and economics [7], but readers with a mathematical background are better advised to consult Ulam's retrospective [10], as well as the more specialized articles of Garrett Birkhoff, Halmos, van Hove, Kadison, Murray, and Kuhn and Tucker in the same issue of the *Bulletin*. The Society's volume on von Neumann's legacy is also recommended [4].

Every true genius is unique. In the 1930s, von Neumann's Princeton milieu was populated by Alexander, Bochner, Church, Einstein, Lefschetz, Tucker, Wedderburn, Weyl, Wigner, and Wilks. Regular visitors included Albert, Bernays, Brauer, Dirac, Gödel, Infeld, Montgomery, Pauli, and Ulam. Even in that company, even among the other *Martians*,[5] von Neumann stood out. It is next to impossible to write uninterestingly about such a subject. Even so, Macrae's biography benefited from his interviews with Mariette Kővesi, who, from 1930[6] to 1937, was von Neumann's first wife. Referring to these interviews, Macrae acknowledged, "My talks with her in 1990 set the book alight." Analogously, Dyson profited from gaining access to Klára von Neumann's unpublished autobiography and other writings, which he credits as "the documents that brought this story to life." From the extensive quotes on which Dyson relies, it is evident that Klára was a very fine writer.

When Klára first spotted von Neumann in Monte Carlo's casino in the late 1920s, he was at the roulette table with a "large piece of paper and a not-too-large mound of chips before him." Von Neumann had a "system", which he delighted in explaining to Klára and her first husband. The system notwithstanding, the mound of chips eventually found its way to its rightful place in the casino's coffers, and Klára paid for the moneyless game theorist's drink. Years later, when von Neumann's first marriage was breaking up in 1937, he reconnected with Klára, who was bored, as she put it, with her second husband, a man eighteen years her senior. John and Klára married in 1938. Klára recorded that von Neumann offered her a divorce when she persisted in her attempts to interest him in skiing, but the marriage endured until his death in 1957. Readers in search of scuttlebutt will do better with [7] and [11] than with Dyson, whose approach to biography leans toward discretion. On the other hand, the standard von Neumann lore—the feats of memory and mental calculation, the testimonials to his superhuman intelligence, the yearly Cadillacs, the reckless driving, the habitual Wall Street banker's attire[7]—are well represented.

Von Neumann's transition into applied and numerical mathematics began in 1937 when he became a consultant to the Ballistics Research Laboratory that the Army Ordnance Department operated at the Aberdeen Proving Ground in Maryland. Veblen had directed the Ballistics group in World War I, and it is believed that he secured von Neumann's involvement when activities in Aberdeen ramped up due to the worsening conditions in Europe. "It was through military science that I was introduced to applied sciences," von Neumann later explained. In 1943, his work for the government took him to England, where he developed "an obscene interest in computational techniques," as he apprised Veblen. It was there that he learned how a National Cash Register accounting machine could be automated to perform some numerical calculations he required. Von Neumann credited that experience with igniting his interest in computing machines. Toward the end of 1943, in Los Alamos, he observed how the equations for the hydrodynamics of implosions could be numerically solved by running punched cards through a sequence of IBM machines. Dyson

[5] *The "Martians" include Erdős, von Kármán, Polyá, Szegő, Szilárd, Teller, and Wigner. The term is credited to Szilárd, who, referring to the lack of sightings of extraterrestrials, is reported to have said, "They are among us, but they call themselves Hungarians."*

[6] *Dyson says 1929, but Macrae dates the wedding to New Year's Day 1930, as does Marina Whitman, von Neumann's daughter from his marriage to Mariette, in her recent memoir,* The Martian's Daughter.

[7] *Dyson includes a tale that may not be so well known in mathematical circles. According to the story, cited in a paper of Paul Samuelson, David Hilbert attended von Neumann's thesis defense. At the end of the presentation, Hilbert had but one question: Who is the candidate's tailor?*

does a good job outlining von Neumann's conversion to an applied mathematician, but the books of historian William Aspray and Herman Goldstine, Assistant ECP Director, chronicle this phase of von Neumann's career even more thoroughly [1], [5].

In April 1943, Goldstine, a University of Michigan mathematician who was fulfilling his military service in Aberdeen at Veblen's behest, brought to his superiors a proposal for the construction of an electronic, general-purpose, digital computer at the University of Pennsylvania's Moore School of Electrical Engineering. No such machine existed at the time, although John Anatasoff at Iowa State had completed a special-purpose precursor the year before. Veblen advised the Army to fund the project despite nearly unanimous skepticism from reviewers that such a venture could succeed. The ENIAC, as the machine was called, was designed by physicist John Mauchly, who was familiar with Anatasoff's computer, and chief engineer J. Presper Eckert. Presumably von Neumann would have learned of the ENIAC from Veblen when it became operational in fall 1945. As it happened, he became aware of the machine in the summer of 1944 thanks to a chance encounter with Goldstine on the Aberdeen railroad platform. Beginning in August 1944, von Neumann regularly visited the Moore School to participate in discussions about the machine and its planned successor, the EDVAC (Electronic Discrete Variable Automatic Computer). In the spring of 1945, Goldstine had von Neumann's notes on the EDVAC project typed up as a document titled "First Draft of a Report on the EDVAC".[8] This report, which contained the first written description of the logical design of a stored-program computer, bore the name of von Neumann alone, thereby leading to the term "von Neumann architecture". Mauchly and Eckert, however, maintained that the report primarily summarized the discussions among members of the entire EDVAC design group. Moreover, they asserted, the design for the implementation of stored-program functionality was in place before von Neumann joined the project. A bitter fight over both intellectual credit and patent rights ensued.

A hint of this controversy occurs on the first page of the preface of *Turing's Cathedral*, where Dyson quotes ECP engineer Willis Ware: "He [von Neumann] was in the right place at the right time with the right connections with the right idea, setting aside the hassle that will probably never be resolved as to whose ideas they really were." In fact, most historians now credit Mauchly and Eckert with the stored-program concept, even if they allow that von Neumann saw further. Dyson analyzes the dispute clearly and with admirable objectivity. Even better, he presents Jan Rajchman's contention that the stored-program concept evolved gradually through a sequence of technological improvements. As evidence of this, Dyson points to the punched paper tape relay computers that George Stibitz and Samuel Williams built at Bell Laboratories. After witnessing a demonstration of their machine, von Neumann reported to Oppenheimer that the "tape carries numerical data, and operational instructions." That was in a letter he wrote on August 1, 1944, a few days before he learned that there was an electronic computer project in the works. At this point, readers of *Turing's Cathedral* may wonder about Turing's place in any of this.

Less satisfactory is Dyson's review of von Neumann's relationship with IBM. In the book's first intimation of a financial arrangement, Dyson mentions that von Neumann, having become an IBM consultant, drove to their laboratory in Poughkeepsie twice a month. The period of time in which these consultations took place is not provided. Twenty-five pages later, we are told that "von Neumann entered into a series of lucrative personal consulting contracts with IBM," but again there is no indication of the effective dates (or the level of lucre). Dyson does quote one sentence from a May 1, 1945, draft of a retainer agreement: it stipulates that "Von Neumann agrees to assign to IBM, with the exception of the inventions specified below, the entire rights to any and all improvements and inventions made by him." Dyson, however, does not catalog the excluded inventions listed in the contract. With the wording of his next sentence in the book, "As Eckert later complained, 'he [von Neumann] sold all our ideas through the back door to IBM,"' Dyson seems to acquiesce to the claims of the ENIAC group. After these incomplete disclosures on pages 55 and 80, Dyson abandons the thread until page 139, when he quotes chief engineer Bigelow's assertion that von Neumann started consulting with IBM in mid-1947; it would seem from the context, when the ECP engineers were required to accept a new contract that would allow them no patent rights. If there is any use to Bigelow's implication that von Neumann and IBM were profiting from his engineering team's concessions, it is to show the extent to which von Neumann kept his chief engineer out of the loop. The new contract was

[8] *The ENIAC was not initially a stored-program computer, but, in 1948, it was retrofitted to operate that way. A reboot of the Pygmalion story involving the von Neumanns arose during that endeavor. John, acting as Henry Higgins, wanted to determine if someone without mathematical training could succeed as a coder. He did not look far for his Eliza Doolittle: he selected Klára, a "mathematical moron" (as she called herself) with no formal education beyond high school, as his guinea pig for the experiment. Not only did Klára code impressively for the ENIAC in its original configuration, but she is also credited with a significant contribution toward the successful retrofit* [9].

necessitated by the assignment of patent rights to the United States government. After inserting this red herring, Dyson puts aside von Neumann's collaboration with IBM until page 267, where we are told of an ECP engineer who asserted, "IBM people kept coming almost weekly to look at the machine's development," and Bigelow, who characterized the IBM 701 computer, Big Blue's gateway to commercial computer domination, as "a carbon copy of our machine." And that is where the thread ends. Brickbats to Dyson not only for his disjointed narration, but also for raising pertinent ethical concerns without elucidating any of them. Nowadays, when many university professors must fill out annual financial disclosure and conflict of interest forms, more is expected from an author.[9]

The IAS Computer

Von Neumann had many scientific interests that would benefit from the availability of a high-speed computer, but one was paramount, and those who knew him knew it. Ted Taylor, a physicist who worked at Los Alamos during the ECP years, ignored the astrophysics, biology, and meteorology to get to the point of von Neumann's project: "The objective of the von Neumann computer was pretty specifically to be able to do the coupled hydrodynamics and radiation flow necessary for H-bombs." Françoise Ulam, perhaps overstating the impact of the IAS machine, expressed the same idea from a different perspective: "It is an irony of fate that much of the high-tech world we live in today, the conquest of space, the extraordinary advances in biology and medicine, were spurred on by one man's monomania and the need to develop electronic computers to calculate whether an H-bomb could be built or not."

At the beginning of the Cold War, there was strong opposition to the building of a hydrogen bomb (or "Super"), but the argument was that if the United States did not build it first, then the Soviet Union would. There was strong opposition to von Neumann building an electronic computer at the Institute, but the argument was that, if he did not build it there, then he would leave and build it elsewhere—Harvard, MIT, the University of Chicago, and IBM were courting von Neumann and his machine. Among the members of the School of Mathematics, the strongest opposition to the ECP was voiced by Albert Einstein, who, knowing von Neumann's motives and inclinations, feared the project "will further ideas of 'preventive' wars."

Referring to the perception that von Neumann favored a preemptive strike against Soviet Russia, Macrae wrote, "I cannot find anything in his papers that suggests that he advocated that, although a lot of honest people thought that he did." With access to documents that were not at Macrae's disposal, Dyson is able to quote a letter in which von Neumann related to Klára a conversation between Oppenheimer and Veblen. Von Neumann wrote, "He [Oppenheimer] disagreed with my views about a 'quick' [preventive] war, but that I might well be right." That letter was private, but von Neumann did not conceal his views. According to Klára, "Johnny quite openly advocated preventive war before the Russians became too strong." Von Neumann's daughter [11, p. 11] and Freeman Dyson [3, p. 160] say the same. Furthermore, in the 1950s you could hardly go public more effectively than by speaking on the record to a *Life* reporter; that is what von Neumann did, and this is how he was quoted: "If you say, why not bomb them tomorrow, I say, why not today? If you say at five o'clock, I say why not at one o'clock?"[10]

On page 7 Dyson tells us that the IAS computer "was christened MANIAC," a name he uses throughout *Turing's Cathedral*. The name originated at the Moore School not as an acronym but as an epithet for ENIAC when it did not work right. There is no doubt that the name MANIAC was commonly used at Princeton for the IAS machine—it appears in the writings of Klára, Marina von Neumann Whitman, and Freeman Dyson—and found its way from there into the popular press. Continuing to refer to the IAS computer as the MANIAC, however, can only bring confusion,[11] because MANIAC was the *official*

[9] *For clarification of Dyson's muddled account, see* [1, pp. 241–245]. *A few details here will avoid presumptions of impropriety. The draft agreement of May 1945 was never finalized. When von Neumann received the green light for the ECP, he abandoned his IBM plans. In any event, he had obtained permission from both the IAS and the government to consult with IBM. The first of his consulting contracts with IBM dates to late 1951.*

[10] *Interview with Clay Blair Jr., reported in "Passing of a Great Mind",* Life, *volume 42, Number 8, February 25, 1957. At the time of this writing, the Wikipedia article on Dr. Strangelove, Stanley Kubrick's fictional, bomb-loving character, states that Strangelove was a composite of RAND strategist Herman Kahn, rocket scientist Wernher von Braun, physicist Edward Teller, and von Neumann. The first two men are, without doubt, correctly included, and Teller's inclusion is plausible. Von Neumann is apparently included because of the mistaken belief of the article's authors that he "proposed the strategy of mutual assured destruction." The purpose of preventive war, of course, was to prevent mutual assured destruction. See footnote 11.*

[11] *For instance, the Wikipedia article on Mutual Assured Destruction, at the time of this writing, claims that "The strategy of Mutually Assured Destruction and the acronym MAD are due to John von Neumann (1903–1957), who had a taste for humorous acronyms, another example being his MANIAC computer." Witness the error propagation. The term "assured destruction" was common in American military circles in the 1960s and made public by Secretary of Defense Robert McNamara. The addition of mutual and the acronym MAD are believed to have been introduced by Don-*

name of the Los Alamos "clone". Nicholas Metropolis, who led the group that built the MANIAC at Los Alamos, proposed the name not as the acronym Dyson mentioned, but "in an attempt to put an end to all such baptismal practices" [9]. With only nineteen pages remaining in his book, Dyson finally lets on that usage of the name MANIAC for the IAS machine might not be right.

On November 12, 1945, television pioneer Vladimir Zworykin hosted the first ECP meeting in his office at RCA's research laboratory in Princeton. His RCA colleague, Jan Rajchman, who was then developing a 4096-bit electrostatic storage tube, was also present. At the meeting, the ECP group decided to use Rajchman's tube, the Selectron, for the IAS computer's memory. Development of the Selectron, however, fell behind schedule. By the time the first operational unit became available in the autumn of 1948, ECP engineers had opted to use the Williams Tube, a type of externally altered cathode ray tube that Frederic Williams and Tom Kilburn had just developed as a binary storage device.[12] The switch to the Williams tube permitted the use of inexpensive, off-the-shelf 5CP1A oscilloscope tubes. The workhorse of the IAS computer was another readily available tube, the 6J6, which RCA had developed for mobile WWII equipment. Of the 3,474 tubes in the IAS machine, 1,979 were 6J6s. ECP engineers discovered that, in addition to the well-known problems of vacuum tube degradation and failure, the tubes, even when new, differed greatly from their specified electrical characteristics. The challenge was to build a reliable machine from thousands of unreliable components.[13] One part of the solution was to disregard the published specifications and redesign the computer based on the characteristics of the weakest tube found in a sample of 1000. James Pomerene, who replaced Bigelow as chief engineer in 1951, once pulled some tubes that were in service in the computer and had them tested. As he recalled, "You never saw a crummier bunch of tubes in your life!"

Readers who crave the details of the obsolete components on which the IAS computer was based will not be disappointed with Dyson's reporting. He attributes much of the credit for coaxing collectively acceptable behavior from individually problematic parts to Jack Rosenberg, an electrical engineer who was overlooked in [1] and [5]. Because most readers of *Turing's Cathedral* will not be acquainted with many members of the ECP staff, Dyson includes a six-page who's who of his story's "principal characters".[14] It is a very useful feature, but it is also a source of frustration. The first entry is for Katalin (Lili) Alcsuti, a cousin of von Neumann. Principal character? There is no index entry for her. Admittedly she does appear as an eleven-year-old in two photographs and as a newlywed in another. Atle Selberg is also listed as a principal character, but he had no ECP role other than being husband to Hedvig, who collaborated with astrophysicist Martin Schwarzschild and was lead ECP coder. Verena Huber-Dyson, the author's mother, is also found among the principal characters even though her only part in the book is to praise Bigelow's good looks and purposefulness. (The index gives her maiden name as Haefeli. That was actually her married name from her first marriage. The name of Dyson's half sister, Katarina, is spelled Katharina in the text.)

Denouements

By the mid-1950s, von Neumann had become disenchanted with Princeton. Moreover, his appointment to the Atomic Energy Commission in 1954 precipitated a falling-out with Veblen. For many years, Klára had been hoping to relocate to the West Coast. In March 1956, von Neumann accepted a professor-at-large-position with the University of California. One month later, however,

ald G. Brennan at the time of the SALT negotiations later in the 1960s. The reviewer is not familiar with any acronym due to von Neumann, but he did have a taste for puns, of which Los Ulamos (for Stanislaw and Françoise) might be mentioned.

[12] *Williams and Kilburn also built a stored-program computer, the Manchester Small-Scale Experimental Machine (known as the SSEM or Baby), to test the feasibility of their tube storage. On June 21, 1948, Kilburn wrote a 17-instruction program that, by starting with* $2^{18}-1$*, decrementing by 1, and running for 52 minutes, found* 2^{17} *to be the largest proper divisor of* 2^{18}*. It is this program that has a claim to being the first stored program implemented on an electronic computer.*

[13] *Younger readers, who are not accustomed to purchasing replacement television parts in their neighborhood convenience stores, may not fully appreciate the magnitude of this challenge. In the days before solid state components attained their dominant role in consumer electronics, the reviewer worked in a corner tobacco store that stocked radio and television tubes. As an aid to customers, an RCA tube-testing machine was available to the do-it-yourselfer who owned a television set that was on the fritz. Business was moderately brisk.*

[14] *A complete list of the documented ECP staff and affiliated researchers is available from the IAS website:* `http://library.ias.edu/files/pdfs/ecpstaff.pdf`*. It includes the reviewer's colleague, A. Edward Nussbaum (1925–2009), ECP coder in 1952 and 1953. In the mid-1990s, the reviewer showed Nussbaum, whose relationship with computers had become distant after four decades, some impressive capabilities of computer algebra systems. That prompted Nussbaum to reminisce about the final shakedown tests of the IAS machine in which the computer raced von Neumann to complete some computations. The reviewer regrets that he did not foresee his current task and consequently did not record the details.*

he was admitted to Walter Reed Hospital, where he spent the better part of a year before he died from metastasizing cancer. Ulam described his friend's mental deterioration as heartbreaking. Dyson's readers will concur.

The Institute never wanted von Neumann's computer, and, once he was gone, the Institute acted quickly to be rid of it. On July 1, 1957, ownership of and responsibility for the machine was transferred to Princeton University. However, right from the start, the University had trouble getting the machine to work. Bigelow was called in and restored the computer to service. In June 1958, Schwarzschild informed Hedvig Selberg, "Your code has run the last couple of weeks wonderfully." Nevertheless, within the month, Princeton announced the retirement of the machine, explaining that it was "essentially developmental and not very carefully engineered." At midnight on July 15, 1958, Bigelow disconnected the power.

Julian Bigelow visited von Neumann every weekend during his final hospitalization and read science journals to him until communication became fruitless. He received many offers of employment after the ECP was closed down, but he declined them. Because he had become a permanent member, the IAS could not terminate his employment, but the institution could and did freeze his salary. To Dyson, Bigelow was the link between theory and the real world. The ECP required members who conceived things and members who built things. Bigelow did both. Atle Selberg remembered him as a "thinker". Martin Davis described him as a man who was most effective with a soldering iron. Bigelow has rarely received his due, but Dyson's appreciative portrayal remedies previous oversights.

In 1958 Klára married Carl Eckart, a distinguished geophysicist at the Scripps Institution of Oceanography. Describing her four marriages, Dyson writes, "The first had been for romance, the second for money, the third for brains, and the fourth for California." On the last page of her unfinished autobiography, Klára wrote, "La Jolla is a wonderful place and I feel that I do not have to travel anymore because I am there already." Not long afterwards, in November 1963, she died, aged 52. Her body, clothed in a black dress, was found washed up on Windansea Beach, La Jolla. Von Neumann's last Cadillac was parked nearby.

Features and Errors

Dyson's penchant for passing along intriguing tidbits is generally laudable, but sometimes he repeats information without questioning it. For example, Dyson, referring to the IAS computer, tells us on page 7, "The new machine was …put to its first test, during the summer of 1951, with a thermonuclear calculation that ran for sixty days nonstop." This assertion is based on the recollection of Bigelow decades later. (Dyson quotes Bigelow's testimony on page 216.) Historians are usually cautious about such memories. Is "nonstop" really credible? Aspray reports that there were a few machine errors during the run [1, p. 85], as would be expected from a computer that would not be officially operational until June 10, 1952. Are we to believe that the computer became *less* reliable in the year during which such glitches were eliminated? According to Aspray, "Unscheduled maintenance decreased to the point that the machine was available 80 percent of the time between July 1952 and June 1953" [1, p. 86].

In his zeal to share diverting material, Dyson often tosses in facts that raise obvious questions that are left unanswered. For instance, within the space of four pages, Dyson acquaints his readers with three facts about British physicist Klaus Fuchs: 1) On May 28, 1946, Fuchs and von Neumann jointly filed for a patent on the design of an H-bomb;[15] 2) Fuchs was a Soviet agent; 3) Fuchs confessed to espionage on January 27, 1950. Nothing more is said about any of this. Readers who are immoderately inquisitive will surely want to know, What was the outcome of the patent application?

Dyson, like Aspray, Goldstine, and Macrae before him, lists the BESM in Moscow as a clone of the IAS machine. If true, what irony! Von Neumann built the IAS machine to effect the means for destroying Moscow. In doing so, was he also responsible for the construction of a machine in Moscow that could effect the means for destroying Washington, thereby giving rise to MAD after all? Given that the Soviet Union gained access to highly classified H-bomb materials, there can be little doubt that the procurement of widely circulated design plans for the IAS machine, if needed, would have been trivial. But, by itself, that does not mean that the BESM was a clone. Soviet historians and some Western scholars have disputed the contention that it was [2], [6].

There are rather too many errors for comfort in *Turing's Cathedral*, but they tend to be inconsequential. Willis Ware is said to have joined RAND, "where the JOHNNIAC had just been built." Actually, Ware was hired by RAND in May 1952 to help build the JOHNNIAC. Although different RAND engineers state different dates for when the JOHNNIAC "went on the air," an idiom that originated in an era when computers relied on radio tubes, the earliest date given is the first half of 1953. In a similar error, Richard Feynman is said

[15] *Although nuclear technology was new, there was a precedent. Szilárd had previously patented the A-bomb.*

to have been a graduate student when he was at Los Alamos. In fact, Feynman's Ph.D. was awarded in 1942, but construction at Los Alamos did not finish until November 30, 1943. Dyson refers to two different British kings as "Her Majesty". One wonders if these references are due to error or to a feud between the author and His Majesty's Foreign Office.

Summary

It is difficult to avoid the conclusion that *Turing's Cathedral* is an idiosyncratic, undisciplined, crazy quilt of a book. The reviewer had no preconceived notions about the sort of book that might be authored by a man who once lived for three years in a treehouse 95 feet above the ground, but the eccentricities of *Turing's Cathedral* do not seem inconsistent with what might be imagined. And yet, for all its flaws, shortcomings, and waywardness, it is a book that amply rewards its readers. By all rights, it should have been rendered redundant by the engrossing biography of Macrae and the expert histories of Aspray and Goldstine that preceded it. But it is not. In large part, that is because Dyson is not so much a biographer or historian as he is a storyteller. It is a labor at which he excels. Over the ages, the best stories have been about extraordinary people performing exceptional deeds. That is just the sort of story that Dyson tells. Once upon a time, bards spun tales of wizards and warriors. In Dyson's hands, computer wizards and cold warriors make splendid substitutes.

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WHAT IS . . .

a Rauzy Fractal?

Pierre Arnoux and Edmund Harriss

There is a long tradition, going back to Hadamard and Morse, of associating symbolic infinite words with dynamical systems coming from geometry or mechanics. Conversely, one may try to give geometric representations to infinite words generated in an algebraic or combinatorial way; elementary examples, such as the Fibonacci word, produce well-known dynamical systems, but natural generalizations give rise to a diverse family of self-similar sets with fractal boundaries.

Define a sequence of words on the alphabet of two letters a, b, starting with a and at each step substituting every a by ab and every b by a. Elementary algebra shows that the lengths of the words $a, ab, aba, abaab\ldots$ are the Fibonacci numbers, the ratio of the frequencies of a and b tends to the golden number $\phi = \frac{1+\sqrt{5}}{2}$, and each word is a prefix of the next one. In this way we define the *Fibonacci word*, the only infinite word $abaababaab\ldots$ that is invariant by the substitution rule.

We can understand this word better by giving it a geometric representation as a broken line in the plane. Every a (resp. b) gives a step to the right (resp. a step up). We see (Figure 1) that this broken line not only has asymptotic slope $1/\phi$, as expected, but is also a very good discrete approximation of a line with slope $1/\phi$.

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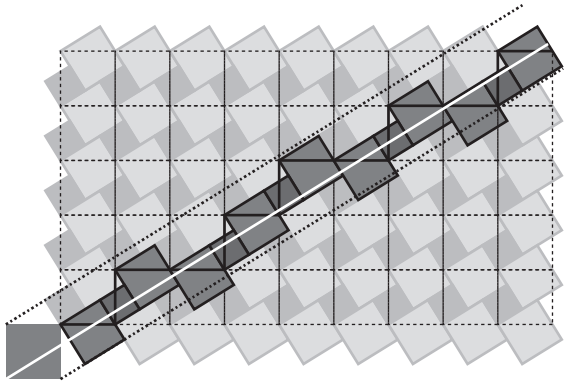

Figure 1. Geometric construction of the Fibonacci word.

This is easily proved. Denote by σ the substitution rule; the associated matrix $\begin{pmatrix} 1 & 1 \\ 1 & 0 \end{pmatrix}$ has one expanding direction associated with the eigenvalue ϕ, and one contracting direction associated with the conjugate $-1/\phi$. Therefore the points associated with the finite Fibonacci words $\sigma^n(a)$ tend to the expanding space. More generally, any initial word U of the infinite Fibonacci word can be written $U = \sigma^k(i_k)\ldots\sigma(i_1)i_0$ for a finite sequence $i_0, i_1, \ldots, i_k$, where i_n is the letter a or the empty word. Using the eigendirections for axes, the coordinates of the corresponding point are therefore given by finite sums. These are bounded by a geometric series, convergent in the contracting direction. The vertices of the broken line, therefore, lie within a bounded distance of the expanding direction.

Even better, if one draws a "corridor" by sliding the unit square with upper right corner at the origin along the expanding direction, the broken line lies within this corridor and is determined by it. This gives an arithmetic definition of the Fibonacci word: its nth letter is an a (resp. b) if $[(n+1)/\phi] - [n/\phi]$ is equal to 1 (resp. 0).

There is a physical interpretation, as a cut-and-project quasicrystal. A crystal is a periodic lattice in Euclidean space. To get a subset that is close to periodic, but not periodic, consider a cylinder in $\mathbb{R}^n$ with irrational direction and bounded base (the *window*). Projecting the points in the intersection of the integer lattice and this cylinder onto the irrational direction gives the cut-and-project quasicrystal associated with this cylinder [Sen95].

For the Fibonacci word, the projection of the vertices on the contracting direction is a bounded set whose closure is an interval; the projection on the expanding line gives a self-similar tiling that is the simplest possible example of a cut-and-project quasicrystal, with the window given by the interval in the contracting direction.

There is also a dynamical interpretation: We can *shift* the Fibonacci word by erasing its first letter; if we consider the closure of the shift-orbit of the Fibonacci word for the natural topology on infinite words, we get a very simple symbolic dynamical system. Its domain is a Cantor-like set, which projects continuously to the interval, and the projection conjugates the shift to the rotation by the golden number.

This is readily seen on the window, which is divided inyo two intervals corresponding to the two letters; the point corresponding to the next vertex of the broken line is obtained by exchanging the two intervals. This translation of intervals corresponds to the step to the right or up associated with each letter. These properties hold if we change the substitution rule, provided the associated matrix has determinant ± 1.

What happens if we increase the number of letters? Consider the three-letter substitution rule $a \mapsto ab$, $b \mapsto ac$, $c \mapsto a$. This rule again defines an infinite word, and the Perron-Frobenius theorem shows that the associated broken line, now in three-dimensional space, has an asymptotic direction. Since all the eigenvalues except the leading eigenvalue have modulus strictly smaller than 1, the same proof shows that the broken line lies within a bounded distance of the expanding direction.

Definition. *First defined by Gérard Rauzy in 1982, the* Rauzy fractal *(also called the* central tile*) is the closure of the projection of the vertices of the broken line to the contracting space along the expanding line.* [Rau82]

To use the word "fractal" is slightly misleading, since this set is the closure of its interior and has the same dimension as the contracting plane; it is the boundary that is fractal. The Rauzy fractal has remarkable properties. Firstly, it is self-similar; more exactly, it is divided into three pieces, corresponding to the three letters, which are the solutions of a graph-directed iterated function system. Secondly, these three pieces admit both a periodic tiling and a nonperiodic self-similar tiling of the contracting plane. Finally, the broken line connects all the integer points contained in the prism given by translating the Rauzy fractal along the expanding line. These points project to a self-similar tiling of the expanding line: this gives another cut-and-project quasicrystal.

The three pieces can be assembled in two ways to partition the Rauzy fractal; this gives rise to a dynamical system, an exchange of the three pieces. This system is conjugate to a rotation of the torus and also to the symbolic dynamical system generated by the substitution rule. One can define three prisms based on the three pieces that form a fundamental domain for the integer lattice in three-dimensional space as well as a Markov partition for the automorphism of the three-torus associated with the matrix of the substitution rule.

We can define a Rauzy fractal for any substitution rule whose associated matrix has all but one eigenvalue of modulus strictly smaller than 1 (so-called *Pisot substitution rules*) and determinant ± 1. All known examples satisfy the properties above. For examples see Figure 2. This gives rise to the main unsolved problem of this area:

Conjecture (Pisot conjecture)**.** *The one-dimensional tiling generated by any Pisot substitution rule on d letters with determinant* ± 1 *is a cut-and-project quasicrystal.*

This conjecture occurs in several areas with many different formulations; the dynamical formulation states that the symbolic system (or the tiling flow) associated with such a substitution rule has pure discrete spectrum. It was proved for 2 letters by Barge and Diamond. While it is open for more letters, there is a terminating algorithm to confirm it holds for any specific substitution rule. The conjecture implies a number of consequences including producing a self-similar tiling and giving a Markov partition for the toral automorphism defined by a matrix.

Various generalizations have been developed. For nonunit determinants, the problem adds an arithmetic component, and one can define a Rauzy fractal using p-adic space. A multi-dimensional framework has been proposed recently for tiling substitution rules, the *Pisot families*. Here the expanding line is replaced by the underlying space

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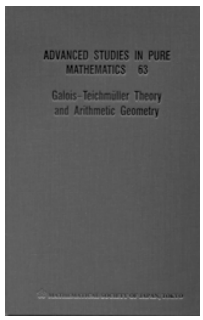

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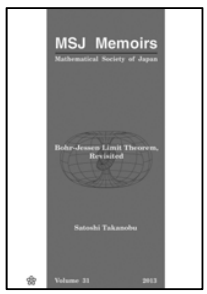

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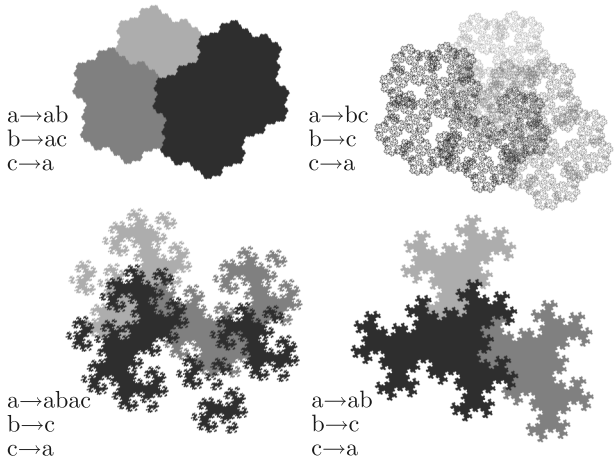

Figure 2. Examples of Rauzy fractals.

of the tiling, and the leading eigenvalue by the expansion matrix of the substitution rule; one requires that any conjugate of modulus > 1 of an eigenvalue of the expansion matrix is an eigenvalue of this matrix, with the same multiplicity. The Pisot conjecture can be generalized to this setting.

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Mathematicians Discuss the Snowden Revelations

The following article was solicited as part of the *Notices* discussion of the National Security Agency. The previous installment in the discussion appeared in the June/July 2014 issue of the *Notices* and included articles by Keith Devlin of Stanford University and Andrew Odlyzko of the University of Minnesota. Those articles were preceded by an introduction that describes how the discussion came about and provides a list of previous *Notices* pieces on this topic, as well as citations to articles that have appeared in other publications. Since then, additional coverage has appeared in the media. On June 7, 2014, the BBC aired a radio story, "Are science and spying connected?", by Gordon Corera. On June 5, 2014, *Forbes* online magazine published an article, "Mathematicians Urge Colleagues to Refuse to Work for The NSA", by Kashmir Hill. Both the BBC broadcast and the *Forbes* article featured interviews with mathematicians, and the latter mentioned the *Notices* discussion.

Other material has appeared on the Web. For example, on May 14, 2014, the International Association for Cryptologic Research issued a statement about mass surveillance: `http://www.iacr.org/misc/statement-May2014.html`. Earlier, in January 2014, "An Open Letter from US Researchers in Cryptography and Information Security" appeared on the Web; see `http://masssurveillance.info`. Since November 2013, Tom Leinster of the University of Edinburgh has moderated a discussion of these issues, with a focus on Britain's GCHQ (Government Communications Headquarters), in n-Category Cafe blog (`http://golem.ph.utexas.edu/category/`).

As we have collaborated on organizing this discussion, we had the impression that mathematicians are hesitant to voice their opinions on this topic. We hope to hear further opinions on this important topic in the future. Unsolicited articles are welcome. Inquiries and submissions may be sent to `notices-snowden@ams.org`. Articles of 800 words or less are preferred. Those of 400 words or less can be considered as Letters to the Editor and should be sent to `notices-letters@ams.org`.

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NSA and the Snowden Issues

Richard George

As a mathematician who worked for the National Security Agency for 41 years, I truly appreciate the American Mathematical Society having this open discussion about a very important topic. At NSA, my entire career was on the information assurance side—white hat—evaluating equipment used to protect U.S. information.

One of the tasks I really enjoyed at NSA was being able to work closely with NIST (National Institute of Standards and Technology) on the evaluation of both the Data Encryption Standard (DES) and the Advanced Encryption Standard (AES); AES is the symmetric algorithm widely used by government, industry, and private citizens to ensure confidentiality. It is a major component of Suite B along with elliptic curve cryptography. Suite B (a set of algorithms and protocols for encryption, key exchange, hashing, and signature) is important

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for international interoperability needs and also enables the government to choose cost-effective commercial security devices to provide protection for classified information. It ensures that strong cryptography is affordable and available to everyone. These were challenging and exciting tasks; problems like these make NSA a great place for mathematicians. The talk about NSA weakening crypto reminds me of the 1970s when the popular line was that "the DES S-boxes don't look like a random set, so that's where the back-door is". Of course they weren't random—they were much stronger than a typical random set as Adi Shamir later showed. As I said at the RSA Conference in 2011, I don't think NSA was clever enough to hide a weakness in crypto that people like Whitfield Diffie and Adi Shamir wouldn't find. And I have never heard of any proven weakness in a cryptographic algorithm that's linked to NSA; just innuendo.

I was not a direct part of the signals intelligence (SIGINT) system, but the math community at NSA is very open; techniques and research are openly shared throughout. As an NSA employee, I was aware of the rules about signals intelligence. When public discussions about foreign intelligence take place, there are some facts about the SIGINT system that people need to know:

- NSA is a supplier of intelligence, not a consumer
- NSA does not choose its targets
- NSA activities and processes are driven by laws established by Congress and by directives from the President, the Secretary of Defense, and the Director of National Intelligence (DNI).

NSA's intelligence activities stem from a foreign-intelligence requirement—initiated by one or more Executive Branch intelligence consumers (the White House, Department of State, Department of Defense, etc.), vetted through the Justice Department as a valid need—and run according to a process managed by the Office of the Director of National Intelligence. When NSA receives those requirements, NSA's analysts look at what's known as the "information need" and determine the best way to satisfy it. That process involves identifying the foreign entities that might have the information, researching how they communicate, and figuring out how best to access those communications in order to acquire the information. The General Counsel of NSA validates that NSA has the authority to carry out the planned activities. The number of requests for information that the NSA receives from the various government entities is huge: in 2012, the requests filled 36,000 pages.

Many of the foreign threats that NSA must monitor to protect our safety and security operate in the same environments and use the same technology as innocent persons. It is NSA's responsibility to find effective and lawful ways to gain access to these communications by foreign targets while protecting the privacy and civil liberties of individuals who occupy the same space or employ the same technology.

NSA does not collect and exploit a class of communications or services that would sweep up communications that don't have information of bona fide foreign intelligence interest. The result of each task that NSA carries out is intelligence that is passed to the group that requested it.

Phone metadata (section 215 of the Patriot Act) has been in the news a great deal since last summer's unauthorized disclosures. Many of the claims about this metadata program were not really true. Under Section 215, the government stored in bulk metadata related to telephone calls. As President Obama said in January, the U.S. government believes this is a capability that must be preserved, and noted that independent reviews did not turn up any indications that the program had been intentionally abused. However, changes were ordered to enhance public confidence; specifically, the president ordered a transition to end the bulk metadata program as it existed, and the establishment of a program that preserves the capabilities the government needs without the government holding the data.

I've heard some knowledgeable people claim that this metadata can be used to create detailed profiles of people. Of course, that's not true. Data is used to create profiles—that's why when I check the weather on the Internet, I get ads for hotels in cities I've looked at or ads for flights to those cities. Big business has already created profiles on us from all the data that is readily available. The only thing metadata alone can be used for is to point to interesting phone numbers; then data can be used to get other information. I find it ironic that no one seems concerned that Big Industry already has the type of profile on Americans that we worry that the government might create. I guess there's no concern that a Big Industry employee might ever misuse the information.

The issue of privacy in all this is very interesting. The folks I knew in SIGINT, and I knew them very well, would not dream of violating U.S. citizens' rights. Please keep in mind that there may be a few bad apples in any set of people who would do something inappropriate, but they would be a minuscule minority. That's true everywhere, though we'd like to think background checks help somewhat at NSA and that people come to work for NSA out of a desire to protect the nation, the citizens, and our way of life. In fact, NSA officials and employees have given up much of their own privacy to accomplish their mission. Each year they disclose to the government their financial dealings and status, grant the government the right to access any and all banking records, grant the government the right to monitor phone calls and

emails on their office systems, and submit to a full background check and polygraph every five years. More importantly, they are fully aware that they are targets of foreign intelligence services that will be watching for any weakness that can be exploited. When I was at NSA, we all knew that a government was likely listening to all our phone calls—just not the U.S. government.

Every time an espionage incident happens—John Walker, Aldrich Ames, Bradley Manning, Edward Snowden—in which someone with a clearance has signed an oath to not disclose information and then violates that oath and trust, it comes as a disappointment, a feeling of betrayal by someone in the family. It hurts NSA and it hurts the country. We are all aware that untrustworthy individuals will continue to crop up, but it's still a shock. System administrators occupy key positions today, much as crypto custodians, the holders of the keys (Walker), did years ago. The damage that such a person can cause to an agency is immense. The trust that is damaged, both within our own country and with other countries as well, will take years to rebuild.

Finding intelligence in the mountain of data that exists today is a monumental task. If it was simple, we would predict all the terrible events that happen—9/11, Boston Marathon bombing, etc.—but it's not. There is much publicity on events that happen and none on those that are stopped. NSA is just one player on the team—from the Department of Homeland Security, FBI, Drug Enforcement Administration, Coast Guard, Air Force, Army, Navy, Marines, to local police and fire departments—whose reason for existence is to protect the people of this nation. Events like the Snowden leaks make that effort harder.

Whether the rules should be changed further is a great topic for debate. What is already clear, however, is that the threats are not easing. And they are not going to go away.

Lusztig Awarded Shaw Prize

George Lusztig

On May 27, 2014, the Shaw Foundation announced the awarding of the 2014 Shaw Prize in Mathematical Sciences to GEORGE LUSZTIG of the Massachusetts Institute of Technology "for his fundamental contributions to algebra, algebraic geometry, and representation theory and for weaving these subjects together to solve old problems and reveal beautiful new connections." The prize carries a cash award of US$1 million.

The Shaw Prize in Mathematical Sciences Committee released the following statement about Lusztig's work.

"For more than two hundred years, symmetry groups have been at the center of mathematics and its applications: in Fourier's work on the heat equation in the early 1800s; in Weyl's work on quantum mechanics in the early 1900s; and in the approach to number theory created by Artin and Chevalley. These classical works show that answers to almost any question involving a symmetry group lie in understanding its realizations as a group of matrices; that is, in terms of its representations.

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"Starting with his early work in the 1970s and 1980s, in part jointly with Deligne, Lusztig gave a complete description of the representations of finite Chevalley groups, these being the building blocks of finite symmetry groups. The Deligne-Lusztig description uses the topology and geometry of Schubert varieties. The latter were introduced in the nineteenth century as a tool to count solutions of algebraic equations.

"The vision of this work is that the algebraic subtleties of representation theory correspond perfectly to the geometric/topological subtleties of Schubert varieties. This vision has grown into a broad and powerful theme in Lusztig's work: he has shown that many central problems in representation theory—including those of real and p-adic Lie groups, which are the language of applications from number theory to mathematical physics—can be related to topology and geometry by means of Schubert varieties. This idea is at the heart of many exciting recent developments, for example in progress toward the Langlands programme in automorphic forms.

"Representations are complicated, as are the Schubert varieties to which they are related. Beginning in a 1979 paper with David Kazhdan, and

emails on their office systems, and submit to a full background check and polygraph every five years. More importantly, they are fully aware that they are targets of foreign intelligence services that will be watching for any weakness that can be exploited. When I was at NSA, we all knew that a government was likely listening to all our phone calls—just not the U.S. government.

Every time an espionage incident happens—John Walker, Aldrich Ames, Bradley Manning, Edward Snowden—in which someone with a clearance has signed an oath to not disclose information and then violates that oath and trust, it comes as a disappointment, a feeling of betrayal by someone in the family. It hurts NSA and it hurts the country. We are all aware that untrustworthy individuals will continue to crop up, but it's still a shock. System administrators occupy key positions today, much as crypto custodians, the holders of the keys (Walker), did years ago. The damage that such a person can cause to an agency is immense. The trust that is damaged, both within our own country and with other countries as well, will take years to rebuild.

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"Representations are complicated, as are the Schubert varieties to which they are related. Beginning in a 1979 paper with David Kazhdan, and

continuing through his most recent work, Lusztig has found combinatorial tools to describe their topology and geometry. (These tools are easy to describe, but had not been used previously in mathematics.) His ideas have guided and inspired the development of perverse sheaves, a tool for studying the topology of general singular algebraic varieties.

"These tools, in the hands of Lusztig and of hundreds of other mathematicians, have made possible a depth of understanding of representations and of Schubert varieties that was unimaginable before his work."

George Lusztig was born in 1946 in Timisoara, Romania. He received his Ph.D. in 1971 from Princeton University under the direction of William Browder. He taught at the University of Warwick from 1974 to 1977, then joined the faculty of the Massachusetts Institute of Technology, where he was Norbert Wiener Professor from 1999 to 2009 and is currently Abdun-Nur Professor of Mathematics. He received the Cole Prize (1985) and the Steele Prize for Lifetime Achievement (2008) from the AMS. He has also been a recipient of the Berwick Prize of the London Mathematical Society (1977) and the Brouwer Medal of the Dutch Mathematical Society (1999). He is a fellow of the Royal Society (1983) and of the American Academy of Arts and Sciences (1991) and a member of the National Academy of Sciences (1992).

The Shaw Prize is an international award established to honor individuals who are currently active in their respective fields and who have achieved distinguished and significant advances, who have made outstanding contributions in culture and the arts, or who have achieved excellence in other domains. The award is dedicated to furthering societal progress, enhancing quality of life, and enriching humanity's spiritual civilization. Preference is given to individuals whose significant work was recently achieved.

The Shaw Prize consists of three annual awards: the Prize in Astronomy, the Prize in Science and Medicine, and the Prize in Mathematical Sciences. Established under the auspices of Run Run Shaw in November 2002, the prize is managed and administered by the Shaw Prize Foundation based in Hong Kong.

Previous recipients of the Shaw Prize in Mathematical Sciences are David L. Donoho (2013), Maxim Kontsevich (2012), Demetrios Christodoulou and Richard S. Hamilton (2011), Jean Bourgain (2010), Simon K. Donaldson and Clifford H. Taubes (2009), Vladimir Arnold and Ludwig Faddeev (2008), Robert Langlands and Richard Taylor (2007), David Mumford and Wen-Tsun Wu (2006), Andrew Wiles (2005), and Shiing-Shen Chern (2004).

— From Shaw Foundation announcements

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Faculty Position(s)
Department of Mathematics

The Department of Mathematics invites applications for tenure-track faculty positions at the rank of Assistant Professor in all areas of mathematics. Applications at the rank of Associate Professor or above may also be considered. Other things being equal, preference will be given to areas consistent with the Department's strategic planning.

Applicants should have a PhD degree and strong experience in research and teaching. Applicants with exceptionally strong qualifications and substantial experience in research and teaching may be considered for positions above the Assistant Professor rank.

Starting rank and salary will depend on qualifications and experience. Fringe benefits include medical/dental benefits and annual leave. Housing will also be provided where applicable. Initial appointment will be on a three-year contract, renewal subject to mutual agreement. A gratuity will be payable upon successful completion of the contract.

Application Procedure
Applications received on or before 31 December 2014 will be given full consideration for appointment in 2015. Applications received afterwards will be considered subject to the availability of positions. Applicants for Assistant Professor position should send their curriculum vitae together with at least three research references and one teaching reference to the Human Resources Office, HKUST, Clear Water Bay, Kowloon, Hong Kong. Applicants for Associate Professor position and above should send a curriculum vitae and the names of at least three research referees to the Human Resources Office.

More information about the University is available on the University's homepage at http://www.ust.hk.

(Information provided by applicants will be used for recruitment and other employment-related purposes.)

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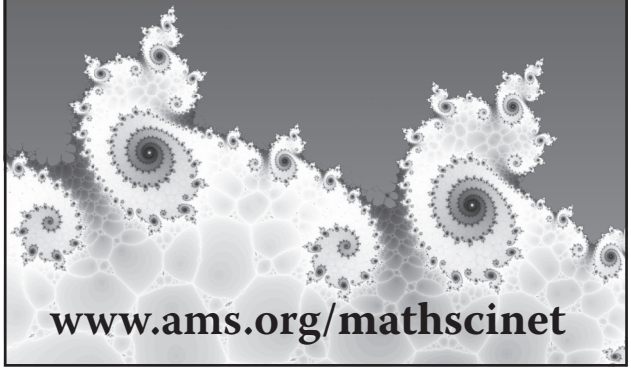

www.ams.org/mathscinet

Planning a 21st Century Global Library for Mathematics Research

Jim Pitman and Clifford Lynch

The literature corpus and knowledge base of mathematics is both bedrock and wellspring for future research. How can we make this resource more valuable as it transitions to digital form and is used in conjunction with new network and computationally based services? Over the past two years, a committee established by the National Research Council, a part of the United States National Academies, with funding from the Alfred P. Sloan foundation, has explored these issues. Many scholarly disciplines are considering these questions; the answers for each discipline seem to be different, and they are shaped by the practices of the discipline, the extent to which the historical literature continues to be relevant to current research, and many other factors. The report of this Committee on Planning a Global Library of the Mathematical Sciences has been recently published by the National Academies Press at `http://www.nap.edu/catalog.php?record_id=18619` and is also available at `http://arxiv.org/abs/1404.1905`.

The committee's charge called for an evaluation of the potential value of such a library and some consideration of its appropriate scope; an assessment of the issues and alliances involved in establishing such a library; the identification of a range of desired capabilities for such a system and a consideration of which of these capabilities were likely to be within reach given current and foreseeable technology; and a sketch of resource needs and the way forward with such a project. The committee was specifically asked not to focus on issues such as copyright and open access, but rather to take a pragmatic view of operating within the current diverse landscape of scholarly information. Further, the committee was asked to focus on the needs of researchers in the mathematical sciences, rather than the needs of the vast range of other disciplines that use and rely on mathematics. In its work, the committee took a broad view of the ecosystem of mathematical literature and information services and the extent to which the needs of mathematics researchers (particularly within major research institutions) are currently met.

The committee report included a number of findings and recommendations, indicated here by italicized paragraphs, which are quoted here verbatim:

Finding: *The construction of mathematical libraries through centralized aggregation of resources has reached a point of diminishing returns, particularly given that much of this construction has been coupled with retrospective digitization efforts.*

Put another way, the committee recognized the potential value of moving toward a broader view, going beyond aggregation alone to create a comprehensive digital mathematics information resource that could be of much greater value than the sum of its contributing publications. Building on the extensive work done by many dedicated individuals under the rubric of the World Digital Mathematical Library, as well as many other

Jim Pitman is a professor in the Departments of Statistics and Mathematics at the University of California, Berkeley. His email address is `pitman@stat.berkeley.edu`.

Clifford Lynch is Director of the Coalition for Networked Information. His email address is `cliff@cni.org`.

Pitman and Lynch were members of the Committee on Planning a Global Library of the Mathematical Sciences, which wrote the report discussed here. Other members were Ingrid Daubechies, Duke University; Kathleen Carley, Carnegie Mellon University; Timothy Cole, University of Illinois at Urbana-Champaign; Judith Klavans, University of Maryland, College Park; Yann LeCun, New York University; Michael Lesk, Rutgers University; Peter Olver, University of Minnesota, Minneapolis; and Zhihong "Jeff" Xia, Northwestern University. Daubechies and Lynch co-chaired the committee.

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community initiatives, the committee recommended establishment of an organization, tentatively called the Digital Mathematics Library (DML), to support a wide variety of new functionalities and services over aggregated mathematical information, including dramatically improved capabilities for searching, browsing, navigating, annotating, and linking mathematical concepts. Specifically, the DML organization should

• develop a collection of platforms, tools, and services for curation and navigation of mathematical information;

• mobilize and coordinate the mathematical community to engage with these capabilities;

• support an ongoing applied research program in mathematical information management to complement the development work.

The report envisions a combination of computational machine learning and textual analysis methods along with community-based editorial efforts, in order to make a significantly greater portion of the information and knowledge in the global mathematical corpus available to researchers as linked open data through the DML. The report describes how such a library might operate—discussing development and research needs; its role in facilitating discovery and interaction; and the importance of establishing partnerships with publishers, abstracting and indexing services, and other current players in the mathematical information ecology. Several of the capabilities described—such as the ability to annotate across the full corpus of mathematical literature—seem to be low-hanging fruit. One focus of particular interest, tantalizingly on the fringe of current technology in the committee's view, when combined with community editing, was the extent to which the mathematical literature might be adequately tagged with identifiers for mathematical concepts to facilitate linking and navigation.

Finding: *While fully automated recognition of mathematical concepts and ideas (e.g., theorems, proofs, sequences, groups) is not yet possible, significant benefit can be realized by utilizing existing scalable methods and algorithms to assist human agents in identifying important mathematical concepts contained in the research literature—even while fully automated recognition remains something to aspire to.*

Following are some further recommendations of the report:

Recommendation: *A DML organization should be created to manage and encourage the creation of a knowledge-based library of mathematical concepts such as theorems and proofs… It should be an advocate for the mathematics community and help develop plans for development and funding of open information systems of use to mathematicians.*

Recommendation: *A primary role of the DML should be to provide a platform that engages the mathematical community in enriching the library's knowledge base and identifies connections in the data.*

Recommendation: *The DML should rely on citation indexing, community sourcing, and a combination of other computationally based methods for linking among articles, concepts, authors, and so on.*

Recommendation: *Community engagement and the success of community-sourced efforts need to be continuously evaluated throughout DML development and operation to ensure that DML missions continue to align with community needs and that community engagement efforts are effective.*

Recommendation: *The DML should be open and built to cooperate with both researchers and existing services. In particular, the content (knowledge structures) of the library, at least for vocabularies, tags, and links, should also be open, although the library will link to both open and copyright-restricted literature.*

Recommendation: *The DML should serve as a nexus for the coordination of research and research outcomes, including community endorsements, and encourage best practices to facilitate knowledge management in research mathematics.*

Recommendation: *The initial DML planning group should set up a task force of suitable experts to produce a realistic plan, timeline, and prioritization of components, using this report as a high-level blueprint, to present to potential funding agencies (both public and private).*

Recommendation: *The DML needs to build an ongoing relationship with the research communities spanning mathematics, computer science, information science, and related areas concerned with knowledge extraction and structuring in the context of mathematics and to help translation of developments in these areas from research to large-scale application.*

Members of the committee and others hope to offer several articles in coming issues of the *Notices* that look into various facets of the proposed DML in more detail, and there are ongoing discussions about how the work outlined in the report might be advanced. But perhaps the most important objective now is broad vetting of the report within the mathematical sciences community. As one step in this process, there will be a presentation and panel discussion about these recommendations by the Committee on Electronic Information and Communication (CEIC) at the upcoming International Congress of Mathematicians in Seoul, Korea, 6:00–7:30 p.m. on August 20, moderated by Peter Olver of the committee that authored the Academies report. The panel discussion will involve Thierry Bouche, Ingrid Daubechies, Gert-Martin Greuel, Rajeeva L. Karandikar, and June Zhang.

Mathematics People

Kuo Awarded 2014 Information-Based Complexity Prize

FRANCES KUO of the University of New South Wales has been named the recipient of the 2014 Prize for Achievement in Information-Based Complexity (IBC). The prize consists of US$3,000 and a plaque, to be presented at the Foundations of Computational Mathematics conference in Montevideo, Uruguay, in December 2014. This annual prize is given for outstanding contributions to information-based complexity.

—Joseph Traub, Columbia University

Prizes of the Association for Women in Mathematics

J. ELISENDA GRIGSBY of Boston College has been awarded the inaugural AWM-Joan and Joseph Birman Research Prize in Topology and Geometry by the Association for Women in Mathematics (AWM) for her "pioneering and influential contributions to low-dimensional topology, particularly in the areas of knot theory and categorified invariants". Her research focuses on the interplay between the combinatorial theory of Khovanov homology and the more geometric Heegaard-Floer homology. She will receive the prize at the Joint Mathematics Meetings in San Antonio, Texas, in January 2015. The Birman Prize recognizes exceptional research in topology and/or geometry by a woman early in her career.

MARIE A. VITULLI of the University of Oregon has been named the 2014 Etta Z. Falconer Lecturer of the AWM and the Mathematical Association of America (MAA). She was honored for her "original and important contributions to commutative algebra and its interactions with algebraic geometry", as well as for her distinguished career. She will deliver the Falconer Lecture, titled "From Algebraic to Weak Subintegral Extensions in Algebra and Geometry", at the MAA MathFest in Portland, Oregon, in August 2014.

—From MAA announcements

Prizes of the Mathematical Society of Japan

The Mathematical Society of Japan (MSJ) has awarded several prizes for 2014.

The Spring Prize has been awarded to YUKINOBU TODA of the University of Tokyo for his outstanding contributions to the study of derived categories of algebraic varieties. The Spring Prize is awarded to researchers under the age of forty who have obtained outstanding mathematical results.

The Algebra Prize has been awarded to YUJI YOSHINO of Okayama University for work on Cohen-Macaulay representation theory and to HIDEKAZU FURUSHO of Nagoya University for work on Grothendieck-Teichmüller theory and multiple zeta values. The Algebra Prize is awarded to researchers who have made significant contributions to the development of algebra in a broad sense by obtaining outstanding results.

The Prize for Science and Technology in Research was awarded to the following individuals: HIROYUKI OCHIAI of the Institute of Mathematics for Industry, Kyushu University, and KEN-ICHI ANJYO of OLM Digital, Inc., for their outstanding contributions to mathematical modeling on discrete image synthesis; to MITSUHIRO NAKAO of Sasebo National College of Technology for outstanding contributions to research on validated computation and its applications to partial differential equations; and to ATSUKO MIYAJI of the Japan Advanced Institute of Science and Technology for her outstanding contributions to secure and efficient elliptic curve cryptsystems.

The Young Scientists' Prize was awarded to YOSHIKO OGATA of the University of Tokyo for her research on operator algebras and their applications to quantum statistical mechanics and to TSUYOSHI YONEDA of the Tokyo Institute of Technology for his research on fluid equations by real analysis.

The Outstanding Paper Prizes were awarded to DAISUKE FUJIWARA of Gakushuin University for the article "An integration by parts formula for Feynman path integrals", *Journal of the Mathematical Society of Japan* **65** (2013), no. 4, 1273–1318, and to HISASHI OKAMOTO of Kyoto University for the article "Blow-up problems in the strained vorticity dynamics and critical exponents", *Journal of the Mathematical Society of Japan* **65** (2013), no. 4, 1079–1099. The prize is awarded to the authors of the most outstanding articles published in the *Journal of the Mathematical Society of Japan* during the preceding year.

The Japan Academy Prize has been awarded to HIRAKU NAKAJIMA of Kyoto University for his outstanding contributions to geometric representation theory and mathematical physics. The Japan Academy Prize is awarded to persons who have achieved notable research landmarks or who have authored particularly outstanding academic papers or books.

—From MSJ announcements

VanderWeele Receives 2013 Carroll Young Investigator Award

TYLER J. VANDERWEELE of Harvard University has been chosen the recipient of the 2013 Raymond J. Carroll Young Investigator Award by the Texas A&M University Department of Statistics. VanderWeele was honored "for his methodological research on how to distinguish association and causation in the social and biomedical sciences". The award is given biannually in odd-numbered years to a statistician who has made important contributions to the area of statistics.

—From a Texas A&M University announcement

Moody's Mega Math Challenge

The winners of the 2014 Mega Math Challenge for high school students have been announced. The topic for this year focused on the question, "Can school lunches be nutritious, affordable, and delicious?"

A team from the North Carolina School of Science and Mathematics in Durham, North Carolina, was awarded the Summa Cum Laude team prize of US$20,000 in scholarship money. The students were ANNE LEE, IRWIN LI, STEVEN LIAO, ZACK POLIZZI, and JENNIFER WU. Their coach was Daniel Teague.

The Magna Cum Laude Team Prize of US$15,000 in scholarship money was awarded to a team from High Technology High School in Lincroft, New Jersey. The team members were CYNTHIA GUO, RUBY GUO, PATRICK LEBLANC, AUSTIN LIU, and ZACHARY LIU. They were coached by Raymond Eng.

Another team from the North Carolina School of Science and Mathematics was awarded the Cum Laude Team Prize of US$10,000 in scholarship money. The members were ALLAN JIANG, PRANAY ORUGUNTA, ANSHUL SUBRAMANYA, MARGARET TIAN, and CHRIS YUAN, and they were also coached by Daniel Teague.

The Meritorious Team Prize of US$7,500 in scholarship money was awarded to a team from Columbus North High School in Columbus, Indiana. The team members were TUSHAR CHANDRA, BRIAN PIERSON, CHRIS VON HOENE, and BYRON ZAHARAKO. Their coach was Michael Spock.

The Exemplary Team Prize of US$5,000 in scholarship money was awarded to the Charter School of Wilmington, Delaware. The members were STEVEN BURCAT, CHRISTOPHER DENG, BYRON FAN, MARTIN KURIAN, and KYLE LENNON. Their coach was Mimi Payne.

The First Honorable Mention Team Prize of US$2,500 was awarded to a team from Arsenal Technical High School in Indianapolis, Indiana.The team members were JOHN FRANCIS, JACKSON HERBERTZ, ELIJAH STEVENSON, and JACK VANSCHAIK. They were coached by Mark Blachly.

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

—From a Moody's Foundation/SIAM announcement

USA Mathematical Olympiad

The 2014 USA Mathematical Olympiad (USAMO) was held April 29–30, 2014. The students who participated in the Olympiad were selected on the basis of their performances on the American High School and American Invitational Mathematics Examinations. The twelve highest scorers in this year's USAMO, listed in alphabetical order, were: JOSHUA BRAKENSIEK, home schooled, Arizona College Prep-Erie, Chandler, Arizona; EVAN CHEN, Irvington High School, Fremont, California; RAVI JAGADEESAN, Phillips Exeter Academy, Exeter, New Hampshire; ALLEN LIU, Penfield Senior High School, Penfield, New York; NIPUN PITIMANAAREE, Pomfret School, Pomfret, Connecticut; MARK SELLKE, William Henry Harrison High School, West Lafayette, Indiana; ZHUOQUN SONG, Phillips Exeter Academy, Exeter, New Hampshire; DAVID STONER, South Aiken High School, Aiken, South Carolina; KEVIN SUN, Phillips Exeter Academy, Exeter, New Hampshire; JAMES TAO, Illinois Mathematics and Science Academy, Aurora, Illinois; ALEXANDER WHATLEY, North Houston Academy of Science and Mathematics, Spring, Texas; SCOTT WU, Baton Rouge Magnet High School, Baton Rouge, Louisiana.

The twelve USAMO winners will attend the Mathematical Olympiad Summer Program (MOSP) at the University of Nebraska, Lincoln. Ten of the twelve will take the team selection test to qualify for the U.S. team. The six students with the highest combined scores from the test and the USAMO will become members of the U.S. team and will compete in the International Mathematical Olympiad (IMO) to be held in Cape Town, South Africa, July 3–13, 2014.

—From Mathematical Association of America announcements

National Academy of Sciences Elections

The National Academy of Sciences (NAS) has elected eighty-four new members and twenty-one foreign associates for 2014. Following are the new members whose work involves the mathematical sciences: RICHARD BORCHERDS, University of California Berkeley; EMMANUEL CANDÈS, Stanford University; CYNTHIA DWORK, Microsoft; LAWRENCE C. EVANS, University of California Berkeley; DREW FUDENBERG, Harvard University; JEFFREY A. HARVEY, Enrico Fermi Institute, University of Chicago; CARLOS E. KENIG, University of Chicago; JUDEA PEARL, University of California Los Angeles; JAMES H. SIMONS, Simons Foundation and Stony Brook University; and BIN YU, University of California Berkeley. Elected as foreign associates were JAMES ARTHUR, University of Toronto; YVES F. MEYER, Centre de Mathématiques et de Leurs Applications, École Normale Supérieure; and EDVARD I. MOSER, Centre for Neural Computation, Kavli Institute for Systems Neuroscience, Norwegian University of Science and Technology.

—From an NAS announcement

Royal Society Elections

The Royal Society of London has elected its new fellows for 2014. The new fellows whose work involves the mathematical sciences are: TOM BRIDGELAND, University of Sheffield; GEOFFREY GRIMMETT, University of Cambridge; MARTIN HAIRER, University of Warwick; VLADIMIR MARKOVIC, University of Cambridge and California Institute of Technology; and NICHOLAS STERN, London School of Economics.

—From a Royal Society announcement

Mathematics Opportunities

AMS Scholarships for "Math in Moscow"

The Math in Moscow program at the Independent University of Moscow (IUM) was created in 2001 to provide foreign students (primarily from the U.S., Canada, and Europe) with a semester-long, mathematically intensive program of study in the Russian tradition of teaching mathematics, the main feature of which has always been the development of a creative approach to studying mathematics from the outset—the emphasis being on problem solving rather than memorizing theorems.

Indeed, discovering mathematics under the guidance of an experienced teacher is the central principle of the IUM, and the Math in Moscow program emphasizes in-depth understanding of carefully selected material rather than broad surveys of large quantities of material. Even in the treatment of the most traditional subjects, students are helped to explore significant connections with contemporary research topics. The IUM is a small, elite institution of higher learning focusing primarily on mathematics and was founded in 1991 at the initiative of a group of well-known Russian research mathematicians, who now comprise the Academic Council of the university. Today, the IUM is one of the leading mathematical centers in Russia. Most of the Math in Moscow program's teachers are internationally recognized research mathematicians, and all of them have considerable teaching experience in English, typically in the United States or Canada. All instruction is in English.

Pending renewal of funding from the National Science Foundation (NSF), the AMS intends to award five scholarships in the amount of US$9,500 for the spring 2015 semester and five scholarships in the amount of US$9,800 for the fall 2015 semester to U.S. students to attend the Math in Moscow program. To be eligible for the scholarships, students must be either U.S. citizens or enrolled at a U.S. institution at the time they attend the Math in Moscow program. Students must apply separately to the IUM's Math in Moscow program and to the AMS Math in Moscow Scholarship program. Undergraduate or graduate mathematics or computer science majors may apply. The deadlines for applications for the scholarship program are **September 15, 2014**, for the spring 2015 semester and **April 15, 2015**, for the fall 2015 semester.

Information and application forms for Math in Moscow are available on the Web at `http://www.mccme.ru/mathinmoscow`, or by writing to: Math in Moscow, P.O. Box 524, Wynnewood, PA 19096; fax: +7095-291-65-01; email: `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 Math-

ematical Society, 201 Charles Street, Providence RI 02904-2294; email student-serv@ams.org.

—AMS Membership and Programs Department

Applications for Adams Prize 2014–2015

Applications are being accepted for the 2014–2015 Adams Prize, which will be awarded for achievements in the field of algebraic geometry. The prize is open to any person under the age of forty who will hold an appointment in the United Kingdom either in a university or in some other institution as of October 31, 2014. (In exceptional circumstances the age limit may be relaxed.) The value of the prize is expected to be approximately £14,000 (approximately US$24,000), of which one-third is awarded to the prizewinner on announcement of the prize, one-third is provided to the prizewinner's institution (for research expenses of the prizewinner), and one-third is awarded to the prizewinner on acceptance for publication in an internationally recognized journal of a substantial (normally at least twenty-five printed pages) original article of which the prizewinner is an author, surveying a significant part of the winner's field. The deadline for receipt of applications is **October 31, 2014**. For more information, see the website http://www.maths.cam.ac.uk/news/4.html.

—From a University of Cambridge announcement

NSF Focused Research Groups

The Focused Research Groups (FRG) activity of the Division of Mathematical Sciences (DMS) of the National Science Foundation (NSF) supports small groups of researchers in the mathematical sciences. The deadline date for full proposals is **September 19, 2014**. The FRG solicitation may be found on the Web at http://www.nsf.gov/pubs/2012/nsf12566/nsf12566.htm.

—From an NSF announcement

NSF Mathematical Sciences Postdoctoral Research Fellowships

The Mathematical Sciences Postdoctoral Research Fellowship program of the Division of Mathematical Sciences (DMS) of the National Science Foundation (NSF) awards fellowships each year that are designed to permit awardees to choose research environments that will have maximal impact on their future scientific development. Awards of these fellowships are made for appropriate research in areas of the mathematical sciences, including applications to other disciplines. Fellows may opt to choose either a research fellowship or a research instructorship. The deadline for this year's applications is **October 15, 2014**. Applications must be submitted via FastLane on the World Wide Web. For more information see the website http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5301.

—From an NSF announcement

NSA Mathematical Sciences Grants and Sabbaticals Program

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

Grants for Research in Mathematics. The Mathematical Sciences Program (MSP) supports self-directed, unclassified research in the following areas of mathematics: Algebra, Number Theory, Discrete Mathematics, Probability, and Statistics. The Research Grants program offers two types of grants, the Young Investigators Grant and the Standard Grant, and also supports Conferences/Workshops/Special Situations (including Research Experiences for Undergraduates, REUs, as well as other innovative programs at a university in one of the five designated areas). The program does not entertain research or conference proposals that involve cryptology. In particular, MSP is interested in supporting efforts that increase broader participation in the mathematical sciences, promote wide dissemination of mathematics, and promote the education and training of undergraduates and graduate students. Principal investigators, graduate students, and all other personnel supported by NSA grants must be U.S. citizens or permanent residents of the United States at the time of proposal submission. Proposals should be submitted **electronically** by **October 15, 2014**, via the program website: http://www.nsa.gov/research/math_research/index.shtml.

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

NSA pays 50 percent of salary and benefits during academic months and 100 percent of salary and benefits during summer months of the sabbatical detail. A housing supplement is available to help offset the cost of local lodging.

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

For more information about the Grants or Sabbaticals Program, please contact the program office at 443-634-4304. You may also send email to mspgrants@nsa.gov.

—From an NSA Mathematical Sciences Program announcement

Call for Nominations for 2014 Sacks Prize

The Association for Symbolic Logic (ASL) invites nominations for the 2014 Sacks Prize for the most outstanding doctoral dissertation in mathematical logic. The Sacks Prize consists of a cash award and five years' free membership in the ASL. Dissertations must have been defended by September 30, 2014. General information about the prize is available at http://www.aslonline.org/info-prizes.html. For details about nomination procedures, see http://www.aslonline.org/Sacks_nominations.html.

—From an ASL announcement

Research Experiences for Undergraduates

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

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

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

Students may not apply to NSF to participate in REU activities. Students apply directly to REU sites and should consult the directory of active REU sites on the Web at http://www.nsf.gov/crssprgm/reu/reu_search.cfm. The deadline for full proposals for REU sites is **August 27, 2014**. Deadline dates for REU supplements vary with the research program; contact the program director for more information. The full program announcement can be found at the website http://www.nsf.gov/pubs/2009/nsf09598/nsf09598.htm.

—From an NSF announcement

News from PIMS

The Pacific Institute for the Mathematical Sciences (PIMS) is seeking nominations of outstanding young researchers in the mathematical sciences for postdoctoral fellowships for the year 2015–2016.

Nominees must have a Ph.D. or equivalent (or expect to receive a Ph.D. by December 31, 2015) and must be within three years of receipt of the Ph.D. at the time of the nomination (i.e., Ph.D. received on or after January 1, 2012). The fellowship may be taken up at any time between September 1, 2015, and January 1, 2016. The fellowship is for one year and is renewable, contingent on satisfactory progress, for at most one additional year. PIMS postdoctoral fellows are expected to participate in all PIMS activities related to their areas of expertise and will be encouraged to spend time at more than one site.

Candidates must be nominated by at least one scientist or by a department (or departments) affiliated with PIMS. The fellowships are intended to supplement support provided by the sponsor and are tenable at any of the PIMS Canadian member universities: the University of Alberta, the University of British Columbia, the University of Calgary, the University of Lethbridge, the University of Regina, the University of Saskatchewan, Simon Fraser University, and the University of Victoria, as well as at the PIMS affiliate, the University of Northern British Columbia.

Complete applications must be uploaded to MathJobs by **December 1, 2014**. For further information, visit: http://www.pims.math.ca/scientific/postdoctoral or contact assistant.director@pims.math.ca.

—From a PIMS announcement

News from MSRI

MSRI invites applications for 40 Research Professors, 200 Research Members, and 30 semester-long Post-Doctoral Fellows in the following programs: New Challenges in PDE: Deterministic Dynamics and Randomness in High and Infinite Dimensional Systems (August 17–December 18, 2015) and Differential Geometry (January 11–May 20, 2016). Research Professorships are intended for senior researchers who will be making key contributions to a program, including the mentoring of postdoctoral fellows, and who will be in residence for three or more months. Research Memberships are intended for researchers who

will be making contributions to a program and who will be in residence for one or more months. Post-Doctoral Fellowships are intended for recent Ph.D.s. Interested individuals should carefully describe the purpose of their proposed visit, and indicate why a residency at MSRI will advance their research program. To receive full consideration, application must be complete, including all letters of support, by the following deadlines: Research Professorships, **October 1, 2014**; Research Memberships, **December 1, 2014**; Post-doctoral Fellowships, **December 1, 2014**. Application information can be found at `https://www.msri.org/web/msri/scientific/member-application`. It is the policy of MSRI actively to seek to achieve diversity in its programs and workshops. Thus, a strong effort is made to remove barriers that hinder equal opportunity, particularly for those groups that have been historically underrepresented in the mathematical sciences. MSRI is proud to announce a new resource to assist visitors with finding childcare in Berkeley. For more information, please contact Sanjani Varkey at `sanjani@msri.org`. Programs are funded by the National Science Foundation.

—From an MSRI announcement

Inside the AMS

Math in Moscow Scholarships Awarded

The AMS has made awards to four mathematics students to attend the Math in Moscow program in the fall of 2014. Following are the names of the undergraduate students and their institutions: HARRISON LEFROIS, University of Nebraska, Omaha; GILLIAN GRINDSTAFF, Pomona College; JACOB SPEAR, Carleton College; and XUANHUA WANG, Hendrix College.

Math in Moscow is a program of the Independent University of Moscow that offers foreign students (undergraduate or graduate students specializing in mathematics and/or computer science) the opportunity to spend a semester in Moscow studying mathematics. All instruction is given in English. The fifteen-week program is similar to the Research Experiences for Undergraduates programs that are held each summer across the United States.

The AMS awards several scholarships for U.S. students to attend the Math in Moscow program. The scholarships are made possible through a grant from the National Science Foundation. For more information about Math in Moscow, consult `http://www.mccme.ru/mathinmoscow` and the article "Bringing Eastern European mathematical traditions to North American students", *Notices*, November 2003, pages 1250–1254.

—Elaine Kehoe

2014 AMS-AAAS Mass Media Fellow Chosen

The 2014 AMS-AAAS Mass Media Fellowship has been awarded to JOSHUA BATSON, a recent Ph.D. graduate in mathematics from the Massachusetts Institute of Technology. He will spend ten weeks this summer working at WIRED magazine.

Joshua Batson

The Mass Media Science and Engineering Fellows program is organized by the American Association for the Advancement of Science (AAAS). This competitive program is designed to improve public understanding of science and technology by placing graduate and postgraduate science, mathematics, and engineering students in media outlets nationwide. The fellows work as reporters, researchers, and production assistants alongside media professionals to sharpen their communication skills and increase their understanding of the editorial process by which events and ideas become news.

The program is available to enrolled college or university students (graduate, doctoral, or upper-level undergraduates) in the physical, biological, geological, health, engineering, computer, or social sciences or mathematics with outstanding written and oral communication skills and a strong interest in learning about the media.

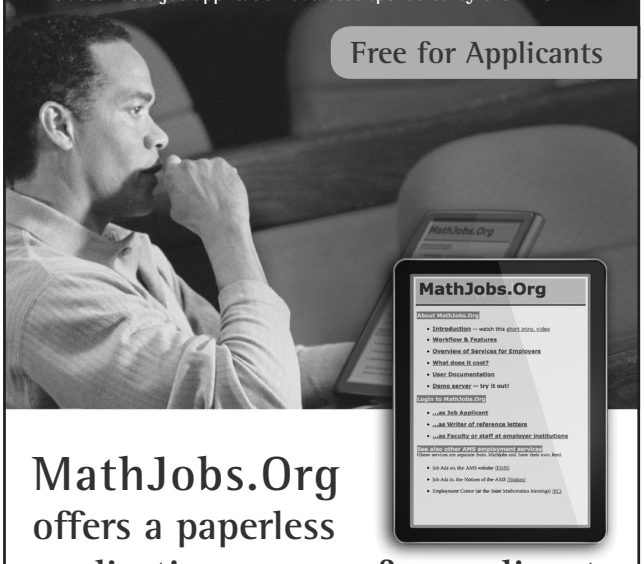
In its fortieth year, this fellowship program has placed over 600 science, mathematics, and engineering scholars

AMERICAN MATHEMATICAL SOCIETY

MathJobs.Org

The automated job application database sponsored by the AMS

Free for Applicants



MathJobs.Org offers a paperless application process for applicants and employers in mathematics

Registered Applicants Can:

- Create their own portfolio of application documents
- Make applications online to participating employers
- Choose to make a cover sheet viewable by all registered employers

Registered Employers Can:

- Post up to seven job ads
- Set all criteria for required documents, and add specific questions
- Receive and upload reference letters
- Manage applicant information and correspondence quickly and easily
- Set limited access permissions for faculty and EOE administrators
- Search for and sort additional applicants in the database
- Choose an advertising-only account, or a discounted single ad account

Visit mathjobs.org for pricing information

Contact: Membership and Programs Department

American Mathematical Society
201 Charles Street
Providence, RI 02904-2294 USA

800.321.4267, ext. 4105
Email: mathjobs@ams.org

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in media organizations nationwide as they research, write, and report today's headlines.

For more information on the AAAS Mass Media Science and Engineering Fellows Program, visit the website http://www.aaas.org/mmfellowship.

—AMS Washington Office

From the AMS Public Awareness Office

AMS at the 2014 USA Science and Engineering Festival. The AMS hosted a curve-stitching activity at the 2014 USA Science and Engineering Festival, which was held this spring in Washington, D.C. About 2,500 people, mostly young people, came by and stitched polygons and approximations to curves at the AMS booth. Susan Wildstrom, Walt Whitman High School, led the activity with help from about a dozen of her students and AMS staff members Mike Breen, Anita Benjamin, and Colleen Rose. Kyle Gatesman, an eighth-grader from Virginia, won US$1,000 playing *Who Wants to Be a Mathematician*, which was held on Sneak Peek Friday, the opening day of the festival. More than 300,000 people attended the three-day festival. See more at http://www.ams.org/meetings/usasef2014.

2014 Mathematical Art Exhibition Album. Images of selected works in the 2014 Mathematical Art Exhibition are now in an album on Mathematical Imagery. Share the e-postcards by email and on social media and explore the world of mathematics and art at http://www.ams.org/mathimagery/thumbnails.php?album=39.

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

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.

Upcoming Deadlines

July 20, 2014: Applications for New York City Master Teacher Fellowships of Math for America (MfA). See http://www.mathforamerica.org/web/guest/apply.

July 23, 2014: Proposals for NSF CAREER Awards. See http://www.nsf.gov/pubs/2014/nsf14532/nsf14532.htm.

July 31, 2014: Nominations for 2014 SASTRA Ramanujan Prize. See http://www.math.ufl.edu/sastra-prize/nominations-2013.html.

August 1, 2014: Applications for United States-Israel Foundation (USIEF) Fulbright Postdoctoral Fellowships. See http://tinyurl.com/nzhcy6l.

August 1, 2014, November 1, 2014: Applications for August and November reviews for National Academies Research Associateship Programs. See 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 12, 2014: Full proposals for NSF Scholarships in Science, Technology, Engineering, and Mathematics (STEM). See http://www.nsf.gov/pubs/2012/nsf12529/nsf12529.htm.

August 15, 2014: Nominations for the 2014 Parzen Prize. See http://www.stat.tamu.edu/events/parzenprize/index.html.

August 27, 2014: Proposals for National Science Foundation (NSF) Research Experiences for Undergraduates (REU) sites. See "Mathematics Opportunities" in this issue.

September 15, 2014: Nominations for Alfred P. Sloan Foundation Research Fellowships. See http://www.sloan.org/fellowships.

September 15, 2014: Applications for Blackwell-Tapia Conference at IPAM. See www.ipam.ucla.edu.

September 15, 2014, April 15, 2015: Applications for spring 2015 and fall 2015 (respectively) semester of Math in Moscow. See http://www.mccme.ru/mathinmoscow, or contact: Math in Moscow, P.O. Box 524, Wynnewood, PA 19096; fax: +7095-291-65-01; email: mim@mccme.ru.

Where to Find It

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

AMS Bylaws—*November 2013, p. 1358*

AMS Email Addresses—*February 2014, p. 199*

AMS Ethical Guidelines—*June/July 2006, p. 701*

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AMS Officers and Committee Members—*October 2012, p. 1290*

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Conference Board of the Mathematical Sciences—*September 2013, p. 1067*

IMU Executive Committee—*December 2011, p. 1606*

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National Science Board—*January 2014, p. 82*

NRC Board on Mathematical Sciences and Their Applications—*March 2014, p. 305*

NSF Mathematical and Physical Sciences Advisory Committee—*February 2014, p. 202*

Program Officers for Federal Funding Agencies—*October 2013, p. 1188 (DoD, DoE); December 2012, p. 1585 (NSF Mathematics Education)*

Program Officers for NSF Division of Mathematical Sciences—*November 2013, p. 1352*

Information and application forms for the AMS scholarships are available on the AMS website at http://www.ams.org/programs/travel-grants/mimoscow, or contact: Math in Moscow Program, Membership and Programs Department, American Mathematical Society, 201 Charles Street, Providence RI 02904-2294; email student-serv@ams.org.

September 19, 2014: Full proposals for National Science Foundation (NSF) Focused Research Groups (FRG). See "Mathematics Opportunities" in this issue.

October 1, 2014: Applications for AWM Travel Grants and Mathematics Education Research Travel Grants. See https://sites.google.com/site/awmmath/programs/travel-grants; telephone: 703-934-0163; or email: awm@awm-math.org; or contact Association for Women in Mathematics, 11240 Waples Mill Road, Suite 200, Fairfax, VA 22030.

October 15, 2014: Proposals for National Security Agency (NSA) Grants for Research in Mathematics. See "Mathematics Opportunities" in this issue.

October 15, 2014: Proposals for NSF Postdoctoral Research Fellowships. See http://www.nsf.gov/pubs/2012/nsf12496/nsf12496.htm.

October 31, 2014: Applications for the 2014–2015 Adams Prize in Algebraic Geometry. See "Mathematics Opportunities" in this issue.

December 1, 2014: Applications for Pacific Institute for the Mathematical Sciences (PIMS) postdoctoral fellowships. See "Mathematics Opportunities" in this issue.

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http://maths.anu.edu.au/about-us/structure/centre-mathematics-its-applications

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email: qgm@au.dk
http://qgm.au.dk/

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Statistical and Applied Mathematical Sciences Institute (SAMSI)
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email: contact@wias-berlin.de
http://www.wias-berlin.de/

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.

Alan M. Turing: Centenary Edition, by Sara Turing. Cambridge University Press, April 2012. ISBN-13: 978-11070-205-80.

Alan Turing: The Enigma, The Centenary Edition, by Andrew Hodges. Princeton University Press, May 2012. ISBN-13: 978-06911-556-47.

Alan Turing: His Work and Impact, edited by S. Barry Cooper and J. van Leeuwen. Elsevier, May 2013. ISBN-13: 978-01238-698-07.

Alan Turing's Electronic Brain: The Struggle to Build the ACE, the World's Fastest Computer, by B. Jack Copeland et al. Oxford University Press, May 2012. ISBN-13: 978-0-19-960915-4.

Algorithms Unlocked, by Thomas H. Cormen. MIT Press, March 2013. ISBN-13: 978-02625-188-02.

**André-Louis Cholesky: Mathematician, Topographer and Army Officer,* by Claude Brezinski and Dominique Tournès. Birkhäuser, August 2014. ISBN: 978-33190-813-42.

A Cabinet of Mathematical Curiosities at Teachers College: David Eugene Smith's Collection, by Diane R. Murray. Docent Press, November 2013. ISBN-13: 978-0-9887449-1-2.

Circles Disturbed. The Interplay of Mathematics and Narrative, edited by Apostolos Doxiadis and Barry Mazur. Princeton University Press, March 2012. ISBN: 978-06911490-42.

Computability: Turing, Gödel, Church, and Beyond, edited by B. Jack Copeland, Carl J. Posy, and Oron Shagrir. MIT Press, June 2013. ISBN-13: 978-02620-189-99.

Do I Count?: Stories from Mathematics, by Günter Ziegler (translation of *Darf ich Zahlen?: Geschichte aus der Mathematik,* Piper Verlag, 2010). CRC Press/A K Peters, July 2013. ISBN-13: 978-1466564916

Enlightening Symbols: A Short History of Mathematical Notation and Its Hidden Powers, by Joseph Mazur. Princeton University Press, March 2014. ISBN-13: 978-06911-546-33.

Four Lives: A Celebration of Raymond Smullyan, edited by Jason Rosenhouse. Dover Publications, February 2014. ISBN-13: 978-04864-906-70.

Fractals: A Very Short Introduction, by Kenneth Falconer. Oxford University Press, December 2013. ISBN-13: 978-01996-759-82.

The Gödelian Puzzle Book: Puzzles, Paradoxes and Proofs, by Raymond M. Smullyan. Dover Publications, August 2013. ISBN-13: 978-04864-970-51.

Good Math: A Geek's Guide to the Beauty of Numbers, Logic, and Computation, by Mark C. Chu-Carroll. Pragmatic Bookshelf, July 2013. ISBN-13: 978-19377-853-38.

**The Grapes of Math: How Life Reflects Numbers and Numbers Reflect Life,* by Alex Bellos. Simon and Schuster, June 2014. ISBN: 978-14516-400-90.

Henri Poincaré: A Scientific Biography, by Jeremy Gray. Princeton University Press, November 2012. ISBN-13: 978-06911-527-14. (Reviewed April 2014.)

A History in Sum: 150 Years of Mathematics at Harvard (1825–1975), by Steve Nadis and Shing-Tung Yau. Harvard University Press, October 2013. ISBN-13: 978-06747-250-03. (Reviewed June/July 2014.)

How Not to Be Wrong: The Power of Mathematical Thinking, by Jordan Ellenberg. Penguin Press, June 2014. ISBN-13: 978-15942-052-24. I

If A, Then B: How the World Discovered Logic, by Michael Shenefelt and Heidi White. Columbia University Press, June 2013. ISBN-13:978-02311-610-53.

Imagined Civilizations: China, the West, and Their First Encounter, by Roger Hart. Johns Hopkins University Press, July 2013. ISBN-13:978-14214-060-60.

The Improbability Principle: Why Coincidences, Miracles, and Rare Events Happen Every Day, by David J. Hand. Scientific American/Farrar, Straus and Giroux, February 2014. ISBN-13: *978-03741-753-44.*

Infinitesimal: How a Dangerous Mathematical Theory Shaped the Modern World, by Amir Alexander. Scientific American/Farrar, Straus and Giroux, April 2014. ISBN-13: 978-03741-768-15.

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. (Reviewed September 2013.)

L. E. J. Brouwer—Topologist, Intuitionist, Philosopher: How Mathematics Is Rooted in Life, by Dirk van Dalen. Springer (2013 edition), December 2012. ISBN-13: 978-14471-461-55. (Reviewed June/July 2014.)

Jane Austen, Game Theorist, by Michael Suk-Young Chwe. Princeton University Press, April 2013. ISBN-13: 978-06911-557-60.

**Levels of Infinity: Selected Writings on Mathematics and Philosophy,* by Hermann Weyl (edited and with an introduction by Peter Pesic). Dover

Publications, January 2013. ISBN: 978-04864-890-32.

The Logic of Infinity, by Barnaby Sheppard Cambridge University Press, May 2014. ISBN-13: 978-11076-786-68.

Love and Math: The Heart of Hidden Reality, by Edward Frenkel. Basic Books, October 2013. ISBN-13: 978-04650-507-41.

Magnificent Mistakes in Mathematics, by Alfred S. Posamentier and Ingmar Lehmann. Prometheus Books, August 2013. ISBN-13: 978-16161-474-71.

The Math Book: From Pythagoras to the 57th Dimension, 250 Milestones in the History of Mathematics, by Clifford A. Pickover. Sterling. February, 2012. ISBN-13: 978-14027-882-91.

Mathematics: An Illustrated History of Numbers, edited by Tom Jackson. Shelter Harbor Press, October 2012. ISBN-13: 978-09853-230-42.

Mathematics in Nineteenth-Century America: The Bowditch Generation, by Todd Timmons. Docent Press, July 2013. ISBN-13: 978-0-9887449-3-6.

Mathematics of the Transcendental, by Alain Badiou (translated by A. J. Bartlett and Alex Ling). Bloomsbury Academic, March 2014. ISBN-13: 978-14411-892-40.

Math Bytes: Google Bombs, Chocolate-Covered Pi, and Other Cool Bits in Computing, by Tim Chartier. Princeton University Press, April 2014. ISBN-13: 978-06911-606-03.

Math in Minutes: 200 Key Concepts Explained in an Instant, by Paul Glendinning. Quercus, September 2013. ISBN-13: 978-16236-500-87.

Math in 100 Key Breakthroughs, by Richard Elwes. Quercus, December 2013. ISBN-13: 978-16236-505-44.

Math Is Murder, by Robert C. Brigham. iUniverse, March, 2012. ISBN-13 978-14697-972-81.

My Brief History, by Stephen Hawking. Bantam Dell, September 2013. ISBN-13: 978-03455-352-83.

Naked Statistics: Stripping the Dread from the Data, by Charles Wheelan. W. W. Norton & Company, January 2013. ISBN-13: 978-03930-719-55.

Naming Infinity: A True Story of Religious Mysticism and Mathematical Creativity, by Loren Graham and Jean-Michel Kantor. Belknap Press of Harvard University Press, March 2009. ISBN-13: 978-06740-329-34. (Reviewed January 2014.)

The New York Times Book of Mathematics: More Than 100 Years of Writing by the Numbers, edited by Gina Kolata. Sterling, June 2013. ISBN-13: 978-14027-932-26. (Reviewed May 2014.)

Numbers Are Forever, by Liz Strachan. Constable, March 2014. ISBN-13: 978-14721-110-43.

Our Mathematical Universe: My Quest for the Ultimate Nature of Reality, by Max Tegmark. Knopf, January 2014. ISBN-13: 978-03075-998-03.

The Outer Limits of Reason: What Science, Mathematics, and Logic Cannot Tell Us, by Noson S. Yanofsky. MIT Press, August 2013. ISBN-13: 978-02620-193-54.

Perfect Mechanics: Instrument Makers at the Royal Society of London in the Eighteenth Century, by Richard Sorrenson. Docent Press, September 2013. ISBN-13: 978-0-9887449-2-9.

The Perfect Theory: A Century of Geniuses and the Battle over General Relativity, by Pedro G. Ferreira. Houghton Mifflin Harcourt, February 2014. ISBN-13: 978-05475-548-91.

Philosophy of Mathematics in the Twentieth Century, by Charles Parsons. Harvard University Press, March 2014. ISBN-13: 978-06747-280-66.

Probably Approximately Correct: Nature's Algorithms for Learning and Prospering in a Complex World, by Leslie Valiant. Basic Books, June 2013. ISBN-13: 978-04650-327-16.

Quantum Computing since Democritus, by Scott Aaronson. Cambridge University Press, March 2013. ISBN-13: 978-05211-995-68.

**Ramanujan's Place in the World of Mathematics: Essays Providing a Comparative Study,* by Krishnaswami Alladi. Springer, 2013. ISBN: 978-81322-076-65. Mathematical Expeditions: Exploring Word Problems Across the Ages, by Frank J. Swetz. Johns Hopkins University Press, June 2012. ISBN: 978-14214-043-87.

The Simpsons and Their Mathematical Secrets, by Simon Singh. Bloomsbury, October 2013. ISBN-13: 978-14088-353-02.

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. (Reviewed November 2013.)

Strange Attractors (comic book), by Charles Soule, Greg Scott, and Robert Saywitz. Archaia Entertainment, May 2013. ISBN-13: 978-19363-936-26.

Symmetry: A Very Short Introduction, by Ian Stewart. Oxford University Press, July 2013. ISBN-13: 978-01996-519-86.

**Synthetic Philosophy of Contemporary Mathematics,* by Fernando Zalamea. Urbanomic/Sequence Press, January 2013. ISBN: 978-09567-750-16.

A Tale of Two Fractals, by A. A. Kirillov. Birkhäuser, May 2013. ISBN-13: 978-08176-838-18.

Théorème vivant, by Cédric Villani (in French). Grasset et Fasquelle, August 2012. ISBN-13: 978-2246798828. (Reviewed February 2014.)

**The Tower of Hanoi: Myths and Maths,* by Andreas M. Hinz, Sandi Klavzar, Uros Milutinovic, and Ciril Petr. Birkhäuser, January 2013. ISBN: 978-303-48023-69.

Turing: Pioneer of the Information Age, by Jack Copeland. Oxford University Press, January 2013. ISBN-13: 978-01996-397-93.

Turing's Cathedral: The Origins of the Digital Universe, by George Dyson. Pantheon/Vintage, December 2012. ISBN-13: 978-14000-759-97. (Reviewed in this issue.)

Undiluted Hocus-Pocus: The Autobiography of Martin Gardner. Princeton University Press, September 2013. ISBN-13: 978-06911-599-11. (Reviewed March 2014.)

Why Is There Philosophy of Mathematics At All?, by Ian Hacking. Cambridge University Press, April 2014. ISBN-13: 978-11070-501-74.

William Fogg Osgood at Harvard: Agent of a Transformation of Mathematics in the United States, by Diann R. Porter. Docent Press, November 2013. ISBN-13: 978-0-9887449-4-3.

AMERICAN MATHEMATICAL SOCIETY

Mathematical Reviews Executive Editor

Applications and nominations are invited for the position of Executive Editor of Mathematical Reviews (MR).

The executive editor provides leadership for the world's premier database of information about research in the mathematical sciences. He or she will play a key role charting the future development of the MR database and in guiding the evolution of the principal online publication, MathSciNet®.

The executive editor heads the MR Division of the American Mathematical Society (AMS) and is a member of the senior executive team of the AMS. He or she will be responsible for the collaborative working culture of MR in Ann Arbor and across divisions of the AMS based in Providence, RI and Washington, D.C.

The executive editor is the primary representative of Mathematical Reviews to the mathematics community and should normally hold a doctorate in the mathematical sciences with a record of research.

Responsibilities of the executive editor include:

- Editorial leadership of MR
- Leadership in setting scientific and editorial standards for MR
- Relations with reviewers and authors
- International outreach to the mathematical community on behalf of the AMS, with special focus on MR
- Executive level leadership of staff in the Ann Arbor office of the AMS
- Collaboration with the AMS Publishing Division on marketing, promotion, branding, and sales initiatives
- Collaboration with the AMS Publishing Division and AMS Governance on new product directions and strategy
- Oversight of budgetary planning for the MR Division in conjunction with the Finance Division

The management and administrative staff assist the executive editor in carrying out day-to-day tasks and non-editorial aspects of MR production, in conjunction with staff in Providence. The MR Editorial Committee provides high-level scientific advice about the editorial standards of MR.

The executive editor currently reports to the executive director.

The MR Division is located in Ann Arbor, Michigan, near the campus of the University of Michigan, and editors enjoy many faculty privileges at the university. MR employs approximately 75 personnel, including associate editors, copyeditors, bibliographic specialists, information technology staff, and clerical support.

The appointment will be for three to five years, with possible renewal, and will commence as early as the summer of 2014. The starting date and length of term are negotiable. The executive editor position is full time, but applications are welcome from individuals taking leaves of absence from another position. Salary is negotiable and will be commensurate with experience.

The period for submission of nominations and applications will remain open until the position is filled. For more information and to submit your application electronically, please visit:

www.ams.org/about-us/ams-jobs/ams-jobs

Confidential inquiries may be sent directly to the Executive Director, Donald E. McClure, at exdir@ams.org.

Applications should include a curriculum vitae, information on editorial and administrative experience, and the names and addresses of at least three references. The American Mathematical Society is an Affirmative Action/ Equal Opportunity Employer.

AMS
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FROM THE AMS SECRETARY

ATTENTION ALL AMS MEMBERS

Voting Information for 2014 AMS Election

AMS members who have chosen to vote online will receive an email message on or shortly after August 18, 2014, from the AMS Election Coordinator, Survey & Ballot Systems.

The From Line will be "AMS Election Coordinator", the Sender email address will be amsvote@directvote.net, and the Subject Line will be "AMS 2014 Election—login information below". If you use a spam filter you may want to use the above address or subject information to configure your spam filter to ensure this email will be delivered to you.

The body of the message will provide your unique voting login information and the address (URL) of the voting website.

AMS members who have chosen to vote by paper should expect to receive their ballot by the middle of September. Unique voting login information will be printed on the ballot, should you wish to vote online.

At midnight (U.S. Eastern Time) on November 7, 2014, the website will stop accepting votes. Paper ballots received after this date will not be counted.

Additional information regarding the 2014 AMS Election is available on the AMS website:
www.ams.org/about-us/governance/elections/election-info;
or by contacting the AMS: election@ams.org, 800-321-4267 (US & Canada), 401-455-4000 (worldwide).

Thank you and . . . please remember to vote.

Carla D. Savage

AMS
American Mathematical Society
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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/.

August 2014

* 4–7 **SIAM Conference on the Life Sciences (LS14)**, Sheraton Charlotte, Charlotte, North Carolina.
Invited Speakers: James J. Collins, HHMI, Boston University and Wyss Institute, Harvard University; Alison P. Galvani, Yale University; Alan Hastings, UC Davis; Oliver E. Jensen, University of Manchester, United Kingdom; Arthur D. Lander, University of California, Irvine; Norman A. Mazer, F. Hoffmann-La Roche Ltd, Switzerland; John Rinzel, New York University; Kristin Rae Swanson, Northwestern University.
Registration/Information: Is now available! Pre-Registration Deadline: Monday, July 7, 1014. Disconnect time is 4:00 PM. EDT Hotel Reservation Deadline: Thursday, July 3, 3014. Registration and the preliminary program for this conference are available at: http://www.siam.org/meetings/ls14/.

* 12–14 **The CUNY workshop on differential cohomologies**, The CUNY Graduate Center, New York, New York.
Description: This workshop is aimed towards the topics of differential cohomology theories, including differential (ordinary) cohomology and differential K-theory, abelian gerbes, algebraic K-theory, free loop spaces, and connections with topological field theories. The goal is to bring together researchers in these areas, from graduate students to senior researchers, to present fundamental material as well as to exchange ideas on recent progress and to lay out new directions for research.
Information: http://qcpages.qc.cuny.edu/~swilson/cunyworkshop14.html.

* 26–29 **The 45th Annual Iranian Mathematics Conference**, Semnan University, Semnan, Iran.
Description: The annual Iranian Mathematics Conference has been held every year since 1970. The goal of this conference is to survey recent advances on a wide range of Mathematics. The conference will provide a forum for mathematicians and scientists worldwide to present their latest results and a means to discuss their recent researches with each other.
Organizers: Semnan University and Iran Math. Soc.
Language: Persian and English.
Themes: Of this conference include all areas of mathematics, statistics and computer sciences and their application.
Information: http://imc45.semnan.ac.ir/index.php?slc_lang=en&sid=1.

September 2014

* 1–12 **Advanced School and Workshop on L-functions and modular forms**, The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy.
Description: This two-week activity consists of a school on aspects of computational algebra and number theory with an emphasis on modular forms and L-functions in the first week and a more focused workshop on the same theme in the second week. The school is intended for advanced graduate students and young researchers. During the school there will be lectures on both theoretical and computational aspects of algebra and number theory, including a general introduction to scientific computing. The afternoons will be devoted to concrete hands-on computational projects. The workshop in the second week will also have a computational bent, being part of the research project LMF: L-functions and Modular Forms (a six year Programme Grant from EPSRC, grant reference EP/K034383/1). The High Performance Computing staff at ICTP will take part of the

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/.

workshop with the goal of helping the interested participants make the jump from desktops to bigger machines.
Information: http://agenda.ictp.it/smr.php?2602.

* 2–5 **XXIII International Fall Workshop on Geometry and Physics**, Faculty of Sciences of Granada University, Granada, Spain.
Description: The Fall Workshops on Geometry and Physics have been held yearly since 1992, and bring together Spanish and Portuguese geometers and physicists, along with an ever increasing number of participants from outside the Iberian peninsula.
Aim: The meetings aim to provide a forum for the exchange of ideas between researchers of different fields in differential geometry, applied mathematics and physics, and always include a substantial number of enthusiastic young researchers amongst the participants. The Workshop is open to any topic in the interplay between geometry and physics, including classical theory of fields, control theory, integrable systems, Lie algebroids and mechanics, Lorentz geometry, mechanics of continuous media, poisson geometry, quantum gravity, quantum mechanics, relativity, Riemannian and pseudo-Riemannian geometry, string theory, supergravity and supersymmetry, and symplectic and contact geometry.
Deadline: For abstract submissions is May 31, 2014.
Information: http://gigda.ugr.es/ifwgp2014/.

* 8–17 **CIMPA Research School on "Operator theory and the principles of quantum mechanics"**, University Moulay Ismail, Meknes, Morocco.
Description: Linear Algebra and Operator Theory are powerful tools in the study of Quantum Mechanics. The main aim of this CIMPA research school is to introduce students, young researchers and all interested mathematicians having background in linear algebra and basic operator theory to the foundations of Quantum Mechanics and Quantum Information.
Information: http://www.cimpa-icpam.org/spip.php?article581.

* 14 **Future Directions in Commutative Rings Inspired by the Work of Laszlo Fuchs**, Tulane University, New Orleans, Louisiana.
Description: Laszlo Fuchs is an outstanding researcher and author, whose extraordinary productivity and influential monographs in the areas of abelian groups, ordered algebraic structures, rings, and modules, have directly impacted the growth and direction of research in these important areas of algebra for the past half century. He has published roughly 250 research papers, four very influential research monographs, and numerous lecture notes. This short conference will primarily focus on Prof. Fuchs' contributions to the theory of commutative rings, with some connections to noncommutative ring theory. His work in commutative rings accentuates the unifying nature of all his work in algebra, and is among his greatest contributions to the broader field. As impressive as his life's work is, Prof. Fuchs' most telling accomplishment has perhaps been his ability to help other researchers focus on the right problems.

* 22–26 **Workshop on Tensor Valuations in Stochastic Geometry and Imaging**, Sandbjerg Estate, Soenderborg, Denmark.
Description: This workshop is dedicated to the mathematical theory and the application of tensor valuations in stochastic geometry and imaging. The workshop is a result of our desire to bring together researchers from stochastic geometry and imaging, who have an interest in the underlying mathematical theory of tensor valuations, along with mathematicians who have an interest in the (potential) application areas of tensor valuations. Also in recent years, there have been very important advances in the mathematical theory of tensor valuations, for instance, concerning the algebraic structure of tensor valuations and the characterization of local tensor measures. At the same time, tensor valuations are starting to be used in a number of research areas, primarily with the purpose of quantifying the morphology and anisotropy of complex spatial structures. At the workshop, overview lectures will be given by experts in the field. The workshop will also have shorter research talks.
Information: http://csgb.dk/activities/2014/tensor/.

* 26–28 **Entropy and Singular Solutions for Conservation Laws; Pressureless Gas Dynamics and Other Applications**, West Virginia University, Morgantown, West Virginia.
Description: For most of the significant equations of mathematical physics, it is impossible to show the existence of classical solutions even starting out from smooth initial values. On the other hand, if we consider distributional weak solutions, they fail to be unique. To overcome this obstacle, we use the entropy criterion as one of the admissibility criteria compatible with the Second Law of Thermodynamics, to help us single out a unique physically meaningful solution. Recently, the entropy criterion has also been used in connection with systems of pressureless gases to ensure uniqueness of solutions. This arises as a consequence of a deeper connection between scalar Conservation Laws (with rather general flux functions) and Pressureless Gas systems. Despite classical results on existence, uniqueness and stability of entropy solutions for Conservation Laws, there are applications that require the accommodation of more general, uncommon flux functions.
Information: http://math.wvu.edu/entropy2014/.

October 2014

* 9–10 **The Eighth International Conference on Provable Security (ProvSec 2014)**, The University of Hong Kong, Hong Kong.
Description: Provable security is an important research area in modern cryptography. Cryptographic primitives or protocols without a rigorous proof cannot be regarded as secure in practice. In fact, there are many schemes that were originally thought as secure but eventually broken, which clearly indicates the need of formal security assurance. With provable security, we are confident in using cryptographic schemes and protocols in various real-world applications. Meanwhile, schemes with provable security sometimes give only theoretical feasibility rather than a practical construction, and correctness of the proofs may be difficult to verify. ProvSec conference thus provides a platform for researchers, scholars and practitioners to exchange new ideas for solving these problems in the provable security area.
Information: http://home.ie.cuhk.edu.hk/~provsec14.

* 12–14 **Information Security, the Seventeenth International Conference (ISC 2014)**, The University of Hong Kong, Hong Kong.
Description: The Information Security Conference (ISC) is an annual international conference covering research in theory and applications of Information Security. ISC aims to attract high quality papers in all technical aspects of information security.
Information: http://isc14.ie.cuhk.edu.hk.

* 13–17 **Fundamental Groups and Periods**, Institute for Advanced Study, Princeton, New Jersey.
Description: A workshop held as part of the yearlong program "Topology of Algebraic Varieties" at the Institute for Advanced Study. It is largely a mystery which groups can be the fundamental group of a smooth complex projective varieties. Hodge theory gives many restrictions on the possible fundamental groups, but there is a big gap between the known examples and the known restrictions. One goal of the workshop is to present the latest work on the possible fundamental groups of algebraic varieties. A second theme is the study of periods, the numbers obtained as integrals of algebraic functions. Multiple zeta values are special periods which are intimately related with the category of mixed Tate motives over the integers.
Information: http://www.topalg2014.org/home/activities/workshop-1.

* 17–19 **Conference "Inverse Problems and Spectral Theory" in honor of the 65th anniversary of Peter Kuchment**, Texas A&M University, College Station, Texas.
Description: The conference will feature 40 minute talks by invited speakers and a poster session for contributed presentations. A limited amount of financial support for travel is available on a competitive basis. Strong preference will be given to young researchers (less than 5 years after Ph.D.), postdoctoral fellows, and graduate students. Women and members of underrepresented groups are especially encouraged to apply. Further information and updates about the conference are available at: http://www.math.tamu.edu/~berko/ipst/index.html.
Information: http://www.math.tamu.edu/~berko/ipst/index.html.

November 2014

* 2–3 **5th International Conference on Mathematics and Natural Sciences 2014**, Institut Teknologi Bandung, Bandung, Indonesia.
Description: The 5th International Conference on Mathematics and Natural Sciences (ICMNS) is organized jointly by Faculty of Mathematics and Natural Sciences (FMIPA), School of Life Sciences and Technology, and School of Pharmacy at Institut Teknologi Bandung, Indonesia.
Aim: The main aim of this conference is to promote multi- and interdisciplinary researches in sciences and related technology and its applications. The scope of the conference is in the fields of, but not limited to: food sciences, health and medical sciences, biosciences and biotechnology, environmental sciences, pharmaceutical sciences, physical sciences, material sciences, mathematics and its applications, computer science and computational science, earth and space sciences, sustainable energy. Accepted papers will be published in the American Institute of Physics (AIP) Conference Proceedings (indexed by SCOPUS).
Information: http://icmns.fmipa.itb.ac.id/pages/home.php.

* 14–15 **Blackwell-Tapia Conference and Awards Ceremony**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: IPAM is honored to host the 2014 Blackwell-Tapia Conference and Awards Ceremony. The conference and prize honors David Blackwell and Richard Tapia, two seminal figures who inspired a generation of African-American, Native American and Latino/Latina students to pursue careers in mathematics. The conference will offer a mix of activities including scientific talks, poster presentations, panel discussions, ample opportunities for discussion and interaction, and the awarding of the Blackwell-Tapia Prize. Participants will come from all career stages and will represent institutions of all sizes across the country.
Support: Applications for travel support are due September 15, 2014. Please consult the webpage for more information.
Information: http://www.ipam.ucla.edu/programs/BTAP2014/.

* 24–26 **The 3rd International Conference on Complex Dynamical Systems and Their Applications: New Mathematical Concepts and Applications in Life Sciences**, TOBB University of Economics and Technology University (TOBB ETU), Ankara, Turkey.
Description: Within CDSC 2014 we will honor Professor Marat Akhmet on the occasion of his 60th birthday. The aims of this conference are to promote, encourage and bring together researchers in the different research areas (Mathematics, Engineering, Medicine, Physics, Biology, etc.), and to unite our energy and possibilities in this direction. Also, we aim to establish a platform at which the novel research ideas of this area will be shared. CDSC became a regular annual organization since 2012.
Information: http://cdss2014.org/.

* 24–28 **IV International scientific conference of students and young scientists "Theoretical and Applied Aspects of Cybernetics" (TAAC-2014)**, Cybernetics Faculty of Taras Shevchenko National University of Kyiv, Kyiv, Ukraine.
Description: The scientific program of the conference includes the following sections: Computer science, applied mathematics, artificial intelligence, software engineering. For today three International Conferences of Students and Young Scientists Theoretical and Applied Aspects of Cybernetics were held at the Faculty of Cybernetics of Taras Shevchenko National University of Kyiv in 2011, 2012 and 2013. Participants from more than 40 universities and 5 research institutes of Ukraine, Russia, Belorussia, Kazakhstan, Poland, Latvia, Lithuania, Estonia, Hungary, Slovakia, Czech Republic, Romania, Moldova, Turkey, Great Britain, Bulgaria, Georgia, Finland and India attended these conferences.
Information: http://taac.org.ua.

December 2014

* 10–12 **I Brazilian Congress of Young Researchers in Pure and Applied Mathematics**, Mathematics and Statistics Institute, University of São Paulo, São Paulo, Brazil.
Description: In Brazil, due to its continental dimensions with several universities distant from major research centers, many new Ph.D. graduates join these universities and end up distancing themselves from their original research groups. This often hinders the development of their research and, consequently, their ongoing professional career. For this reason, young researchers decided to create an appropriate framework to share research results, thus giving rise to "I Brazilian Congress of Young Researchers in Pure and Applied Mathematics".
Information: http://jovens.ime.usp.br/jovens/en.

January 2015

* 12–16 **Multiple Sequence Alignment**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: Despite the importance of MSA estimation and active research, many challenges persist. The research community is addressing them through improved mathematical formalization of MSA estimation; development of sophisticated and biologically meaningful models of sequence evolution that include insertions, deletions, and rearrangements; and design of new methods that have good mathematical properties and empirical performance for large datasets. This workshop will engage researchers from different fields, including mathematicians, statisticians, evolutionary biologists, structural biologists, and computer scientists, with the aim of integrating diverse viewpoints, improving mathematical foundations, and developing new and more powerful methods for estimating MSAs.
Support: Applications for travel support are due November 17, 2014. Please consult the webpage for more information.
Information: http://www.ipam.ucla.edu/programs/MSA2015/.

* 20–23 **AIM Workshop: Inference in high-dimensional regression**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to explore recent methodological and theoretical advances in inference for high-dimensional statistical models.
Information: http://aimath.org/workshops/upcoming/inferencehighdim.

* 26–30 **Symmetry and Topology in Quantum Matter**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: Topological phases of matter are remarkable both for their richness of physical phenomena, and for their mathematical description by topological quantum field theories (TQFTs). Recently, the prediction and experimental discovery of topological insulators has spurred physicists to explore the role of symmetry in

topological phases, leading to the identification of new classes of phases of matter, and new insights into their classification, properties, and potential physical realizations. This is an area with a history of strong connections between physics and mathematics, and the time is ripe for the emerging understanding of symmetric topological phases to benefit from new mathematical ideas in TQFTs, and vice versa. This interdisciplinary workshop will bring together theoretical physicists and mathematicians to discuss symmetric topological phases and TQFTs, with a goal of forging productive new interactions between these communities.
Deadline: Applications are due December 1, 2014.
Information: http://www.ipam.ucla.edu/programs/stq2015/.

* 29–30 **Connections for Women: Geometric and Arithmetic Aspects of Homogeneous Dynamics**, Mathematical Sciences Research Institute, Berkeley, California.
Description: This workshop will consist of several mini-courses given by prominent female mathematicians in the field, intended for graduate students, post-docs, and researchers in areas related to the program. The workshop will also include an informal panel discussion session among female researchers on career issues.
Information: http://www.msri.org/workshops/741.

February 2015

* 4–6 **Computational Photography and Intelligent Cameras**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: Computational photography is a new area of computer graphics and vision, seeking to create new types of photographs and to allow photographers to acquire better images or images they never could observe before. This involves research into new software algorithms for fusing data from multiple images, video streams, or other types sensors as well as into new hardware architectures for capturing the data needed for the software and numerical processing. Applications of computational photography paradigms include compressed sensing cameras, extended depth of field/refocussing, high dynamic range images, invertible motion blurs, and plenoptic cameras, and mathematics is an important tool for inventing and optimizing these new cameras. This workshop will serve as a gathering place for all those interested in theories, algorithms, methodologies, hardware designs, and experimental studies in computational photography.
Deadline: Applications are due December 10, 2014. Consult the webpage for more information.
Information: http://www.ipam.ucla.edu/programs/CP2015/.

* 9–13 **Zariski-dense Subgroups**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: This workshop will survey the recent progress in the study of Zariski-dense subgroups (both arithmetic and non-arithmetic) of semi-simple algebraic groups; the impact of this work on adjacent areas such as algebraic groups, division algebras, and Galois cohomology; and applications in further areas such as geometry (isospectral and length-commensurable locally symmetric spaces) and combinatorics (expander graphs). These developments have led to new connections between different areas of mathematics (algebra, number theory, algebraic and Lie groups, differential geometry and topology, and combinatorics), and the workshop will bring together people working in those areas, using the subject of Zariski-dense subgroups as a common thread to build new scientific connections as well as to solve new problems that have recently appeared.
Deadline: Applications for travel support are due December 15, 2014. Please consult the webpage for more information.
Information: http://www.ipam.ucla.edu/programs/ZDS2015/.

* 23–27 **Machine Learning for Many-Particle Systems**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: This workshop will address the reaches and limitations of ML as applied to many-particle systems and highlight examples where physical models can be successfully combined with ML algorithms. The workshop aims to create novel synergistic collaborations between researchers in two different fields: modeling of many-particle (quantum and classical) systems and machine learning. Interactions between many constituent particles generally give rise to collective (or emergent) phenomena in matter. Even when the interactions between the particles are well defined and the governing equations of the system are understood, the collective behavior of the system as a whole does not trivially emerge from these equations.
Deadline: Applications for travel support are due January 1, 2015. Consult the webpage for more information.
Information: http://www.ipam.ucla.edu/programs/ML2015/.

March 2015

* 9–12 **Broad Perspectives and New Directions in Financial Mathematics**, Institute for Pure and Applied Mathematics (IPAM), UCLA, Los Angeles, California.
Description: This IPAM "long program" will address the stability of the network of financial institutions, the impact of high frequency and algorithmic trading, the financialization of the commodity markets, and the huge challenges raised by the size and the speed of trade data. This program will bring together academic mathematicians, economists, regulators, and experts from the finance industry to seed research – even if speculative – in these areas. The program will open with tutorials, and will be punctuated by four major workshops and a culminating workshop. Long program participants will participate for extended periods up to the entire length of the program. Applications for individual workshops are separate and are posted on individual workshop home pages. Applications for the long program will be accepted through December 9, 2014 but decisions will be made starting in July. Please consult the webpage for more information.
Information: http://www.ipam.ucla.edu/programs/fm2015/.

* 18–20 **IAENG International Conference on Scientific Computing 2015**, Royal Garden Hotel, Hong Kong.
Description: The IAENG International Conference on Scientific Computing (ICSC'15) will take place in Hong Kong, 18-20 March, 2015. The conference ICSC'15 is held under the International MultiConference of Engineers and Computer Scientists 2015. The IMECS 2015 is organized by the International Association of Engineers (IAENG), a non-profit international association for the engineers and the computer scientists.
Information: http://www.iaeng.org/IMECS2015/ICSC2015.html.

* 23–27 **AIM Workshop: Dynamical algebraic combinatorics**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will focus on dynamical systems arising from algebraic combinatorics.
Information: http://aimath.org/workshops/upcoming/dynalgcomb.

May 2015

* 18–22 **AIM Workshop: Carleson theorems and multilinear operators**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to a selection of questions at the intersection of Carleson operators and multilinear operators.
Information: http://aimath.org/workshops/upcoming/multilinops.

* 27–30 **Seventh International Conference on Dynamic Systems and Applications & Fifth International Conference on Neural, Parallel, and Scientific Computations**, Department of Mathematics, Morehouse College, Atlanta, Georgia.
Description: This is a joint international conference on selected topics of Dynamic Systems and Applications & Neural, Parallel, and Scientific Computations.
Information: http://www.dynamicpublishers.com.

June 2015

* 8–12 **AIM Workshop: Mathematical aspects of physics with non-self-adjoint operators**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will emphasize the state-of-the-art techniques for the mathematically rigorous analysis of non-self-adjoint phenomena encountered in main stream and newly developing fields of physics.
Information: http://aimath.org/workshops/upcoming/nonselfadjoint.

July 2015

* 14–17 **International Conference on Nonlinear Operators, Differential Equations and Applications, ICNODEA-2015**, Babes-Bolyai University, Cluj-Napoca, Romania.
Description: The conference will explore new developments in the theory of nonlinear operators and its applications to integral, differential and partial differential equations and inclusions. A special emphasis will be on applications in biology, medicine, economics, physics and engineering.
Conference Sessions: Nonlinear ODEs and Applications; Topological and Variational Methods for Nonlinear PDEs; Mathematical Models in Applied Sciences; Fixed Point Theory.
Keynote Speakers: Ravi P. Agarwal, Gabiele Bonanno, Alberto Cabada, Wojtek Kryszewski, Dumitru Motreanu, Themistocles M. Rassias, Mircea Sofonea.
Organizers: Radu Precup, Adrian Petrusel, Adriana Buica, Marcel Serban, Szilárd András.
Information: http://www.cs.ubbcluj.ro/~icnodeacj/index.htm.

August 2015

* 3–7 **AIM Workshop: First passage percolation and related models**, American Institute of Mathematics, Palo Alto, California.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to the study of first passage percolation on the d-dimensional integer lattice and related models.
Information: http://aimath.org/workshops/upcoming/firstpercolation.

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.

September 2015

* 1–4 **IMA Conference on Numerical Methods for Simulation**, Mathematical Institute, University of Oxford, UK.
Description: Developments in numerical methods underpin simulations in many ways, for example, in any area where high-dimensional problems are governed by differential equations. Computational fluid dynamics has driven many developments in this area; however there is a wide range of application areas where the problems, and indeed solution techniques may be similar. Numerical methods are important in diverse areas such as geophysical modelling, fluid-structure interaction, high-dimensional dynamical systems, weather prediction, climate modelling, oil reservoir simulation, and so on. The conference will bring together application specialists, applied mathematicians, numerical analysts and computational scientists who develop and use numerical simulations. Applications which focus on data assimilation, inverse problems, uncertainties or control, which contain as a major component a high-dimensional forward model, will also be represented.
Information: http://www.ima.org.uk/conferences/conferences_calendar.cfm.html.

* 21–26 **International Conference in Mathematics Education**, Catania, Sicily, Italy.
Description: Dear friends in Mathematics Education, The 12th International Conference of the Mathematics Education into the 21st Century Project will be held this year from Sep. 21-26 in Montenegro. Already more than 160 people have registered and it promises to be a very successful and productive meeting. The First Announcement and Call for Papers, with full details of the conference and a registration form, as well as background on our Project and Conferences, can be downloaded at: http://www.cdnalma.poznan.pl/static/alan/FAMontenegro6.doc. We are starting to plan our next conference, to be held in a beautiful hotel convention centre overlooking the sea close to Catania, Sicily, Italy, in late September, 2015. It will feature papers and workshops on all aspects of innovation in Mathematics, Science, Statistics and Computer Education. Our conferences are renowned for their friendly and productive atmosphere and they attract many of the movers and shakers in education from all over the world.
Information: Would you be kind enough to give us some personal feedback as follows? It is probable/possible/impossible (please choose one) that I can attend the Catania Conference in late September 2015. Thanks and best wishes, Dr. Alan Rogerson, D. Phil (Oxon), M.Sc., B.Sc., B.A. (Lon), Dip.Ed., Cert. Ed. (Cantab). International Coordinator of the Mathematics Education into the 21st Century Project.

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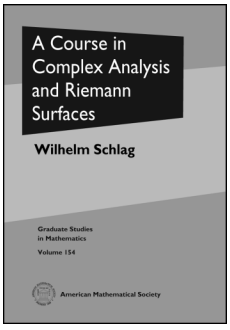
Analysis



A Course in Complex Analysis and Riemann Surfaces

Wilhelm Schlag, *University of Chicago, IL*

Complex analysis is a cornerstone of mathematics, making it an essential element of any area of study in graduate mathematics. Schlag's treatment of the subject emphasizes the intuitive geometric underpinnings of elementary complex analysis that naturally lead to the theory of Riemann surfaces.

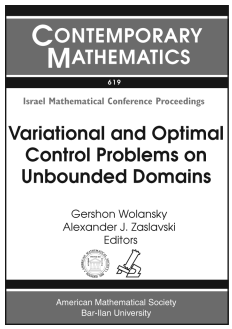
The book begins with an exposition of the basic theory of holomorphic functions of one complex variable. The first two chapters constitute a fairly rapid but comprehensive course in complex analysis. The third chapter is devoted to the study of harmonic functions on the disk and the half-plane, with an emphasis on the Dirichlet problem. Starting with the fourth chapter, the theory of Riemann surfaces is developed in some detail and with complete rigor. From the beginning, the geometric aspects are emphasized and classical topics such as elliptic functions and elliptic integrals are presented as illustrations of the abstract theory. The special role of compact Riemann surfaces is explained, and their connection with algebraic equations is established. The book concludes with three chapters devoted to three major results: the Hodge decomposition theorem, the Riemann-Roch theorem, and the uniformization theorem. These chapters present the core technical apparatus of Riemann surface theory at this level.

This text is intended as a fairly detailed yet fast-paced intermediate introduction to those parts of the theory of one complex variable that seem most useful in other areas of mathematics, including geometric group theory, dynamics, algebraic geometry, number theory, and functional analysis. More than seventy figures serve to illustrate concepts and ideas, and the many problems at the end of each chapter give the reader ample opportunity for practice and independent study.

Contents: From i to z: the basics of complex analysis; From z to the Riemann mapping theorem: some finer points of basic complex analysis; Harmonic functions; Riemann surfaces: definitions, examples, basic properties; Analytic continuation, covering surfaces, and algebraic functions; Differential forms on Riemann surfaces; The theorems of Riemann-Roch, Abel, and Jacobi; Uniformization; Review of some basic background material; Bibliography; Index.

Graduate Studies in Mathematics, Volume 154

September 2014, approximately 393 pages, Hardcover, ISBN: 978-0-8218-9847-5, LC 2014009993, 2010 *Mathematics Subject Classification:* 30-01, 30F10, 30F15, 30F20, 30F30, 30F35, **AMS members US$63.20**, List US$79, Order code GSM/154



Variational and Optimal Control Problems on Unbounded Domains

Gershon Wolansky and **Alexander J. Zaslavski**, *Technion–Israel Institute of Technology, Haifa, Israel*, Editors

This volume contains the proceedings of the workshop on Variational and Optimal Control Problems on Unbounded Domains, held in memory of Arie Leizarowitz, from January 9–12, 2012, in Haifa, Israel.

The workshop brought together a select group of worldwide experts in optimal control theory and the calculus of variations, working on problems on unbounded domains.

The papers in this volume cover many different areas of optimal control and its applications. Topics include needle variations in infinite-horizon optimal control, Lyapunov stability with some extensions, small noise large time asymptotics for the normalized Feynman-Kac semigroup, linear-quadratic optimal control problems with state delays, time-optimal control of wafer stage positioning, second order optimality conditions in optimal control, state and time transformations of infinite horizon problems, turnpike properties of dynamic zero-sum games, and an infinite-horizon variational problem on an infinite strip.

This item will also be of interest to those working in applications.

This book is co-published with Bar-Ilan University (Ramat-Gan, Israel).

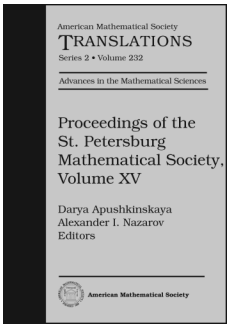
Contents: S. M. Aseev and **V. M. Veliov**, Needle variations in infinite-horizon optimal control; **A. Berman**, **F. Goldberg**, and **R. Shorten**, Comments on Lyapunov α-stability with some extensions; **V. S. Borkar** and **K. S. Kumar**, Small noise large time asymptotics for the normalized Feynman-Kac semigroup; **Y. Dolgin** and **E. Zeheb**, Linear constraints for convex approximation of the stability domain

of a polynomial in coefficients space; **V. Y. Glizer**, Singular solution of an infinite horizon linear-quadratic optimal control problem with state delays; **I. Ioslovich** and **P.-O. Gutman**, Time-optimal control of wafer stage positioning using simplified models; **J. Kogan** and **Y. Malinovsky**, Robust stability and monitoring threshold functions; **E. Ocaña** and **P. Cartigny**, One dimensional singular calculus of variations in infinite horizon and applications; **N. P. Osmolovskii**, Second order optimality conditions in optimal control problems with mixed inequality type constraints on a variable time interval; **I. Shafrir** and **I. Yudovich**, An infinite-horizon variational problem on an infinite strip; **D. Wenzke**, **V. Lykina**, and **S. Pickenhain**, State and time transformations of infinite horizon optimal control problems; **A. J. Zaslavski**, Turnpike properties of approximate solutions of discrete-time optimal control problems on compact metric spaces; **A. J. Zaslavski**, Turnpike theory for dynamic zero-sum games.

Contemporary Mathematics, Volume 619

August 2014, 247 pages, Softcover, ISBN: 978-1-4704-1077-3, LC 2013045474, 2010 *Mathematics Subject Classification:* 34-XX, 35-XX, 49-XX, 60-XX, 68-XX, 78-XX, 90-XX, 91-XX, 92-XX, 93-XX, **AMS members US$72.80**, List US$91, Order code CONM/619

Differential Equations



Proceedings of the St. Petersburg Mathematical Society, Volume XV

Advances in Mathematical Analysis of Partial Differential Equations

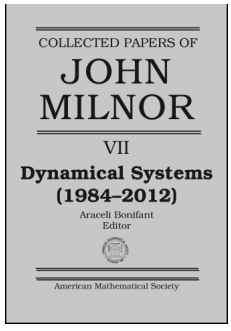
Darya Apushkinskaya, *Universität des Saarlandes, Saarbrücken, Germany*, and **Alexander I. Nazarov**, *Steklov Mathematical Institute, St. Petersburg, Russia, and St. Petersburg State University, Russia*, Editors

This book presents the proceedings of the international workshop, "Advances in Mathematical Analysis of Partial Differential Equations" held at the Institut Mittag-Leffler, Stockholm, Sweden, July 9–13, 2012, dedicated to the memory of the outstanding Russian mathematician Olga A. Ladyzhenskaya. The volume contains papers that engage a wide set of modern topics in the theory of linear and nonlinear partial differential equations and applications, including variational and free boundary problems, mathematical problems of hydrodynamics, and magneto-geostrophic equations.

Contents: H. B. da Veiga, On singular parabolic p-Laplacian systems under non-smooth external forces. Regularity up to the boundary; **S. Boccia** and **N. V. Krylov**, On the fundamental matrix solution for higher-order parabolic systems; **N. V. Filimonenkova** and **N. M. Ivochkina**, On variational ground of the m-Hessian operators; **S. Friedlander**, **W. Rusin**, and **V. Vicol**, The magneto-geostrophic equations: a survey; **M. Fuchs**, Variations on Liouville's theorem in the setting of stationary flows of generalized Newtonian fluids in the plane; **A. V. Fursikov**, On the normal-type parabolic system corresponding to the three-dimensional Helmholtz system; **M. Del Mar Gonzalez, M. Gualdani, and H. Shahgholian**, A discrete Bernoulli free boundary problem; **S. Hildebrandt** and **F. Sauvigny**, On Plateau's problem in Riemannian manfiolds; **H. Kim** and **M. Safonov**, The boundary Harnack principle for second order ellitpic equations in John and unfiorm domains; **V. Kozlov** and **A. Nazarov**, Oblique derivative problem for non-divergence parabolic equations with time-discontinuous coefficients; **T. P. Pukhnachev**, Singular solutions of Navier-Stokes equations; **G. A. Seregin** and **T. N. Shilkin**, The local regularity theory for the Navier–Stokes equations near the boundary; **V. A. Solonnikov**, L_p-theory of free boundary problems of magnetohydrodynamics in simply connected domains.

American Mathematical Society Translations—Series 2, Volume 232

August 2014, approximately 229 pages, Hardcover, ISBN: 978-1-4704-1551-8, 2010 *Mathematics Subject Classification:* 35B05, 35B65, 35J60, 35K20, 35K41, 35Q35, 35R35, 76D03, 76D05, **AMS members US$96**, List US$120, Order code TRANS2/232



Collected Papers of John Milnor

VII. Dynamical Systems (1984–2012)

Araceli Bonifant, *University of Rhode Island, Kingston, RI*, Editor

This volume is the seventh in the series "Collected Papers of John Milnor." Together with the preceding Volume VI, it contains all of Milnor's papers in dynamics, through the year 2012. Most of the papers are in holomorphic dynamics; however, there are two in real dynamics and one on cellular automata. Two of the papers are published here for the first time.

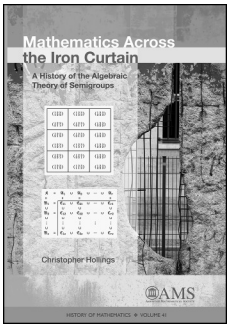
The papers in this volume provide important and fundamental material in real and complex dynamical systems. Many have become classics, and have inspired further research in the field. Some of the questions addressed here continue to be important in current research. In some cases, there have been minor corrections or clarifications, as well as references to more recent work which answers questions raised by the author. The volume also includes an index to facilitate searching the book for specific topics.

Contents: Introduction; Notes on surjective cellular automaton-maps (Unpublished manuscript of 1984); Tsujii's monotonicity proof for real quadratic maps (Unpublished manuscript of 2000); Local connectivity of Julia sets: Expository lectures (2000); On rational maps with two critical points (2000); Periodic orbits, external rays and the Mandelbrot set: An expository account (2000); Pasting together Julia sets—A worked out example of mating (2004); On Lattès maps (2006); with **A. Bonifant and M. Dabija**, Elliptic curves as attractors in $\mathbb{P}^2$, Part I: Dynamics (2007); with **A. Bonifant**, Schwarzian derivatives and cylinder maps (2008); Cubic polynomial maps with periodic critical orbit, Part I (2009); with **A. Bonifant and J. Kiwi**, Cubic polynomial maps with periodic critical orbit, Part II: Escape regions (2010); with **A. Bonifant and J. Kiwi**, Errata for "Cubic polynomial maps with periodic critical orbit, Part II: Escape regions" (2010); with an appendix by **A. Poirier**, Hyperbolic components (2012); Index.

Collected Works, Volume 19

August 2014, approximately 594 pages, Hardcover, ISBN: 978-1-4704-0937-1, LC 2014012208, 2010 *Mathematics Subject Classification:* 37-02, 37B15, 37B40, 37C70, 32H50, 37F10, 37F45, 37F50, 30D05, 14H52, **AMS members US$100**, List US$125, Order code CWORKS/19.7

General Interest



Mathematics across the Iron Curtain

A History of the Algebraic Theory of Semigroups

Christopher Hollings

The theory of semigroups is a relatively young branch of mathematics, with most of the major results having appeared after the Second World War. This book describes the evolution of (algebraic) semigroup theory from its earliest origins to the establishment of a full-fledged theory.

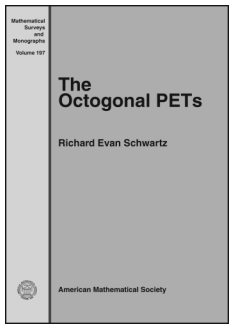
Semigroup theory might be termed 'Cold War mathematics' because of the time during which it developed. There were thriving schools on both sides of the Iron Curtain, although the two sides were not always able to communicate with each other, or even gain access to the other's publications. A major theme of this book is the comparison of the approaches to the subject of mathematicians in East and West, and the study of the extent to which contact between the two sides was possible.

Contents: Algebra at the beginning of the twentieth century; Communication between East and West; Anton Kazimirovich Sushkevich; Unique factorisation in semigroups; Embedding semigroups in groups; The Rees Theorem; The French school of 'demi-groupes'; The expansion of the theory in the 1940s and 1950s; The post-Sushkevich Soviet school; The development of inverse semigroups; Matrix representations of semigroups; Books, seminars, conferences, and journals; Basic theory; Notes; Bibliography; List of abbreviations of journal titles; Name index; Subject index.

History of Mathematics, Volume 41

August 2014, approximately 449 pages, Hardcover, ISBN: 978-1-4704-1493-1, LC 2014008281, 2010 *Mathematics Subject Classification:* 01A60, 20-03, **AMS members US$87.20**, List US$109, Order code HMATH/41

Geometry and Topology



The Octogonal PETs

Richard Evan Schwartz, *Brown University, Providence, RI*

A polytope exchange transformation is a (discontinuous) map from a polytope to itself that is a translation wherever it is defined. The 1-dimensional examples, interval exchange transformations, have been studied fruitfully for many years and have deep connections to other areas of mathematics, such as Teichmüller theory. This book introduces a general method for constructing polytope exchange transformations in higher dimensions and then studies the simplest example of the construction in detail. The simplest case is a 1-parameter family of polygon exchange transformations that turns out to be closely related to outer billiards on semi-regular octagons. The 1-parameter family admits a complete renormalization scheme, and this structure allows for a fairly complete analysis both of the system and of outer billiards on semi-regular octagons. The material in this book was discovered through computer experimentation. On the other hand, the proofs are traditional, except for a few rigorous computer-assisted calculations.

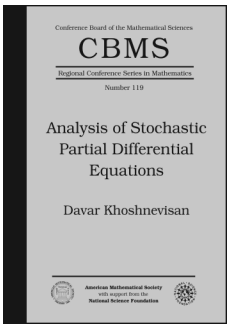
This item will also be of interest to those working in differential equations.

Contents: Introduction; *Friends of the octagonal PETs:* Background; Multigraph PETs; The alternating grid system; Outer billiards on semiregular octagons; Quarter turn compositions; *Renormalization and symmetry:* Elementary properties; Orbit stability and combinatorics; Bilateral symmetry; Proof of the main theorem; The renormalization map; Properties of the tiling; *Metric properties:* The filling lemma; The covering lemma; Further geometric results; Properties of the limit set; Hausdorff convergence; Recurrence relations; Hausdorff dimension bounds; *Topological properties:* Controlling the limit set; The arc case; Further symmetries of the tiling; The forest case; The Cantor set case; Dynamics in the arc case; *Computational details:* Computational methods; The calculations; The raw data; Bibliography.

Mathematical Surveys and Monographs, Volume 197

July 2014, 212 pages, Hardcover, ISBN: 978-1-4704-1522-8, LC 2014006823, 2010 *Mathematics Subject Classification:* 37E20, 37E05, 37E15, **AMS members US$72**, List US$90, Order code SURV/197

Probability and Statistics



Analysis of Stochastic Partial Differential Equations

Davar Khoshnevisan, *University of Utah, Salt Lake City, UT*

The general area of stochastic PDEs is interesting to mathematicians because it contains an enormous number of challenging open problems. There is also a great deal of interest in this topic because it has deep applications in disciplines that range from applied mathematics, statistical mechanics, and theoretical physics, to theoretical neuroscience, theory of complex chemical reactions [including polymer science], fluid dynamics, and mathematical finance.

The stochastic PDEs that are studied in this book are similar to the familiar PDE for heat in a thin rod, but with the additional restriction that the external forcing density is a two-parameter stochastic process, or what is more commonly the case, the forcing is a "random noise," also known as a "generalized random field." At several points in the lectures, there are examples that highlight the phenomenon that stochastic PDEs are not a subset of PDEs. In fact, the introduction of noise in some partial differential equations can bring about not a small perturbation but truly fundamental changes to the system that the underlying PDE is attempting to describe.

The topics covered include a brief introduction to the stochastic heat equation, structure theory for the linear stochastic heat equation, and an in-depth look at intermittency properties of the solution to semilinear stochastic heat equations. Specific topics include stochastic integrals à la Norbert Wiener, an infinite-dimensional Itô-type stochastic integral, an example of a parabolic Anderson model, and intermittency fronts.

There are many possible approaches to stochastic PDEs. The selection of topics and techniques presented here are informed by the guiding example of the stochastic heat equation.

This item will also be of interest to those working in differential equations.

A co-publication of the AMS and CBMS.

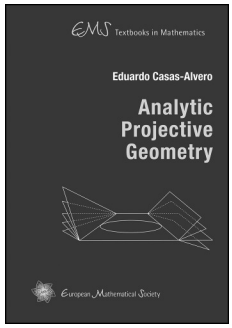
Contents: Prelude; Wiener integrals; A linear heat equation; Walsh-Dalang integrals; A non-linear heat equation; Intermezzo: A parabolic Anderson model; Intermittency; Intermittency fronts; Intermittency islands; Correlation length; Some special integrals; A Burkholder-Davis-Gundy inequality; Regularity theory; Bibliography.

CBMS Regional Conference Series in Mathematics, Number 119

July 2014, 116 pages, Softcover, ISBN: 978-1-4704-1547-1, LC 2014003696, 2010 *Mathematics Subject Classification:* 60H15; 35R60, 60H30, **All Individuals US$29.60**, List US$37, Institutional member US$29.60, Order code CBMS/119

New AMS-Distributed Publications

Geometry and Topology



Analytic Projective Geometry

Eduardo Casas-Alvero, *Universitat de Barcelona, Spain*

Projective geometry is concerned with the properties of figures that are invariant by projecting and taking sections. It is considered one of the most beautiful parts of geometry and plays a central role because its specializations cover the whole of the affine, Euclidean and non-Euclidean geometries. The natural extension of projective geometry is projective algebraic geometry, a rich and active field of research. The results and techniques of projective geometry are intensively used in computer vision.

This book contains a comprehensive presentation of projective geometry, over the real and complex number fields, and its applications to affine and Euclidean geometries. It covers central topics such as linear varieties, cross ratio, duality, projective transformations, quadrics and their classifications—projective, affine and metric—as well as the more advanced and less usual spaces of quadrics, rational normal curves, line complexes and the classifications of collineations, pencils of quadrics and correlations.

Two appendices are devoted to the projective foundations of perspective and to the projective models of plane non-Euclidean geometries. The book uses modern language, is based on linear algebra, and provides complete proofs. Exercises are proposed at the end of each chapter; many of them are beautiful classical results.

The material in this book is suitable for courses on projective geometry for undergraduate students, with a working knowledge of a standard first course on linear algebra. The text is a valuable guide to graduate students and researchers working in areas using or related to projective geometry, such as algebraic geometry and computer vision, and to anyone looking for an advanced view of geometry as a whole.

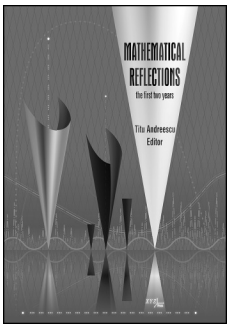
A publication of the European Mathematical Society (EMS). Distributed within the Americas by the American Mathematical Society.

Contents: Projective spaces and linear varieties; Projective coordinates and cross ratio; Affine geometry; Duality; Projective transformations; Quadric hypersurfaces; Classification and properties of quadrics; Further properties of quadrics; Projective spaces of quadrics; Metric geometry of quadrics; Three projective classifications; Appendix A. Perspective (for artists); Appendix B. Models of non-Euclidean geometries; Bibliography; Symbols; Index.

EMS Textbooks in Mathematics, Volume 15

May 2014, 636 pages, Hardcover, ISBN: 978-3-03719-138-5, 2010 *Mathematics Subject Classification:* 51-01, 51N15, 51N10, 51N20, **AMS members US$62.40**, List US$78, Order code EMSTEXT/15

Math Education



Mathematical Reflections: The First Two Years

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, Editor

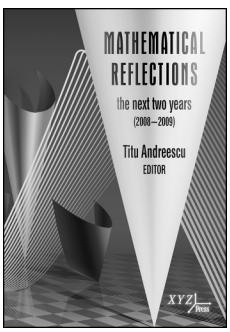
This book is aimed at high school students, participants in math competitions, undergraduates, as well as anyone who has a fire for mathematics. Many of the problems, solutions, and articles were submitted by passionate readers. They require creativity, experience, and comprehensive mathematical knowledge. The junior section features introductory problems. The senior and Olympiad sections are for students preparing for USAMO or the IMO. The graduate section offers college students a unique opportunity to solve non-routine problems in areas such as linear algebra, calculus, or graph theory.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Problems; Solutions; Articles; Problem author index; Article author index.

XYZ Series, Volume 10

August 2011, 619 pages, Hardcover, ISBN: 978-0-9799269-2-1, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$55.96**, List US$69.95, Order code XYZ/10



Mathematical Reflections: The Next Two Years (2008–2009)

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, Editor

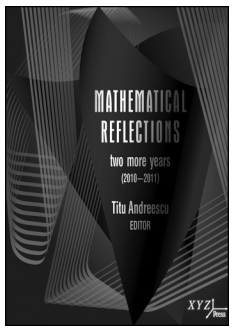
This book is a compilation and revision of the 2008 and 2009 volumes from the online journal of the same name. This book is aimed at high school students, participants in math competitions, undergraduates, and anyone who has a fire for mathematics. Many of the problems, solutions, and articles were submitted by passionate readers and all require creativity, experience, and comprehensive mathematical knowledge. This book is a great resource for students training for advanced national and international mathematics competitions such as USAMO and IMO.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Problems; Solutions; articles; Problem author index; Article author index.

XYZ Series, Volume 11

August 2012, 507 pages, Hardcover, ISBN: 978-0-9799269-6-9, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$55.96**, List US$69.95, Order code XYZ/11



Mathematical Reflections: Two More Years (2010–2011)

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, Editor

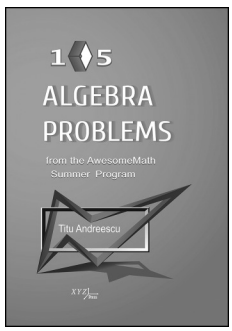
This book is a compilation and revision of the 2010 and 2011 volumes from the online journal of the same name. This book is aimed at high school students, participants in math competitions, undergraduates, and anyone who has a fire for mathematics. Many of the problems, solutions, and articles were submitted by passionate readers and all require creativity, experience, and comprehensive mathematical knowledge. This book is a great resource for students training for advanced national and international mathematics competitions such as USAMO and IMO.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Problems; Solutions; Articles; Problem author index; Article author index.

XYZ Series, Volume 12

February 2014, 497 pages, Hardcover, ISBN: 978-0-9885622-4-0, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$55.96**, List US$69.95, Order code XYZ/12



105 Algebra Problems from the AwesomeMath Summer Program

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*

The main purpose of this book is to provide an introduction to central topics in elementary algebra from a problem-solving point of view. While working with students who were preparing for various mathematics competitions or exams, the author observed that fundamental algebraic techniques were not part of their mathematical repertoire. Since algebraic skills are not only critical to algebra itself but also to numerous other mathematical fields, a lack of such knowledge can drastically hinder a student's performance. Taking the above observations into account, the author has put together this introductory book using both simple and challenging examples which shed light upon essential algebraic strategies and techniques, as well as their application in diverse meaningful problems. This work is the first volume in a series of such books.

The featured topics from elementary and classical algebra include factorizations, algebraic identities, inequalities, algebraic equations and systems of equations. More advanced concepts such as complex numbers, exponents and logarithms, as well as other topics, are

generally avoided. Nevertheless, some problems are constructed using properties of complex numbers which challenge and expose the reader to a broader spectrum of mathematics. Each chapter focuses on specific methods or strategies and provides an ample collection of accompanying problems that graduate in difficulty and complexity. In order to assist the reader with verifying mastery of the theoretical component, 105 problems are included in the last sections of the book, of which 52 are introductory and 53 are advanced.

All problems come together with solutions, many employing several approaches and providing the motivation behind the solutions offered.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Preface; Completing the square and quadratic equations; Factorizations and algebraic identities; Factoring expressions involving $a-b, b-c, c-a$; Factoring $a^3+b^3+c^3-3abc$; AM-GM and Hölder's inequality; Lagrange's identity and the Cauchy-Schwarz inequality; Making linear combinations; Fixed points and monotonicity; The floor function; Taking advantage of symmetry; Introductory problems; Advanced problems; Solutions to introductory problems; Solutions to advanced problems.

XYZ Series, Volume 2

July 2013, 200 pages, Hardcover, ISBN: 978-0-9799269-5-2, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$39.96**, List US$49.95, Order code XYZ/2

Topics in Functional Equations

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, **Iurie Boreico**, *Stanford University, CA*, and **Oleg Mushkarov** and **Nikolai Nikolov**, *Bulgarian Academy of Sciences, Sofia, Bulgaria*

This book is a systematic and comprehensive approach to functional equations as a whole. Unlike in other branches of competitive mathematics, there is very little theory; instead, the methods and techniques utilized in solving these equations play the most important part. For this reason the book takes a highly practical path and includes lots of problems designed to teach students how to familiarize themselves with every strategy employed, as well as how to experiment in combining and manipulating different techniques.

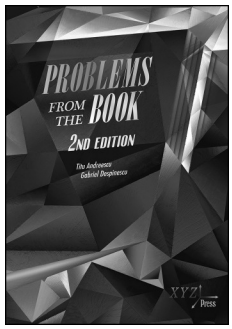
This work contains all the important functional equations given at contests in recent years, classified by the way the equations are solved. It explains the reasoning behind each method and offers advice on how to invent meaningful solutions.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Cauchy's equations; Generalized Cauchy equations; Reducing to Cauchy; Substitutions; Symmetrization and additional variables; Iterations and recurrence relations; Constructive problems; The D'Alembert equation; The Aczél–Gołá–Schinzel equation; Arithmetic functional equations; Binary and other bases; Geometric functional equations; Approximating by linear functions; Extremal element method; Fixed points; Functional equations for polynomials; Functional inequalities; Miscellaneous problems; Hints and solutions; Notation and abbreviations; Bibliography.

XYZ Series, Volume 7

August 2012, 505 pages, Hardcover, ISBN: 978-0-9799269-9-0, 2010 *Mathematics Subject Classification:* 00A07, 39B05, 97U40, 97D50, **AMS members US$47.96**, List US$59.95, Order code XYZ/7



Problems from the Book

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, and **Gabriel Dospinescu**, *Ecole Normale Supérieure de Lyon, France*

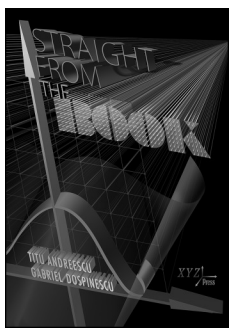
The authors provide a combination of enthusiasm and experience, which will delight any reader. In this volume, they present innumerable beautiful results, intriguing problems, and ingenious solutions. The problems range from elementary gems to deep truths. A truly delightful and highly instructive book, this will prepare the engaged reader not only for any mathematics competition they may enter but also for a lifetime of mathematical enjoyment. This book is a must for the bookshelves of both aspiring and seasoned mathematicians.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Some useful substitutions; Always Cauchy-Schwarz…; Look at the exponent; Primes and squares; T2's lemma; Some classical problems in extremal graph theory; Complex combinatorics; Formal series revisited; A brief introduction to algebraic number theory; Arithmetic properties of polynomials; Lagrange interpolation formula; Higher algebra in combinatorics; Geometry and numbers; The smaller, the better; Density and regular distribution; The digit sum of a positive integer; At the border of analysis and number theory; Quadratic reciprocity; Solving elementary inequalities using integrals; Pigeonhole principle revisited; Some useful irreducibility criteria; Cycles, paths, and other ways; Some special applications of polynomials; Bibliography; Index.

XYZ Series, Volume 13

August 2010, 571 pages, Hardcover, ISBN: 978-0-9799269-0-7, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$55.96**, List US$69.95, Order code XYZ/13



Straight from the Book

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, and **Gabriel Dospinescu**, *Ecole Normale Supérieure de Lyon, France*

This book is a compilation of many suggestions, much advice, and even more hard work. Its main objective is to provide solutions to the problems which were originally proposed in the first 12 chapters of *Problems from the Book*. The volume is far more than a collection of solutions. The solutions are used as motivation for the introduction of some very clear

mathematical expositions. This is absolutely state-of-the-art material. Everyone who loves mathematics and mathematical thinking should acquire this book.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

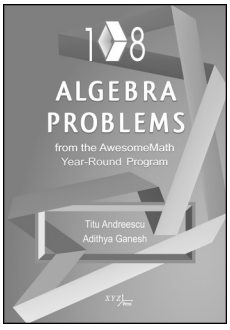
Contents: Some useful substitutions; Always Cauchy-Schwarz…; Look at the exponent; Primes and squares; T_2's lemma; Some classical problems in extremal graph theory; Complex combinatorics; Formal series revisited; A little introduction to algebraic number theory; Arithmetic properties of polynomials; Lagrange interpolation formula; Higher algebra in combinatorics; Bibliography.

XYZ Series, Volume 6

August 2012, 590 pages, Hardcover, ISBN: 978-0-9799269-3-8, 2010

Mathematics Subject Classification: 00A05, 00A07, 97U40, 97D50,

AMS members US$55.96, List US$69.95, Order code XYZ/6



108 Algebra Problems from the AwesomeMath Year-Round Program

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, and **Adithya Ganesh**, *Massachusetts Institute of Technology, Cambridge, MA*

The book covers many classical topics in elementary algebra, including factoring, quadratic functions, irrational expressions, Vieta's relations, equations and systems of equations, inequalities, sums and products, and polynomials. Expanding upon the previous work in the series, *105 Problems in Algebra from the AwesomeMath Summer Program*, this book features additional more advanced topics, including exponents and logarithms, complex numbers, and trigonometry.

The special section on trigonometric substitutions and more explores seemingly algebraic problems with natural geometric and trigonometric interpretations. To give the reader practice with the strategies and techniques discussed in each of the chapters, the authors have included 108 diverse problems, of which 54 are introductory and 54 are advanced. Solutions to all of these problems are provided, in which different approaches are compared.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

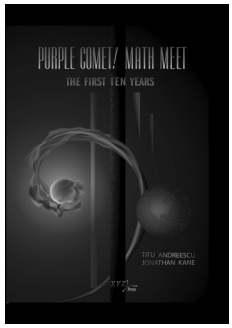
Contents: Let's factor; Quadratic functions; Systems of equations; Vieta's relations and symmetry; Exponents and logarithms; Irrational expressions; Complex numbers; More inequalities; Sums and products; Polynomials; Trigonometric substitutions and more; Introductory problems; Advanced problems; Solutions to introductory problems; Solutions to advanced problems.

XYZ Series, Volume 5

February 2014, 210 pages, Hardcover, ISBN: 978-0-9885622-7-1, 2010

Mathematics Subject Classification: 00A05, 00A07, 97U40, 97D50,

AMS members US$39.96, List US$49.95, Order code XYZ/5



Purple Comet! Math Meet

The First Ten Years

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, and **Jonathan Kane**, *Chair of AIME Committee, Madison, WI*

This book is a comprehensive compilation of all the problems and solutions from the 2003 to 2012 Purple Comet! Math Meet contests for middle and high school students. The problems featured not only employ an extensive range of mathematical concepts from algebra, geometry, number theory, and combinatorics but also encourage team collaboration.

Any student interested in mathematics—whether looking to prepare for contests or, even more importantly, to sharpen math problem-solving skills—would cherish and enjoy this unique and pertinent collection of meaningful problems and solutions.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

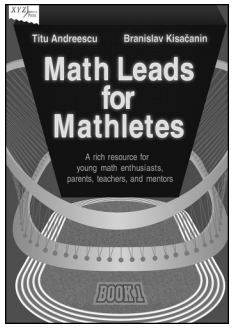
Contents: Problems; Solutions; Appendix.

XYZ Series, Volume 1

April 2013, 340 pages, Hardcover, ISBN: 978-0-9799269-1-4, 2010

Mathematics Subject Classification: 00A05, 00A07, 97U40, 97D50,

AMS members US$39.96, List US$49.95, Order code XYZ/1



Math Leads for Mathletes

A Rich Resource for Young Math Enthusiasts, Parents, Teachers, and Mentors

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, and **Branislav Kisačanin**, *Interphase Corporation, Plano, TX*

The topics contained in this book are best suited for advanced fourth and fifth graders as well as for extremely talented third graders or for anyone preparing for AMC 8 or similar mathematics contests. The concepts and problems presented could be used as enrichment material by teachers, parents, math coaches, or in math clubs and circles.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

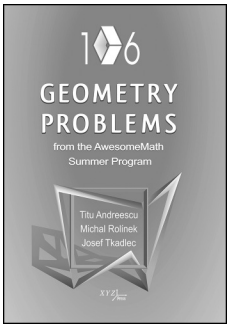
Contents: Part 1. Concepts, exercises, and problems; Part 2. Solutions to exercises and problems.

XYZ Series, Volume 9

February 2014, 220 pages, Hardcover, ISBN: 978-0-9885622-6-4, 2010

Mathematics Subject Classification: 00A05, 00A07, 97U40, 97D50,

AMS members US$47.96, List US$59.95, Order code XYZ/9



106 Geometry Problems from the AwesomeMath Summer Program

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, **Michal Rolinek**, *Institute of Science and Technology, Klosterneuburg, Austria*, and **Josef Tkadlec**, *Charles University, Prague, Czech Republic*

This book contains 106 geometry problems used in the AwesomeMath Summer Program to train and test top middle and high school students from the U.S. and around the world. Just as the camp offers both introductory and advanced courses, this book also builds up the material gradually.

The authors begin with a theoretical chapter where they familiarize the reader with basic facts and problem-solving techniques. Then they proceed to the main part of the work, the problem sections.

The problems are a carefully selected and balanced mix which offers a vast variety of flavors and difficulties, ranging from AMC and AIME levels to high-end IMO problems. Out of thousands of Olympiad problems from around the globe, the authors chose those which best illustrate the featured techniques and their applications. The problems meet the authors' demanding taste and fully exhibit the enchanting beauty of classical geometry. For every problem, they provide a detailed solution and strive to pass on the intuition and motivation behind it. Many problems have multiple solutions.

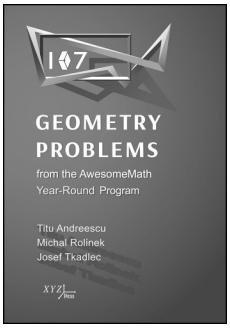
Directly experiencing Olympiad geometry both as contestants and instructors, the authors are convinced that a neat diagram is essential to efficiently solve a geometry problem. Their diagrams do not contain anything superfluous, yet emphasize the key elements and benefit from a good choice of orientation. Many of the proofs should be legible only from looking at the diagrams.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Foundations of geometry; Introductory problems; Advanced problems; Solutions to introductory problems; Solutions to advanced problems; Further reading; Index.

XYZ Series, Volume 3

July 2013, 174 pages, Hardcover, ISBN: 978-0-9799269-4-5, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$39.96**, List US$49.95, Order code XYZ/3



107 Geometry Problems from the AwesomeMath Year-Round Program

Titu Andreescu, *University of Texas at Dallas, Richardson, TX*, **Michal Rolinek**, *Institute of Science and Technology, Klosterneuburg, Austria*, and **Josef Tkadlec**, *Charles University, Prague, Czech Republic*

This book contains 107 geometry problems used in the AwesomeMath Year-Round Program. The problems offer additional challenges for those who have progressed through the 106 Geometry Problems from the AwesomeMath Summer Camp publication. The book begins with a theoretical chapter, where the authors review basic facts and familiarize the reader with some more advanced techniques. The authors then proceed to the main part of the work, the problem sections. The problems are a carefully selected and balanced mix which offers a vast variety of flavors and difficulties, ranging from AMC and AIME levels to high-end IMO problems. Out of thousands of Olympiad problems from around the globe the authors chose those which best illustrate the featured techniques and their applications. The problems meet the authors' demanding taste and fully exhibit the enchanting beauty of classical geometry. For every problem the authors provide a detailed solution and strive to pass on the intuition and motivation behind it. Numerous problems have multiple solutions.

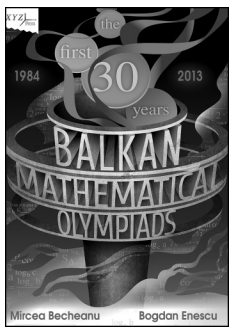
Directly experiencing Olympiad geometry both as contestants and instructors, the authors are convinced that a neat diagram is essential to efficiently solve a geometry problem. Their diagrams do not contain anything superfluous, yet emphasize the key elements and benefit from a good choice of orientation. Many of the proofs should be legible only from looking at the diagrams.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Advanced topics in geometry; Introductory problems; Advanced problems; Solutions to introductory problems; Solutions to advanced problems; Further reading; Index.

XYZ Series, Volume 4

July 2013, 188 pages, Hardcover, ISBN: 978-0-9799269-7-6, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$39.96**, List US$49.95, Order code XYZ/4



Balkan Mathematical Olympiads

Mircea Becheanu, *University of Bucharest, Romania*, and **Bogdan Enescu**, *BP Hasdeu National College, Buzau, Romania*

The authors, who have attended the BMO several times as leaders and/or deputy leaders, present a complete description of the evolution of the BMO from its creation until the present. All problems are presented with complete solutions. Many problems have alternative solutions or extensions. A preparatory addendum, containing additional concepts and useful classical results, has been incorporated at the end of the book.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

Contents: Problems and solutions; Supplementary problems; Glossary; Index of notations; References.

XYZ Series, Volume 8

February 2014, 273 pages, Hardcover, ISBN: 978-0-9885622-5-7, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$47.96**, List US$59.95, Order code XYZ/8

Classified Advertisements

Positions available, items for sale, services available, and more

ALABAMA

UNIVERSITY OF ALABAMA
Mathematics Department

The University of Alabama Mathematics Department invites applications for a non-tenure-track, Postdoctoral Research Associate position in Computational Molecular Biology, beginning August 16, 2014. The initial appointment will be for one year and is renewable for up to two years, depending on performance. A Ph.D. in Computational Mathematics, Mathematical Biology, or a related field is required. Strong programming skills are also required. Candidates with expertise in Poisson-Boltzmann models, mathematical biophysics, biomolecular simulations, ion channel transport, and immersed interface/boundary methods are encouraged to apply. All application materials must be submitted online at http://facultyjobs.ua.edu/postings/35006 and should include the following: 1) curriculum vitae, 2) cover letter, 3) one-page research statement, and 4) copies of up to 3 selected publications. Applicants should also arrange for three letters of reference to be sent to: szhao@ua.edu.

000027

THE UNIVERSITY OF ALABAMA
Mathematics Department
FY 15 Full-Time Temporary Instructor
Posting #0808824

The Mathematics Department at The University of Alabama invites applications for a non-tenure-track temporary instructor position. The appointment will begin on August 16, 2014, and is a one-, two- or three-year term depending on experience and with the possibility of renewal based on funding, availability, and performance. Candidate must possess a Master's degree in mathematics, mathematics education, or a closely related field. Apply online at https://facultyjobs.ua.edu/postings/35055 and arrange for three letters of recommendation to be sent to math@ua.edu. The University of Alabama is an Equal Opportunity Affirmative Action Employer. Women and minorities are encouraged to apply.

000028

BRAZIL

UNIVERSITY OF SÃO PAULO
Postdoctoral opportunities

The recently established Research, Innovation and Dissemination Center on Neuromathematics (RIDC NeuroMat), hosted by the University of São Paulo, Brazil, and funded by FAPESP (São Paulo Research Foundation) is offering several postdoctoral fellowships for recent Ph.D.s with outstanding research potential. Candidates should have strong background in probability theory with emphasis on stochastic processes or in statistics with emphasis on statistical model selection. Previous knowledge of rigorous statistical mechanics, random graphs or stochastic modeling in biosciences will be favorably considered. The initial appointments are for two years, with a possible extension to up to four years. Salary is competitive at international level and fellows benefit from extra funds for traveling and research expenses, plus limited support for relocation. See http://neuromat.numec.prp.usp.br/postdoc for details.

000025

CHILE

PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
Departments of Mathematics and Statistics

The Departments of Mathematics and Statistics of the Pontificia Universidad Catolica de Chile invite applications for two postdoctoral positions, one in Mathematics and the other in Statistics, starting at any date between May 2015 and September 2015. These positions are intended for a new or recent Ph.D. with outstanding potential in research. The duration of the position is one year, with the possibility of extension.

The approximate yearly salary will be of USD $32,000 plus USD $2,500 for moving expenses. Successful applicants will be required to apply to the Chilean national grant system.

Applications must include a cover letter, description of research plans, curriculum vitae, and three or more letters of recommendation. The application deadline date is December 12, 2014. Application materials should be sent to:

Alejandro Ramirez
Facultad de Matematicas
Pontificia Universidad
Catolica de Chile
Av. Vicua Mackenna 4860,
Macul, Santiago
fax: [56](2)25525916
email: aramirez@mat.puc.cl.

000023

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 2014 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: September 2014 issue–June 30, 2014; October 2014 issue–July 29, 2014; November 2014 issue–September 4, 2014; December 2014 issue–September 30, 2014; January 2015–October 29, 2014; February 2015 issue–December 8, 2014.

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.

SCOTLAND

UNIVERSITY OF ST. ANDREWS
School of Mathematics and Statistics
Regius Professor of Mathematics
Ref No ME837R

The School of Mathematics and Statistics at the University of St. Andrews is looking to appoint a Regius Professor of Mathematics. This prestigious chair was established in 1668, and the first holder was James Gregory. We are looking for candidates with an outstanding track record of research and academic achievement in any of the key areas of mathematical sciences. The ability to lead the strategic development of mathematical sciences in St. Andrews, and to represent the school prominently within the UK and internationally are essential. We expect the appointment to expand our existing research portfolio in a significant way, with the possibility of forming a new research group, but synergies with the current expertise would be welcome. The school prides itself on its inclusive and family-friendly work environment, actively striving to achieve diversity and equality of opportunity for all of its staff, students, and visitors.

For further details contact Professor Nik Ruskuc, the Head of School, mathshead@st-andrews.ac.uk.

Closing Date: September 15, 2014.

Apply online at http://www.vacancies.st-andrews.ac.uk/welcome.aspx or call +44 (0)1334 462571 for an application pack.

000026

BOOK FOR SALE

Book for sale on Amazon.com: D.S. Tselnik, Life of a Scientist.

000024

LIBRARY FOR SALE

For sale: 118-volume mathematical library. Willing to let this entire library go for the cost of this ad and the shipping charges.

Contact Clint at 303-758-1953.

000029

Conferences

Call for Proposals for the 2016 von Neumann Symposium

Through a bequest from Dr. and Mrs. Carrol V. Newsom to memorialize the late John von Neumann and his accomplishments, the Society established a quadrennial symposium called the von Neumann Symposium. Subjects of these one-week symposia are to be topics of emerging significance that are expected to underlie future mathematical development.

Ideas expressed and shared at these symposia, and the new understandings embodied in the von Neumann proceedings, will reflect exceptional mathematical leadership. Conference topics in this series have included Quantization and Nonlinear Wave Equations (1994); Arithmetic Fundamental Groups and Noncommutative Algebra (1999); Symposium on Complex Geometry, Calibrations and Special Holonomy (2003); Sparse Representation and High-Dimensional Geometry (2007); and Multimodel and Multialgorithm Coupling for Multiscale Problems (2011). More information about past symposia is located on the AMS website (see http://www.ams.org/meetings/amsconf/symposia/symposia).

Proposals for topics for the 2016 symposium are invited from mathematicians, either singly or in groups. Proposals must include (1) the names and affiliations of the proposed members and the chair of the Organizing Committee; (2) a two-to-four page narrative addressing the focus of the topic, including its importance and timeliness; (3) an estimate of the number of attendees; (4) a list of recent conferences in the same or closely related areas; (5) a tentative list of names and affiliations of the proposed principal speakers; and (6) a list of likely candidates who would be invited to participate and their current affiliations.

Individuals willing to serve as organizers should be aware that the professional meetings staff in the Society's Providence office will provide full support and assistance before, during, and after the conference, thus relieving the organizers of most of the administrative detail. There is some flexibility on the dates for when the symposium can be held in 2016.

Organizers should also note that it is required that the proceedings be published by the AMS and a member of the Organizing Committee must be willing to serve as editor of the proceedings.

An application form to be used when submitting suggested proposal(s) may be obtained by contacting the director of meetings and conferences: Penny Pina, Director of Meetings and Conferences, American Mathematical Society, 201 Charles St., Providence, RI 02904; telephone: 401-455-4145; fax: 401-455-4004; email: meet@ams.org.

Deadline for proposals is **September 30, 2014**. Proposals will be considered by the Von Neumann Symposium Selection Committee.

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Regius Professor of Mathematics
Ref No ME837R

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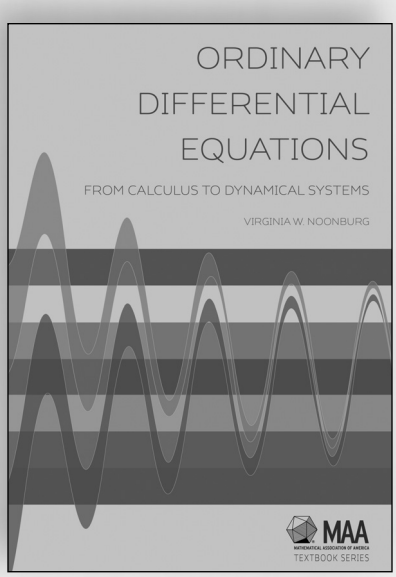
Deadline for proposals is **September 30, 2014**. Proposals will be considered by the Von Neumann Symposium Selection Committee.

New ODE Textbook

Ordinary Differential Equations: From Calculus to Dynamical Systems

By V.W. Noonburg

MAA Textbooks



Catalog Code: FCDS
ISBN: 978-1-93951-204-8
334 pp., Hardbound, 2014
List: $60.00
MAA Member: $48.00

This book presents a modern treatment of material traditionally covered in the sophomore-level course in ordinary differential equations. While this course is usually required for engineering students the material is attractive to students in any field of applied science, including those in the biological sciences.

The standard analytic methods for solving first and second-order differential equations are covered in the first three chapters. Numerical and graphical methods are considered, side-by-side with the analytic methods, and are then used throughout the text. An early emphasis on the graphical treatment of autonomous first-order equations leads easily into a discussion of bifurcation of solutions with respect to parameters.

The fourth chapter begins the study of linear systems of first-order equations and includes a section containing all of the material on matrix algebra needed in the remainder of the text. Building on the linear analysis, the fifth chapter brings the student to a level where two-dimensional nonlinear systems can be analyzed graphically via the phase plane. The study of bifurcations is extended to systems of equations, using several compelling examples, many of which are drawn from population biology. In this chapter the student is gently introduced to some of the more important results in the theory of dynamical systems. A student project, involving a problem recently appearing in the mathematical literature on dynamical systems, is included at the end of Chapter 5.

A full treatment of the Laplace transform is given in Chapter 6, with several of the examples taken from the biological sciences. An appendix contains completely worked-out solutions to all of the odd-numbered exercises.

The book is aimed at students with a good calculus background that want to learn more about how calculus is used to solve real problems in today's world. It can be used as a text for the introductory differential equations course, and is readable enough to be used even if the class is being "flipped." The book is also accessible as a self-study text for anyone who has completed two terms of calculus, including highly motivated high school students. Graduate students preparing to take courses in dynamical systems theory will also find this text useful.

To order visit maa-store.hostedbywebstore.com or call 800-331-1622.

MAA
MATHEMATICAL ASSOCIATION OF AMERICA

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.

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: 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

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/internmtgs.html`.

Invited Addresses

Ian Agol, University of California, Berkeley, *3-manifolds and cube complexes*.

Gil Kalai, Hebrew University, *Influence, thresholds, and noise sensitivity*.

Michael Larsen, Indiana University, *Borel's theorem on word maps and some recent variants*.

Andrei Okounkov, Columbia University, *The M-theory index*.

Leonid Polterovich, Tel-Aviv University, *Symplectic topology: From dynamics to quantization*.

Tamar Zeigler, Technion, Israel Institute of Technology, *Patterns in primes and dynamics on nilmanifolds*.

Special Sessions

Additive Number Theory, **Melvyn B. Nathanson**, City University of New York, and **Yonutz V. Stanchescu**, Afeka Tel Aviv Academic College of Engineering.

Algebraic Groups, Division Algebras and Galois Cohomology, **Andrei Rapinchuk**, University of Virginia, and **Louis H. Rowen** and **Uzi Vishne**, Bar Ilan University.

Applications of Algebra to Cryptography, **David Garber**, Holon Institute of Technology, and **Delaram Kahrobaei**, City University of New York Graduate Center.

Asymptotic Geometric Analysis, **Shiri Artstein** and **Boaz Klar'tag**, Tel Aviv University, and **Sasha Sodin**, Princeton University.

Combinatorial Games, **Aviezri Fraenkel**, Weizmann University, **Richard Nowakowski**, Dalhousie University, Canada, **Thane Plambeck**, Counterwave Inc., and **Aaron Siegel**, Twitter.

Combinatorics, **Gil Kalai**, Hebrew University of Jerusalem.

Dynamics and Number Theory, **Alex Kontorovich**, Yale University.

Field Arithmetic, **David Harbater**, University of Pennsylvania, and **Moshe Jarden**, Tel Aviv University.

Financial Mathematics, **Jean-Pierre Fouque**, University of California, and **Eli Merzbach** and **Malka Schaps**, Bar Ilan University.

Geometric Group Theory and Low-Dimensional Topology, **Ian Agol**, University of California, Berkeley, and **Zlil Sela**, Hebrew University.

Geometry and Dynamics, **Yaron Ostrover**, Tel Aviv University.

History of Mathematics, **Leo Corry**, Tel Aviv University, **Michael N. Fried**, Ben Gurion University, and **Victor Katz**, University of the District of Columbia.

Mirror Symmetry and Representation Theory, **Roman Bezrukavnikov**, Massachusetts Institute of Technology, and **David Kazhdan**, Hebrew University.

Nonlinear Analysis and Optimization, **Boris Mordukhovich**, Wayne State University, and **Simeon Reich** and **Alexander Zaslavski**, Technion Israel Institute of Technology.

PDEs: Modeling Theory and Numerics, **Edriss S. Titi**, University of California, Irvine.

Qualitative and Analytic Theory of ODE's, **Andrei Gabrielov**, Purdue University, and **Yossef Yomdin**, Weizmann Institute of Science.

Quasigroups, Loops and Applications, **Tuval Foguel**, Western Carolina University.

Random Matrix Theory, **Brendan Farrell**, California Institute of Technology, **Mark Rudelson**, University of Michigan, and **Ofer Zeitouni**, Weizmann Institute of Science.

Recent Trends in History and Philosophy of Mathematics, **Misha Katz**, Bar Ilan University, and **David Sherry**, Northern Arizona University.

Teaching with Mathematical Habits in Mind, **Theodore Eisenberg**, Ben Gurion University, **Davida Fishman**, California State University, San Bernardino, and **Jennifer Lewis**, Wayne State University.

The Mathematics of Menahem M. Schiffer, **Peter L. Duren**, University of Michigan, and **Lawrence Zalcman**, Bar Ilan University.

Topological Graph Theory and Map Symmetries, **Jonathan Gross**, Columbia University, and **Toufik Mansour**, University of Haifa.

Eau Claire, Wisconsin

University of Wisconsin-Eau Claire

September 20–21, 2014

Saturday – Sunday

Meeting #1102

Central Section
Associate secretary: Georgia 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: Expired
For abstracts: July 29, 2014

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Matthew Kahle, Ohio State University, *To be announced.*

Markus Keel, University of Minnesota, *To be announced.*

Svitlana Mayboroda, University of Minnesota, *To be announced.*

Dylan Thurston, Indiana University, *To be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `http://www.ams.org/cgi-bin/abstracts/abstract.pl`.

Algebraic Combinatorics (Code: SS 8A), **Pavlo Pylyavskyy**, **Victor Reiner**, and **Dennis Stanton**, University of Minnesota.

Algorithms in Algebraic Geometry (Code: SS 14A), **Adriana Salerno**, Bates College, and **Ursula Whitcher**, University of Wisconsin-Eau Claire.

Analysis and Geometry on Lie Groups (Code: SS 16A), **Chal Benson** and **Gail Ratcliff**, East Carolina University.

Cohomology and Representation Theory of Groups and Related Structures (Code: SS 6A), **Christopher Bendel**, University of Wisconsin-Stout, and **Christopher Drupieski**, De Paul University.

Commutative Ring Theory (Code: SS 3A), **Michael Axtell**, University of St. Thomas, and **Joe Stickles**, Millikin University.

Directions in Commutative Algebra: Past, Present, Future. Dedicated to the memory of H.-B. Foxby (Code: SS 1A), **Joseph P. Brennan**, University of Central Florida, and **Robert M. Fossum**, University of Illinois at Urbana-Champaign.

Graph and Hypergraph Theory (Code: SS 7A), **Sergei Bezrukov**, University of Wisconsin-Superior, **Dalibor Froncek**, University of Minnesota Duluth, and **Xiaofeng Gu**, **Uwe Leck**, and **Steven Rosenberg**, University of Wisconsin-Superior.

Knot Concordance and 4-Manifolds (Code: SS 9A), **Christopher W. Davis**, University of Wisconsin-Eau Claire, **Taylor Martin**, Sam Houston State University, and **Carolyn Otto**, University of Wisconsin-Eau Claire.

Lie Algebras and Representation Theory (Code: SS 5A), **Michael Lau**, Université Laval, **Ian Musson**, University of Wisconsin-Milwaukee, and **Matthew Ondrus**, Weber State University.

New Trends in Toric Varieties (Code: SS 4A), **Christine Berkesch Zamaere**, University of Minnesota, **Daniel Erman**, University of Wisconsin-Madison, and **Hal Schenck**, University of Illinois Urbana-Champaign.

Number Theory (Code: SS 17A), **Colleen Duffy**, University of Wisconsin-Eau Claire, and **Rafe Jones**, Carleton College.

Patterns in Permutations and Words, and Applications (Code: SS 15A), **Manda Riehl**, University of Wisconsin-Eau Claire, and **Alex Woo**, University of Idaho.

Problem Solving in Extremal Combinatorics and Combinatorial Geometry (Code: SS 10A), **Jeremy Alm**, Illinois College, and **Jacob Manske**, Epic.

Random Spaces (Code: SS 13A), **Matthew Kahle**, Ohio State University, and **Dylan Thurston**, Indiana University.

The Mathematical Education of Future K-12 Teachers (Code: SS 12A), **Charles Bingen** and **Ryan Harrison**, University of Wisconsin-Eau Claire.

Wavelets, Frames, and Time-Frequency Analysis (Code: SS 11A), **Patrick Van Fleet**, University of St. Thomas, and **James S. Walker**, University of Wisconsin-Eau Claire.

von Neumann Algebras and Related Fields (Code: SS 2A), **Stephen Avsec** and **Ken Dykema**, Texas A&M 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 July 29, 2014.**

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. Participants must state that they are with the **American Mathematical Society (AMS) Meeting at University of Wisconsin Eau Claire** 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.**

America's Best Value Inn Campus View, 809 W. Clairemont, Eau Claire, WI 54701, 715-834-6611; www.americasbestvalueinn.com/bestv.cfm?idp=1566. Rates are US$75.95. Please note that hotel tax is 13.75%. Amenities include an enjoyable indoor pool and whirlpool, a relaxing outdoor pool and sunning patio, and a Conference Center with spacious banquet and meeting facilities. Guests may enjoy free live entertainment on the weekends in the hotel's pub or enjoy a meal in the casual on-site restaurant—Mancino's Grinders and Pizza. This location is directly across the road from the University of Wisconsin-Eau Claire (approximatly .8 miles walking) and easy access to parks, bike trails, shops and restaurants, all of which are well within walking distance. Check-in time is 3:00 p.m. and check-out time is 12:00 p.m. **The deadline for reservations is August 19, 2014.**

Baymont Inn & Suites, 4075 Commonwealth, Eau Claire, WI 54701, 715-839-7100; www.baymontinns.com. Rates are US$84. Please note that the hotel tax is 13.75%. Amenities include indoor heated swimming pool, Business Center, free Internet in all guest rooms, and complimentary Baymont Breakfast Corner. The hotel is located approximately 5 miles from campus. Check-in time is 3:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is August 19, 2014.**

Best Western Plus Trail Lodge Hotel & Suites, 3340 Mondovi Rd., Eau Claire, WI 54701, 715-838-9989; http://bestwesternwisconsin.com/eau-claire-hotels. Rates are US$93.49. Please note the hotel tax is 13.75%. Amenities include pool, whirlpool & Fitness Center, free HBO, coffee maker, hair dryer & iron with ironing board, desktop modem connection, and complimentary breakfast buffet, shuttle service to Fanny Hill, and wireless Internet. The hotel is located approximately 3 miles from campus. Check-in time is 3:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is August 19, 2014.**

Comfort Inn Eau Claire, 3117 Craig Rd., Eau Claire, WI 54701, 715-833-9798; www.comfortinn.com/hotel-eau_claire-wisconsin-WI026. Rates are US$74. Please note the hotel tax is 13.75%. Amenities include free hot breakfast, free high-speed Internet, and an indoor heated pool and hot tub. All rooms include coffee makers, microwaves and refrigerators. This hotel is located 2 miles from campus. Check-in time is 3:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is August 19, 2014.**

Country Inn & Suites, 3614 Gateway Dr., Eau Claire, WI 54701, 715-832-7289; www.countryinns.com/eau-claire-hotel-wi-54701/wiclaire. Rates are US$99. Please note the hotel tax is 13.75%. Amenities include indoor pool & whirlpool, continental breakfast, restaurants and shopping mall within walking distance. This hotel is located 4.6 miles from campus. Check-in time is 3:00 p.m. and check out-time is 11:00 a.m. **The deadline for reservations is August 19, 2014.**

Days Inn Campus-Eau Claire, 2305 Craig Road, Eau Claire, WI 54701, 715-834-3193; www.daysinn.com/hotels/wisconsin/eau-claire/days-inn-eau-claire-campus/hotel-overview. Rates are US$69 for a single room and US$79.00 for a double room. Please note the hotel tax is 13.75%. Amenities include free Internet and fitness center. This hotel is located 1.2 miles from campus. Check-in time is 3:00 p.m. and check-out time is 12:00 p.m. **The deadline for reservations is August 19, 2014.**

Hampton Inn, 2622 Craig Rd., Eau Claire, WI 54701, 715-833-0003; hamptoninn3.hilton.com/en/hotels/wisconsin/hampton-inn-eau-claire-EAUCRHX/index.html. Rates are US$99. Please note the hotel tax is 13.75%. Amenities include indoor pool, whirlpool, fitness room, free continental breakfast, in-room movies, non-smoking rooms, restaurants and shopping within walking distance. This hotel is located 2 miles from campus. Check-in time is 3:00 p.m. and check-out time is 12:00 p.m. **The deadline for reservations is August 19, 2014.**

Holiday Inn Eau Claire South, 4751 Owen Ayres Court, Eau Claire, WI 54701, 715-830-9889; http://www.ihg.com/holidayinn/hotels/us/en/eau-claire/eauhi/hoteldetail. Rates are US$109.95. Please note the hotel tax is 13.75%. Amenities include free Wi-Fi access, a 24-hour business center, relaxing outdoor patios and fire pits, an indoor pool, whirlpool, and a complete fitness center. This hotel is located 5.4 miles from campus. Check-in time is 3:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is August 19, 2014.**

Metropolis Resort and Conference Center, 5150 Fairview Dr., Eau Claire, WI 54701, 715-852-6000; https://www.metropolisresort.com/. Rates are US$139. Please note the hotel tax is 13.75%. Amenities include the Action City Family Entertainment Center featuring the largest indoor go-kart track in the Midwest. The gaming center also features laser tag, a super arcade, bumper cars, and the Chaos Water Park featuring slides, a lazy river and water basketball. Just steps from your hotel room, every resort stay includes free passes to Chaos and a hot breakfast buffet. This hotel is located 5 miles from campus. Check-in time is 4:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is August 19, 2014.**

Plaza Hotel & Suites, 1202 W. Clairemont, Eau Claire, WI 54701, 715-834-3181; http://www.plazaeauclaire.com/. Rates are US$89.99 or US$99.99 for a business class room. Reservations should be made under the Group Block #8685 or American Mathematical Society. Please note the hotel tax is 13.75%. Amenities include 233 new guest rooms and new indoor recreation center. All rooms feature a microwave, refrigerator, coffee maker. Valet service and on-site coin-operated laundry are available as well

as complimentary airport shuttle. This hotel is located 2 miles from campus. Check-in time is 3:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is August 18, 2014.**

Food Services

On Campus: The Davies Student Center offers a few dining options open on the weekends including the **Blu Flame Grill** open 11:00 a.m.-3:00 p.m. Saturday and Sunday. The Blu Flame Grill offers a variety of sandwiches and burgers.

Off Campus: There is a wide variety of restaurants and fast food close to campus on Water Street.

Dooley's Pub, 442 Water St., Eau Claire, WI 54703; 715-834-2388. Offering traditional Irish pub food. Open Monday-Sunday 11:00 a.m.-close.

Mogie's Pub & Restaurant, 436 Water St. Eau Claire, WI 54703, 715-836-9666; www.mogiespub.com. Mogie's Pub is home of Eau Claire's greatest burgers. They offer fun, casual atmosphere, 17 tap beers, full bar, and televised sporting events. Located on historic Water Street. Open Monday-Friday 11:00 a.m.-midnight.

Splash Wine Bistro, 416 Water St., Eau Claire, WI, 54703, 715-514-3610; www.splashwinebistro.com. Splash Wine Bistro offers delicious food, prepared simply and with fresh ingredients, as well as a love of experiencing more about specialty and unique wines and craft beers. Friday-Saturday 3:00 p.m.-midnight.

The Goat Coffee House, 336 Water St., Eau Claire, WI, 54703, 715-831-4491; www.thegoatcoffeehouse.com. Open Saturday 7:30 a.m.-5:00 p.m. and Sunday 10:00 a.m.-3:00 p.m.

The Nucleus Cafe, 405 Water St., Eau Claire, WI, 54703, 715-834-7777. Open Saturday and Sunday 8:00 a.m.-2:00 p.m.

Mona Lisa's, 428 Water St., Eau Claire, WI 54703, 715-839-8969; www.monalisas.biz. Mona Lisa's is a contemporary Italian and Mediterranean restaurant serving eats such as pasta, seafood, steak, salad, pizza and more, as well as a large selection of wines. Open Friday and Saturday 4:00 p.m.-midnight.

Stella Blues, 306 E. Madison St., Eau Claire, WI, 54703, 715-855-7777; www.stellablues.biz. Stella Blues is a Cajun-influenced restaurant serving delicious sandwiches, seafood, steaks, pasta, and vegetarian choices. Open Friday and Saturday 4:00 p.m.-midnight.

Registration and Meeting Information

Advance Registration

Advance registration for this meeting will open on **August 1, 2014**. Fees will be US$56 for AMS members, US$78 for nonmembers, and US$5 for students, unemployed mathematicians, and emeritus members.

Onsite Information and Registration

Registration, the book exhibit, Special Sessions, and the Invited Addresses will be located in Hibbard Hall, which houses the Department of Mathematics, 124 Garfield Avenue, Eau Claire, WI ("Lower Campus" area). You can find the campus map here: www.uwec.edu/Maps/bldgtour/hhh/index.htm.

The onsite registration desk will be open on Saturday, September 20, 7:30 a.m.-4:00 p.m. and Sunday, September 21, 8:00 a.m.-12:00 p.m. Fees are US$56 for AMS members, US$78 for nonmembers; and US$5 for students, unemployed mathematicians, and emeritus members. Fees are payable onsite via cash, check, or credit card.

Special Needs

It is the goal of the AMS to ensure that its conferences are accessible to all, regardless of disability. The AMS will strive, unless it is not practicable, to choose venues that are fully accessible to the physically handicapped.

If special needs accommodations are necessary in order for you to participate in an AMS Section Meeting, please communicate your needs in advance to the AMS Meetings Department by:

Registering early for the meeting

Checking the appropriate box on the registration form

Sending an email request to the AMS Meetings Department at mmsb@ams.org or meet@ams.org.

Other Activities

Book Sales: Stop by the onsite AMS bookstore and review the newest titles from the AMS, enjoy up to 25% off all AMS publications, or take home an AMS t-shirt! Complimentary coffee will be served courtesy of AMS Membership Services.

AMS Editorial Activity: An acquisitions editor from the AMS book program will be present to speak with prospective authors. If you have a book project that you would like to discuss with the AMS, please stop by the book exhibit.

Local Activities: The University of Wisconsin, Eau Claire Department of Mathematics will host a reception for conference attendees Saturday, September 20, between 6:00 p.m. - 7:15 p.m. in Ojibwe Grand Ballroom, Davies Center, Room 330. The AMS thanks our hosts for their gracious hospitality.

Local Information and Maps

This meeting will take place on the "Lower Campus" area of the University of Wisconsin, Eau Claire. A campus map can be found at www.uwec.edu/Maps/bldgtour/index.htm. Information about the the Department of Mathematics may be found at www.uwec.edu/Math/index.htm. Please visit the university's website at www.uwec.edu/ for additional information on the campus.

Parking

There is free weekend parking in the Hibbard Lot located next to Hibbard Hall. The University asks that you remember to always park HEAD INTO STALL to avoid being ticketed. Don't back in or pull through the stall. This is enforced 7 days a week.

Travel

The University of Wisconsin Eau Claire campus is located in Eau Claire, Wisconsin. The **Chippewa Valley Regional Airport (CVRA)** is located approximately 7 miles north of the university.

Driving to Eau Claire
From Hwy. 53 north or south:
Take exit #87 off of Hwy. 53 onto Clairemont Ave. (Hwy. 12) and go west. Turn left on Patton St. Take a quick right onto Lexington Blvd. Turn right on State St. (down hill). Turn left on Roosevelt Ave. (at bottom of hill). Go one block and Visitor Center will be on your left.
From the south on Hwy. 93:
Take Hwy. 53 north and follow directions above after exiting onto Clairemont Ave. west.
I-94 from the west:
Exit Interstate 94 at Hwy. 312/12 (exit #59) and turn right. Continue east about 3 miles until you reach the Clairemont Avenue (Hwy. 12) exit. Take the exit and turn right onto Clairemont. Stay on Clairemont 2.7 miles until you reach Menomonie Street. Turn left on Menomonie Street (which will veer left onto Water Street at fork in road) and continue 1.5 miles. After crossing over the Chippewa River you'll come to Park Avenue. Turn right onto Park Avenue and continue to Roosevelt Avenue (at second stop sign). Visitor Center will be directly in front of you.
I-94 from the east:
Exit Interstate 94 at Hwy. 53 (exit #70) and follow Hwy. 53 north. Take exit #87 off of Hwy. 53 onto Clairemont Ave. (Hwy. 12) and turn left (to head west). Turn left on Patton St. Take a quick right onto Lexington Blvd. Turn right on State St. (down hill). Turn left on Roosevelt Ave. (at bottom of hill). Go one block and Visitor Center will be on your left.
From the Airport: Continue to Starr Ave. (0.3 mi.) Take US-53 BUS S and E. Clairemont Ave. to University Dr. in Eau Claire County (6.7 mi.) Turn right onto Starr Ave. (0.8 mi.) Turn left onto Eddy Ln. (0.3 mi.) Turn right onto US-53 BUS S (3.5 mi.) Turn right onto Brackett Ave. (0.4 mi.) Turn left onto Rudolph Rd. (0.5 mi.) Turn right onto E. Clairemont Ave (1.2 mi.) Turn right onto University Dr.

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).

Shuttle Service to Eau Claire from Minneapolis/St. Paul airport (MSP) : Shuttle service is available from the Minneapolis/St. Paul airport to Eau Claire Terminal located at 6204 Chuck Lane, Eau Claire, WI. The trip is approximately 1.5 hours. For rates and schedules please visit: www.chippewavalleyairportservice.com/.

Local Transportation
Taxi Service
A1 Eau Claire Taxi: 715-831-8294
Door 2 Door Taxi: 715-225-1754; www.door2doortaxi.com
Mr Cab: 715-271-1000
Bus Service
Eau Claire City Transit: 715-839-5111; www.ci.eau-claire.wi.us

Weather
The month of September is characterized by daily high temperatures ranging from 70°F to 80°F over the course of the month to the 50°F range at night.

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 sites.nationalacademies.org/pga/biso/visas/ and 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 mkl@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.

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: Expired
For abstracts: August 19, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

François Bergeron, Université du Québec à Montréal, *Algebraic combinatorics and finite reflection groups*.

Sourav Chatterjee, Stanford University, *Nonlinear large deviations*.

William M. Goldman, University of Maryland, *Moduli spaces and the classification of geometric structures on manifolds*.

Sujatha Ramdorai, University of British Columbia, *Galois representations and Iwasawa theory*.

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Advances in Harmonic Analysis and Partial Differential Equations (Code: SS 14A), **David Cruz-Uribe**, Trinity College, and **Scott Rodney**, Cape Breton University.

Combinatorial Representation Theory (Code: SS 8A), **Cristina Ballantine**, College of the Holy Cross, **Rosa Orellana**, Dartmouth College, and **Mercedes Rosas**, Universidad de Sevilla.

Commutative Algebra and Its Interactions with Algebraic Geometry (Code: SS 2A), **Susan Marie Cooper**, North Dakota State University, **Sara Faridi**, Dalhousie University, and **William Traves**, U.S. Naval Academy.

Differential Geometry and Mathematical Physics (Code: SS 7A), **Virginie Charette**, Université de Sherbrooke, and **Karin Melnick**, University of Maryland.

Experimental Mathematics in Number Theory, Analysis, and Combinatorics (Code: SS 10A), **Marc Chamberland**, Grinnell College, and **Karl Dilcher**, Dalhousie University.

Games on Graphs (Code: SS 6A), **Jason Brown** and **Jeannette Janssen**, Dalhousie University.

General Relativity (Code: SS 12A), **Jack Gegenberg**, University of New Brunswick.

Generalized Catalan Algebraic Combinatorics (Code: SS 9A), **François Bergeron** and **Franco Saliola**, Université du Québec á Montréal, **Hugh Thomas**, University of New Brunswick, and **Nathan Williams**, Université du Québec á Montréal.

Hopf Algebras (Code: SS 11A), **Yuri Bahturin**, Memorial University of New Foundland, **Margaret Beattie**, Mount Allison University, and **Mitja Mastnak**, Saint Mary's University.

New Directions in Category Theory (Code: SS 5A), **Pieter Hofstra**, University of Ottawa, and **Dorette Pronk**, Dalhousie University.

Sampling Theory (Code: SS 4A), **John J. Benedetto**, University of Maryland, **Jean-Pierre Gabardo**, McMaster University, and **Ozgur Yilmaz**, University of British Columbia.

Special Functions and Their Applications. (Code: SS 3A), **Mourad E. H. Ismail**, University of Central Florida, and **Nasser Saad**, University of Prince Edward Island.

Symbolic Dynamics and Combinatorics on Words (Code: SS 13A), **Srecko Brlek**, Université du Québec á Montréal, and **Reem Yassawi**, Trent University.

p-adic Methods in Arithmetic (Code: SS 1A), **Henri Darmon**, McGill University, **Adrian Iovita**, Concordia University, and **Sujatha Ramdorai**, University of British Columbia.

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 19, 2014.**

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 of 2% or the Harmonized Sales Tax (HST) of 15%. The HST is a single rate of 15% added to the base of all goods and services. Participants must state that they are with the **American Mathematical Society (AMS) Meeting at Dalhousie 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.**

Atlantica Hotel Halifax, 1980 Robie Street, Halifax, N.S., B3H 3G5; (902)423-1161; www.atlanticahotelhalifax.com. Rates are CAD$135 per night for single/double occupancy. Each additional person will be chargedCAD$15 per room/per night. Amenities include complimentary wireless Internet in guest rooms; complimentary local calls; on-property business center; fitness center; swimming pool; and *Seasons* restaurant and lounge on property serving breakfast, lunch, dinner, and late night dining. Parking is subject to availability in a heated underground garage for overnight guests at a rate of CAD$17 plus tax per day. This hotel is pet-friendly. This property is located approximately 1 mi /1.7 km from the campus by car or 11 minutes walking time. **The deadline for reservations at this rate is September 17, 2014.**

Cambridge Suites Hotel, 1583 Brunswick Street, Halifax, Nova Scotia, B3J 3P5; (800)565-1263; http://www.cambridgesuiteshalifax.com/. Rates are CAD$149 per night for a studio room featuring a kitchenette, queen bed, and a pull-out sofa or two double beds; CAD$174 for a Junior Suite featuring a separate bedroom with a queen bed and living area with pull-out sofa and kitchenette; and CAD$199 for a One-Bedroom Suite featuring a separate bedroom with a king bed or two double beds with a

separate living area with a pull-out sofa and kitchenette. Amenities include complimentary continental breakfast, complimentary wireless Internet access, fitness center, onsite restaurant *Canvas Resto Lounge*, and free local calls. Parking is available onsite for a fee of CAD$18 plus tax, per night. Reference *American Mathematical Society* for a quick, easy booking process with an onsite agents. This property is located approximately 1.5 mi /2.5 km from the campus by car or approximately 21 minutes walking time. **The deadline for reservations at this rate is September 18, 2014.**

Garden South Park Inn, 1263 South Park Street, Halifax, N.S., B3H 3G5; (877)414-8577; http://www.gardeninn.ns.ca/. Rates are CAD$103.20 per night for one double bed, CAD$111.20 per night for one queen bed, or CAD$11.20 per night for two twin beds. Amenities include complimentary Internet, complimentary continental breakfast buffet, and complimentary evening tea and snacks. Parking is available on-site, based on availablity, for a cost of CAD$12 per night. Please request a room in the AMS block. This property is located approximately .6 mi/ 1 km from the campus by car or approximately 13 minutes walking time. **This rate will be offered by the property until September 30, 2014, based upon availablity of rooms.**

Lord Nelson Hotel and Suites, 1515 South Park Street, Halifax, Nova Scotia, Canada B3J2L2; (902)423-6331; http://lordnelsonhotel.ca/. Rates are CAD$149 per night for single/double occupancy in a classic guest room. Each additional adult in the same room is charged at a rate of CAD$20 per adult. Amenities include complimentary wireless Internet access in guest rooms; complimentary local calls; a restaurant on-site, *The Arms,* serving breakfast, lunch, dinner, and room service; fitness center; and business center. Parking is available for CAD$22 plus tax per night for registered guests. This property is located approximately 1.3 km from the campus by car or approximately 14 minutes walking time.**The deadline for reservations at this rate is September 5, 2014.**

Food Services

On Campus: Residence dining halls are located in Howe Hall, and Sherriff Hall and are open to the public. On weekends brunch is served between 10:30 a.m.–1:30 p.m.; a limited meal service is available between 1:30 p.m.–4:30 p.m.; and dinner is served between 4:30 p.m.–6:30 p.m. There are two options available in Killam Hall, Killam Second Cup and Killam *Subway.* Both locations are open on Saturday between 10:00 a.m.–8:00 p.m.; and on Sunday between 10:00 a.m.–Midnight. Another option, The Pub at the University Club (902-494-6511; daluclub.ca/the-pub), is located on campus at 1 Alumni Crescent, very close to the meeting. The Pub will be kept open for lunch on Saturday and Sunday, hours of operation to be determined, please watch the website for further details.

Off Campus: Downtown Halifax offers shopping, entertainment and many restaurants. There are many choices for dining convenient to campus, here are some local options:

Fine dining, Maritime cuisine:

The Cellar Bar and Grill, 5677 Brenton Place, 902-835-1592; Fine dining, pizza, pasta, meat, seafood.

Chives Canadian Bistro, 1537 Barrington Street, 902-420-9626; (reservations advisable). Fine dining with locally sourced ingredients and a seasonally changing menu.

Saege Bistro, 5883 Spring Garden Road, 902-429-1882, www.saege.ca. Fine dining; lunch, dinner, weekend brunch.

The Wooden Monkey, 1707 Grafton Street, 902-444-3844; Fine dining from local ingredients; gluten-free, vegetarian, vegan and free range options available.

Seafood and lobster:

Five Fisherman Restaurant & Grill, 1740 Argyle Street, 902-422-4421; Fine dining with all-you-can-eat salad bar; excellent for seafood and lobster.

McKelvie's, 1680 Lower Water Street, 902-421-6161. Fine dining, excellent for seafood and lobster.

Salty's Seafood Restaurant, 1869 Upper Water Street, 902-423-6818; Bar and grill downstairs, fine dining upstairs. Serving seafood with a waterfront location.

Pubs with dining:

The Henry House, 1222 Barrington Street, 902-423-5660; A very popular local pub with fine dining. English-style ales, pub fare, and Maritime cuisine.

The Old Triangle Irish Alehouse, 5136 Prince Street, 902-492-4900; Popular local pub, often with live music.

Casual dining:

Athens Restaurant, 6273 Quinpool Road, 902-422-1595; A low-key restaurant with Greek and North American options (moussaka, burgers, etc.).

Bluenose II Restaurant, 1824 Hollis Street, 902-425-5092; A diner serving staples such as fish and chips, clam chowder, burgers, and traditional diner food.

Coburg Coffee, 6085 Coburg Road, 902-429-2326, coburgcoffee.com; soups and sandwiches.

Subway, 1403 Robie Street, 902-422-4355. Fast food sandwiches.

International food:

Baan Thai, 5234 Blowers Street, 902-446-4301; Family-owned Thai restaurant, one of the oldest in town.

Cafe Istanbul, 5986 Spring Garden Road, 902-405-4028, cafeistanbul.ca. Popular lunch spot, high-end Turkish food.

Piatto Pizzeria + Enoteca, 5144 Morris Street, 902-406-0909; Neapolitan pizza, certified authentic by the pizza authorities of Naples.

Turkish Delight, 5680 Spring Garden Road, 902-446-4366; Turkish restaurant featuring halal food, kebabs, mezze, etc.

Shiraz, 1240 Hollis Street, 902-404-3300. A small Persian restaurant.

Registration and Meeting Information

Advance Registration

Advance registration for this meeting will open on **August 1, 2014**. Advance Registration Fees will be US$56 for AMS members, US$78 for nonmembers, and US$5

for students, unemployed mathematicians, and emeritus members.

Onsite Information and Registration

Registration will be located in the McCain Foyer and the AMS book exhibit will be located in the McCain Upper Foyer. Special Sessions will be held in the Marion McCain Building. All Invited Addresses will take place in the Scotia Bank Auditorium also located in the McCain Building. Please refer to the general campus map at http://campusmaps.dal.ca/for specific locations. The registration desk will be open on Saturday, October 18, 7:30 a.m.–4:00 p.m. and Sunday, October 19 8:00 a.m. – 12:00 noon. Fees onsite will be US$56/ CAD$61 for AMS or Canadian Mathematical Society Members (CMS)members, US$78/ CAD$85 for nonmembers; and US/CAD$5 for students, unemployed mathematicians, and emeritus members. Fees are payable on-site via Canadian or American currency, Canadian or American check, or credit card.

Special Needs

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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.

Local Information and Maps

This meeting will take place on the Studley Campus of Dalhousie University, located in Halifax. A campus map can be viewed at http://campusmaps.dal.ca/. Information about the Dalhousie Department of Mathematics and Statistics may be found at http://www.dal.ca/faculty/science/math-stats.html. Please watch the website available at www.ams.org/meetings/sectional/sectional.html for additional information on this meeting. Please visit the Dalhousie University website at http://www.dal.ca/ for additional information on the campus.

Parking

All campus parking in lots and at meters is available free of charge to visitors on weekends. Parking in the McCain Parkade Garage is available at a cost of CAD$4 per day. This parkcade can be accessed by turning onto Seymour Street just before the Marion McCain Building (located at 6135 University Ave). Additional information on visitor parking can be found at http://campusmaps.dal.ca/ by searching the map for *parking*.

Travel

Dalhousie's Studley campus is located in the South End of Halifax, within a 15-to 20-minute walk to the downtown area.

By Air: Robert L. Stanfield International Airport is located iapproximately 33 km/20 mi from the city of Halifax and is approximately a 40-minute drive from the airport to Dalhousie University. The website is http://hiaa.ca/.

Taxi service is offered at a set rate of CAD$63 for a one-way trip into Halifax city center. Airport car services are available curbside in the arrivals area for all arriving flights. For more information, check at the Ground Transportation kiosk in the domestic arrivals area. To prearrange service please visit the airport's website for a list of drivers licensed at Halifax Stanfield International Airport: http://hiaa.ca/transportation/taxi-limos/.

Rental cars are available through a number of rental agencies at the airport. Please visit the airport website for information on rental car companies in Halifax.

There are two options for bus service from the airport to the downtown area. Metro Transit operates its MetroX service from downtown to Halifax Stanfield International Airport. The #320 bus operates every 30 minutes during peak morning (6:00 a.m. to 9:00 a.m.) and afternoon (3:00 p.m. to 6:00 p.m.) times. The regular schedule departs every 60 minutes. Fares are CAD$3.50 for adults/students and CAD$2.75 for children/seniors. For more for more information please visit their website http://www.halifax.ca/metrotransit/Schedules/index.php. The second option is Maritime Bus which has routes thoughout the Maritimes including service to and from the airport. For more information, call 800-575-1807.

By Train: VIA Rail Canada (http://www.viarail.ca/) provides transcontinental train service; there is a station in Halifax. Call toll-free 888-842-7245.

By Bus: Greyhound (http://www.greyhound.com/) provides service from New York and Voyageur (https://www.greyhound.ca/) provides service from Montreal. Each bus line connects with Maritime Bus which serves Atlantic Canada. For more information on Maritime Bus, please call 800-575-1807.

By Car:

From the airport: Take the 102 to Halifax (stay right at exit 5, which is the Halifax/Bedford exit). Continue to go straight. The 102 will turn into Bayers Road. On Bayers Road, after you pass the Halifax Shopping Centre, turn right at the next set of lights. This is Connaught Avenue. Take Connaught until it ends at a three-way stop. Turn left onto Jubilee Road. At the first set of lights, turn right

onto Oxford Street. Take Oxford to Coburg Road. Arrive at the Studley Campus.

From all other points: The university can be accessed by car through any of the highways feeding into the city, but the most direct route is via the 102 inbound. The interactive campus map found on the Dalhousie website provides a way to customize directions, using the "get directions" tab. The map can be found here: http://campusmaps.dal.ca/.

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 the AMS convention number **(CV): 04N30004.** You can also call Hertz directly at 800-654-2240 (U.S. and Canada) or 405-749-4434 (other countries). 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 Ferry Service: Halifax metro transit offers urban bus routes and ferry service to cities outside of Halifax. For schedules and information on pricing please visit http://www.halifax.ca/metrotransit/.

Weather

The average high temperature for October is is approximately 20 degrees Celsius or 70 degrees Fahrenheit and the average low is approximately 10 degrees Celsius or 50 degrees Fahrenheit. Weather in Halifax is moderate, but temperatures can fluctuate a great deal throughout the day and can vary depending on proximity to the ocean. It is recommended that visitors dress in layers. Prepare for inclement weather and check weather forecasts in advance of arrival in Halifax.

Information for International Participants

All United States citizens visiting Canada must possess a valid passport, NEXUS card, or U.S. Coast Guard Merchant Mariner document. For more information on passport requirements for travel to Canada, visit the U.S. Department of State, National Passport Information Center website (http://travel.state.gov/content/passports/english/passports.html) or access U.S. passport application services from the United States Postal Service.

Visitors from the United States, United Kingdom, France, Germany, Mexico, Japan, the Republic of Korea, and Australia do not require a visa to enter Canada. If you are not from one of these countries, you should contact your Canadian consulate or embassy to learn what documents you may require. The Foreign Affairs and International Trade Canada website (http://www.tradecommissioner.gc.ca/eng/trade-offices.jsp) provides links to over 150 Canadian embassies and offices around the world.

For complete information on entry requirements and what you are permitted to bring into Canada, visit the Citizenship and Immigration Canada's Visiting Canada website (http://www.cic.gc.ca/english/visit/index.asp).

For up-to-date information for visitors from the Canadian Border Services Agency, go to www.cbsa.gc.ca or call 1800-461-9999 (within Canada) or 506-636-5064. Information on visas for temporary residents can be found on the Citizenship and Immigration website or by calling 1888-242-2100. In the U.S. refer to www.travel.state.gov.

Passport and visa requirements for visiting Canada will vary according to your citizenship, residency, and purpose for visiting Canada. It is recomended to obtain more information before completing your travel plans by contacting the nearest Canadian Embassy, High Commission, or your country's Customs/Immigration office.

This list is not to be considered complete. Please visit the websites above for the most up-to-date information.

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 11, 2014
Program issue of electronic *Notices*: October 2014
Issue of *Abstracts*: Volume 35, Issue 4

Deadlines

For organizers: Expired
For abstracts: September 3, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Kai Behrend, University of British Columbia, Vancouver, Canada, *Title to be announced.*

Kiran S. Kedlaya, University of California, San Diego, *Title to be announced.*

Julia Pevtsova, University of Washington, Seattle, *Title to be announced.*

Jim Simons, Euclidean Capital, *Mathematics, Common Sense, and Good Luck.*

Burt Totaro, University of California, Los Angeles, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Algebraic Geometry (Code: SS 1A), **Renzo Cavalieri**, Colorado State University, **Noah Giansiracusa**, University of California, Berkeley, and **Burt Totaro**, University of California, Los Angeles.

Algebraic Statistics (Code: SS 8A), **Elizabeth Gross**, San Jose State University, and **Kaie Kubjas**, Aalto University.

Applications of Knot Theory to the Entanglement of Biopolymers (Code: SS 15A), **Javier Arsuaga**, San Francisco State University, **Michael Szafron**, University of Saskatchewan, and **Mariel Vazquez**, San Francisco State University.

Categorical Methods in Representation Theory (Code: SS 4A), **Eric Friedlander**, University of Southern California, **Srikanth Iyengar**, University of Nebraska, Lincoln, and **Julia Pevtsova**, University of Washington.

Combinatorics and Algebraic Geometry (Code: SS 9A), **Madhusudan Manjunath**, University of California, Berkeley, and **Farbod Shokrieh**, Cornell University.

Computational Algebraic Geometry and Applications to Science and Engineering (Code: SS 17A), **Daniel Brake** and **Dhagash Mehta**, North Carolina State University, Raleigh.

Developments from MSRI Programs in Commutative Algebra and Noncommutative Algebraic Geometry and Representation Theory (Code: SS 18A), **Kenneth Chan**, University of Washington, and **Jack Jeries**, University of Utah.

Geometry of Submanifolds (Code: SS 3A), **Yun Myung Oh**, Andrews University, **Bogdan D. Suceava**, California State University, Fullerton, and **Mihaela B. Vajiac**, Chapman University.

Hamiltonian Partial Differential Equations (Code: SS 12A), **Marius Beceanu**, University of California, Berkeley, **Magdalena Czubak**, Binghamton University, **Dong Li**, University of British Columbia, and **Xiaoyi Zhang**, University of Iowa.

High-Dimensional Convexity and Applications (Code: SS 14A), **Luis Rademacher**, Ohio State University, **Stanislaw Szarek**, Case Western Reserve University and Université Pierre et Marie Curie-Paris 6, and **Elisabeth Werner**, Case Western Reserve University, Université de Lille 1, UFR de Mathématique.

Homotopy Theory (Code: SS 11A), **Julie Bergner**, University of California, Riverside, and **Angélica Osorno**, Reed College.

Interactions between Knots and Manifolds (Code: SS 10A), **Stanislav Jabuka** and **Swatee Naik**, University of Nevada, Reno, and **Cornelia Van Cott**, University of San Francisco.

Nonlinear Partial Differential Equations (Code: SS 6A), **Nathan Glatt-Holtz**, Virginia Tech, **Geordie Richards**, University of Rochester, and **Vlad Vicol**, Princeton University.

Polyhedral Number Theory (Code: SS 2A), **Matthias Beck**, San Francisco State University, **Martin Henk**, Universität Magdeburg, and **Joseph Gubeladze**, San Francisco State University.

Probabilistic and Statistical Problems in Stochastic Dynamics (Code: SS 7A), **Alexandra Piryatinska**, San Francisco State University.

Recent Progress in Geometric Analysis (Code: SS 5A), **David Bao**, San Francisco State University, and **Ovidiu Munteanu**, University of Connecticut.

Recent Progress in Harmonic Analysis and Several Complex Variables (Code: SS 16A), **Gustavo Hoepfner** and **Paulo Liboni**, Universidade Federal de São Carlos, and **Irina Mitrea**, Temple University.

Topological Combinatorics and Combinatorial Commutative Algebra (Code: SS 13A), **Anton Dochtermann**, University of Miami, **Augustine O'Keefe**, University of Kentucky, and **Alexander Engstrom**, Aalto 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 September 2, 2014.

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. Participants must state that they are with the **American Mathematical Society (AMS) Meeting at San Francisco State 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.**

Days Inn San Francisco at the Beach, 2600 Sloat Blvd. (at Great Highway), San Francisco, CA 94116, 415-834-6611; `www.daysinn.com`. Rates are US$165 for a single and US$175 for a double. Please note that hotel tax is 16.32%. Amenities include a complimentary daily breakfast, free Internet, and parking. This location is also close to public transportation. This location is 2.3 miles from campus. Check in-time is 2:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is September 24, 2014.**

Hampton Inn, 2700 Junipero Serra Blvd., Daly City, CA 94015; 650-755-7500; `www.hamptoninn.com`. Rates are US$189 for a single or double room. Please note that the hotel tax is 16.32%. Reservations can be made online here: `hamptoninn.hilton.com/en/hp/groups/personalized/S/SFODCHX-AMS-20141024/index.jhtml?WT.mc_id=POG`. Amenities include complimentary breakfast, free Internet and parking, and fitness center. Hotel is located 1 mile from the Daly City BART station and approximately 3 miles from campus. Check-in time is 3:00 p.m. and check-out time is 12:00 p.m. **The deadline for reservations is September 24, 2014.**

Great Highway Inn, 1234 Great Highway, San Francisco, CA 94112, 415-731-6644; `www.greathwy.com/`. Rates are US$144 for a room with one queen bed, US$158 for a room with one king bed, or US$178 for a room with two queen beds. Please note the hotel tax is 16.32%. Amenities include free parking and complimentary coffee and pastries in the morning. The hotel is located approximately 4 miles from campus. Check-in time is 4:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is October 2, 2014.**

Mission Inn, 5630 Mission Street, San Francisco, CA 94112, 415-584-5020. Rates are US$75 for a single and

US$85 for a double. Please note the hotel tax is 16.32%. Amenities include free coffee, free high-speed Internet, and parking. This hotel is located 2.3 miles from campus. Check-in time is 3:00 p.m. and check-out time is 11:00 a.m. **The deadline for reservations is October 1, 2014.**

Embassy Suites San Francisco Airport - South San Francisco, 250 Gateway Boulevard, South San Francisco, California, 94080; 650-589-3400; embassysuites3.hilton.com/en/hotels/california/embassy-suites-san-francisco-airport-south-san-francisco-SFOSOES/index.html. Rates are US$180 for a single room and US$190 for a double. Please note the hotel tax is 16.32%. Amenities include complimentary breakfast and evening drinks/snacks, and complimentary access to the fitness center. This hotel is located 11 miles from campus. Check-in time is 3:00 p.m. and check-out time is 12:00 p.m. **The deadline for reservations is October 3, 2014.**

Serrano Hotel, 405 Taylor Street, San Francisco, CA 94102, 415-885-2500; www.serranohotel.com. Rate is US$199. Please note the hotel tax is 16.32%. Amenities include complimentary coffee in the lobby, Internet, and fitness center. This location is steps from Union Square and is located 9.7 miles from campus. Check-in time is 3:00 p.m. and check-out time is 12:00 p.m. **The deadline for reservations is September 24, 2014.**

Villa Florence, 224 Powell Street, San Francisco, CA 94102, 415-617-1062; http://www.villaflorence.com/. Rates are US$209. Please note the hotel tax is 16.32%. Amenities include complimentary high-speed Internet access. This downtown San Francisco hotel is located 9.7 miles from campus. Check-in time is 3:00 p.m. and check-out time is 12:00 p.m. **The deadline for reservations is September 26, 2014.**

Food Services

On Campus: the Cesar Chavez Student Union offers a few dining options open on Saturday including **Cafe 101, Taqueria Girasol, Gold Coast Grill, the SFSU Pub, Tuk-Tuk Thai SF, Asia Express** and **Ike's Place** open 8:00 a.m.-4:00 p.m. on Saturday.

Off Campus: There is a wide variety of restaurants and fast food close to campus.

Cafe Rosso, 1600 Holloway Ave, San Francisco, CA 94132; 415-405-0923. Open Saturday 8:00 a.m.-3:00 p.m.

Hall of Flame Burgers, 73 Cambon Dr., San Francisco, CA 94132; 415-584-4444. Open Saturday 11:00 a.m.-9:00 p.m. and Sunday 11:00 a.m.-6:00 p.m.

Dinosaurs Vietnamese Sandwiches, 2522 Ocean Avenue, San Francisco, CA 94132; 415-334-1421; eatdinosaurs.com. Open 7:00 a.m.-7:00 p.m. daily.

BullsHead Restaurant, 840 Ulloa St, San Francisco, CA 94127; 415-665-4350; http://www.bullsheadsf.com/. Serving steaks and burgers. Open Saturday 11:00 a.m.-10:00 p.m. and Sunday 11:00 a.m.-9:00 p.m.

Spiazzo Ristorante, 33 W. Portal Ave., San Francisco, CA 94127; 415-6649511. Offering Italian and seafood. Open Saturday 11:00 a.m.-10:30 p.m. and Sunday 11:00 a.m.-10:00 p.m.

Bursa, 60 West Portal Ave., San Francisco, CA 94127; 415-564-4006; bursasf.com. Serving Middle Eastern, Turkish, and Mediterranean fare. Open Friday and Saturday 11:00 a.m.-10:00 p.m. and Sunday 11:00 a.m.-9:00 p.m.

Taraval Okazu Ya Restaurant, 1735 Taraval St., San Francisco, CA 94116; 415-759-6850. Offering Japanese and sushi. Open Saturday 12:00 p.m.-10:00 p.m. and Sunday 5:00 p.m.-10:00 p.m.

Registration and Meeting Information

Advance Registration

Advance registration for this meeting will open on **August 1, 2014**. Fees will be US$56 for AMS members, US$78 for nonmembers, and US$5 for students, unemployed mathematicians, and emeritus members.

Onsite Information and Registration

Onsite registration and the book exhibit will be located outside of Room 404 of Thornton Hall. Special Sessions will be located in Thornton Hall, Hensill Hall, and the Business Building. The Invited Addresses will be located in the Science building. You can find the campus map here: http://www.sfsu.edu/~sfsumap/.

The onsite registration desk will be open on Saturday October 25, 7:30 a.m.-4:00 p.m. and Sunday, October 26, 8:00 a.m.-12:00 p.m. Fees are US$56 for AMS members, US$78 for nonmembers, and US$5 for students, unemployed mathematicians, and emeritus members. Fees are payable onsite via cash, check, or credit card.

Special Needs

It is the goal of the AMS to ensure that its conferences are accessible to all, regardless of disability. The AMS will strive, unless it is not practicable, to choose venues that are fully accerssible to the physically handicapped.

If special needs accommodations are necessary in order for you to participate in an AMS Section Meeting, please communicate your needs in advance to the AMS Meetings Department by:

Registering early for the meeting

Checking the appropriate box on the registration form

Sending an email request to the AMS Meetings Department at mmsb@ams.org or meet@ams.org.

AMS Einstein Public Lecture in Mathematics

The 2014 Einstein Public Lecture will be held on October 25, 2014, at 7:30 p.m. in the Towers Conference Center on the San Francisco State University campus. The lecturer will be **James H. Simons**, Chairman, Simons Foundation. The talk is titled *Mathematics, Common Sense, and Good Luck.*

The lecture will be followed by a reception hosted by the American Mathematical Society and the Department of Mathematics of San Francisco State University, which will take place from 7:15 p.m. to 8:45 p.m. in the Seven Hills Conference Center on the SFSU campus. Since a very large audience is expected, an RSVP for planning purposes is encouraged but not required. Please RSVP at https://docs.google.com/forms/d/1LxXik9IeROQcGU-LOi-

Wml5Mu9Ztca8heBxPoj3-K2tg/viewform?usp=send_form.

Other Activities

Book Sales: Stop by the onsite AMS bookstore and review the newest titles from the AMS, enjoy up to 25% off all AMS publications, or take home an AMS t-shirt! Complimentary coffee will be served courtesy of AMS Membership Services.

AMS Editorial Activity: An acquisitions editor from the AMS book program will be present to speak with prospective authors. If you have a book project that you would like to discuss with the AMS, please stop by the book exhibit.

Local Information and Maps

This meeting will take place on the campus of San Francisco State University. A campus map can be found at www.sfsu.edu/~sfsumap/. Information about the the Department of Mathematics may be found at math.sfsu.edu/.Please visit the university's website at sfsu.edu/ for additional information on the campus.

Parking

Parking Lot 19 is located towards back campus and can be accessed by entering on State Drive off of Lake Merced Blvd.

For information on parking rates and details please go to: www.sfsu.edu/~parking/text/parking.html.

For those who are planning to purchase a daily permit for Lot 19 parking garage on campus, be sure to scratch off the correct date.

To get to Thornton Hall (TH) from Parking Lot 19 you will need to take the elevator to the fifth floor of the garage. Exit to the left from the elevator. From there you will take a left to cross the bridge that connects the garage with campus. After crossing the bridge, make a left and follow the road uphill and keeping right at the fork. You will walk for a few hundred yards, passing the athletic field/track which will be to your left, until you reach Thornton Hall, a gray building at the very end of the road. Turn right. Walk a few more yards and turn left into the garage-looking entrance for Thornton Hall. Enter the first door on your left. You will be on the second floor. Stairs to the fourth floor are on your right, or elevators are located near the middle of the corridor in which you are standing.

Travel

The San Francisco State University campus is located at 1600 Holloway Street, San Francisco, California. The **San Francisco International Airport (SFO)** is located approximately 9 miles south of the university.

Driving to the University
From the north:
Take Highway 101 South, cross the Golden Gate Bridge. Stay in the far right lane after crossing to take Highway 1 South/19th avenue exit. Follow 19th Avenue to campus, which is at Holloway Avenue.
To get to the parking garage, turn right onto Holloway Ave. and continue to Font Blvd. Turn right onto Font Blvd. and continue to Lake Merced Blvd. Turn right onto Lake Merced Blvd. then take an immediate right onto State Drive which leads to the entrance of the parking garage.

From the south:
Take I-280 North, exit at 19th Avenue. Take Junipero Serra Boulevard to Holloway Avenue, turn left on Holloway Avenue to campus at 19th Avenue. (If you missed Junipero and stayed on 19th Ave., you would have to U-turn at the Stonestown Mall.)
To get to the parking garage, continue on Holloway Ave. to Font Blvd. Turn right onto Font Blvd. and continue to Lake Merced Blvd. Turn right onto Lake Merced Blvd. then take an immediate right onto State Drive which leads to the entrance of the parking garage.

From the east:
Take I-80 West across the Bay Bridge to Highway 101 South. Take 101 South to I-280 toward Daly City. Take the San Jose Avenue/Mission St. exit (immediately after the Ocean Avenue exit), bearing right onto Sagamore Street to Brotherhood Way.

To get to the parking garage stay on Brotherhood Way and turn right onto Lake Merced Blvd. Turn right onto State Drive which is the third light after turning onto Lake Merced Blvd. and immediately after Font Blvd. The entrance to the parking garage is at the end of State Drive.

From the San Francisco International Airport:
Take the I-280 North to exit at 19th Avenue. Take Junipero Serra Boulevard to Holloway Avenue; turn left on Holloway Avenue to campus at 19th Avenue.
To get to the parking garage, continue on Holloway Ave to Font Blvd. Turn right onto Font Blvd. and continue to Lake Merced Blvd. Turn right onto Lake Merced Blvd. then take an immediate right onto State Drive which is the entrance to the parking garage.
From the Oakland Airport:
Take I-880 North towards Downtown Oakland. Take the I-80 West exit towards Bay Bridge/San Francisco. Continue on US-101 South. Take 101 South to I-280 toward Daly City. Take the San Jose Avenue/Mission St. exit (immediately after the Ocean Avenue exit), bearing right onto Sagamore Street to Brotherhood Way to Junipero Serra Boulevard North. Take Junipero Serra Boulevard to Holloway Avenue; turn left on Holloway Avenue to campus at 19th Avenue.

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).

By BART (within the Bay Area or from SF International Airport and Oakland Airport):
Take any San Francisco-bound BART train to the Daly City BART station. From the BART station, there will be multiple taxi cabs available. The estimated fare to campus is approximately US$8 or you can obtain a transfer for the 28 Muni (good for one ride to and from BART) from the machine (press green button) in the lobby before exiting the station. Exit at the "SFSU 19th Ave. & Holloway Ave." stop. Head north on 19th Ave. past the Science Building.

Turn left at Hensill Hall and Thornton Hall will be in front of you.

Local Transportation

Taxi Service

Taxi cabs are available within San Francisco. You may reserve in advance with Yellow Cab 415-333-3333 or Luxor Cab 415-282-4141. If you are staying in Daly City, please use Serra Yellow Cab 650-991-2345 or 650-991-3881.

Weather

The best way to describe San Francisco is a "micro climate", the dry period of May to October is mild to warm, with average high temperatures of 64–71 °F (18–22 °C) and lows of 51–56 °F (11–13 °C).

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 `sites.nationalacademies.org/pga/biso/visas/` and `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 `mkl@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.

* 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.

Greensboro, North Carolina

University of North Carolina at 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: Expired
For abstracts: September 23, 2014

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Susanne C. Brenner, Louisiana State University, *Novel finite element methods for optimal control problems with PDE constraints*.

Skip Garibaldi, Emory University, E_8 *and other exceptional groups*.

Stavros Garoufalidis, Georgia Institute of Technology, *Knots and q-series*.

James Sneyd, University of Auckland, *The dynamics of calcium: Oscillations, waves, theories, and experiments* (AMS-NZMS Maclaurin Lecture).

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the

abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Algebraic Structures Motivated by Knot Theory (Code: SS 9A), **Jozef H. Przytycki**, George Washington University, and **Radmila Sazdanovic**, North Carolina State University.

Algorithms for Local Fields (Code: SS 14A), **Chad Awtrey**, Elon University, and **Sebastian Pauli**, University of North Carolina at Greensboro.

Automorphic Forms and Related Topics (Code: SS 11A), **Matthew Boylan**, University of South Carolina, **Jayce Getz**, Duke University, and **Dan Yasaki**, University of North Carolina at Greensboro.

Connections in Number Theory (Code: SS 20A), **Joseph Vandehey**, University of Georgia.

Difference Equations and Applications (Code: SS 1A), **Michael A. Radin**, Rochester Institute of Technology, and **Youssef Raffoul**, University of Dayton.

Discontinuous Galerkin Finite Element Methods (Code: SS 13A), **Susanne C. Brenner** and **Joscha Gedicke**, Louisiana State University, and **Thomas Lewis**, University of North Carolina at Greensboro.

Discrete Structures in Classical Geometries (Code: SS 4A), **Philip L. Bowers**, Florida State University.

Exceptional Groups in Physics, Algebra, and Geometry (Code: SS 17A), **Asher Auel**, Yale University, **Anthony Ruozzi**, Emory University, and **George McNinch**, Tufts University.

Galois Theory and Its Interactions with Algebra and Number Theory (Code: SS 12A), **Chad Awtrey**, Elon University, and **Michael Bush**, Washington and Lee University.

Geometric Analysis (Code: SS 6A), **Hubert Bray**, Duke University, and **Andrew Cooper**, North Carolina State University.

Geometry and Combinatorics on Homogeneous Spaces (Code: SS 10A), **Leonardo C. Mihalcea**, Virginia Tech University, and **Richard Rimanyi**, University of North Carolina Chapel Hill.

Knot Theory and Its Applications (Code: SS 7A), **Elizabeth Denne**, Washington & Lee University, and **Laura Taalman**, James Madison University.

Mirror Symmetry (Code: SS 18A), **Matthew Ballard**, University of South Carolina, and **David Favero**, University of Alberta.

Movement in Mathematical Biology (Code: SS 19A), **Jonathan T. Rowell** and **Jan Rychtar**, University of North Carolina at Greensboro.

Multiple Combinatorial Numbers and Associated Identities (Code: SS 16A), **Hasan Coskun**, Texas A&M University Commerce.

Nonlinear Boundary Value Problems (Code: SS 5A), **Maya Chhetri**, University of North Carolina at Greensboro, and **Stephen Robinson**, Wake Forest University.

Partial Differential Equations Related to Fluids (Code: SS 15A), **Dhanapati Adhikari**, Marywood University.

Recent Advances in Numerical Methods for Fluid Flow Problems (Code: SS 2A), **Leo Rebholz**, Clemson University, and **Zhu Wang**, University of South Carolina.

Recent Developments in Graph Theory and Hypergraph Theory (Code: SS 3A), **David Galvin**, University of Notre Dame, and **Clifford Smyth**, University of North Carolina at Greensboro.

Set Theoretic Topology (Code: SS 8A), **Peter J. Nyikos**, University of South Carolina, and **Jerry Vaughan**, University of North Carolina at Greensboro.

Sessions for Contributed Talks

There also will be sessions 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 September 23, 2014.**

Accommodations

Participants should make their own arrangements directly with the properties listed below. Special rates for the meeting have been negotiated and are available for Friday and Saturday nights, November 7 and 8; rates may be extended to one day before or after these dates if rooms are available; please ask when you make your reservation. Please cite **AMS Math Meeting on the UNCG Campus** when making a reservation. The AMS is not responsible for the availability of rates or the quality of the accommodations. **Hotels have varying cancellation or early checkout penalties; be sure to ask for details when making your reservation.** The room rates quoted below do not include applicable taxes; the current tax rate on hotel rooms is 12.75%.

As it is not possible to walk to campus from most of the following hotels, the **UNC-Greensboro Department of Mathematics and Statistics will provide limited shuttle service** from the Courtyard Marriott, Extended Stay America, Hyatt Place, La Quinta Inn and Suites Greensboro, and the Wingate by Wyndham-Greensboro (all in the same general vicinity near shopping and restaurants, and a bit more than five miles from campus). Please note that all hotels have a smoke-free policy except where noted.

Courtyard by Marriott Greensboro, 4400 West Wendover Avenue, Greensboro, NC 27407; 800-321-2211 or 336-294-3800 (phone), 301-576-6174 (fax). www.marriott.com/hotels/travel/gsown-courtyard-greensboro. US$104/single or double. All rooms include a coffee maker (refrigerators available on request), free in-room wireless, free parking, and a complimentary hot breakfast. There is a full-service restaurant on the premises serving breakfast and dinner. This property has its own fitness center and seasonal outdoor pool. **The deadline for reservations is October 17, 2014.**

Extended Stay America, 1705 Stanley Rd., Greensboro, NC 2740; 336-574-0405 (phone) 336-218-5692 (fax); www.extendedstayamerica.com/hotels/nc/greensboro/wendover-ave. This hotel offers meeting participants 5% off the prevailing rate when reservations are made. Rates at the time this announcement was prepared were between US$50 and US$70 per night. All rooms are equipped with free Wi-Fi, full kitchens, a refrigerator, coffee maker, cookware, utensils, microwave, and include complimentary continental breakfast, free local calls, one queen bed, and one sleeper sofa. You may check the hotel's website to find the prevailing rate of the day; when you contact the hotel to make your reservation, they will apply the 5%

discount. There is no deadline for reservations, however, participants are advised to make reservations early to avoid a sellout situation. **This offer is only applicable for stays at the 1705 Stanley Rd. property**.

Hyatt Place,1619 Stanley Road, Greensboro, NC 27407; 336-852-1443 (phone) 336-854-9339 (fax); http://greensboro.place.hyatt.com. US$95/single or double. All rooms include a coffee maker and small refrigerator, complimentary wireless, free parking, and complimentary hot breakfast. There is a fitness center, outdoor seasonal pool, and a restaurant and lounge on the premises. The hotel also offers a limited shuttle service to venues within five miles. As a special service for this meeting, they will pick up participants at the Greensboro airport. **The deadline for reservations is October 7, 2014.**

La Quinta Inns & Suites Greensboro, 1201 Lanada Rd., Greensboro, NC 27407; 866-527-1498, 336-316-0100 (phone), 336-316-0190 (fax); www.laquintagreensboro.com/; US$79/single/double/triple/quad. All rooms include a coffee maker (king-bedded rooms also include microwave and refrigerator), free wireless, free local phone calls, complimentary expanded continental breakfast (make-your-own-waffles), and free parking. Complimentary coffee and tea are available in the lobby 24 hours a day. On the premises is a health club, hot tub, and seasonal outdoor pool. Smoking rooms may be available. The hotel also offers a complimentary shuttle service from and to the airport; this service may be limited during peak times. **The deadline for reservations is October 20, 2014**; please cite block #01909295 when making your reservation.

Wingate by Windham-Greensboro, 6007 Landmark Center Blvd., Greensboro, NC 27407; 336-854-8610 (phone), 336-854-8680 (fax). US$85/single or double. All rooms include coffee maker, microwave, and refrigerator; complimentary hot breakfast, and in-room Wi-Fi. There is free parking on the premises, a 24-hour fitness center, and a seasonal outdoor pool. The hotel provides free shuttle service to and from the airport on a limited schedule between 6:00 a.m. and 11:00 p.m., however, you must make a reservation 24 hours in advance. **The deadline for reservations is October 24, 2014**.

Greensboro Marriott Downtown, 304 North Green Street, Greensboro, NC 27401; 336-379-8000 or 800-228-9290 (phone), 336-387-8024 (fax) www.marriott.com/hotels/travel/gsodt-greensboro-marriott-downtown; US$119/single or double; all rooms have coffee makers; in-room Internet is available for an extra fee. On the premises is an indoor pool, fitness center, and a full service restaurant and bar. Self-parking is US$11/day; valet parking is US$15/day. It is a 1.8 mile walk from this to the School of Education Building on campus where the meeting will be held. As this property is much closer to campus, participants will be on their own to get to the meeting site. **The deadline for reservations is October 7, 2014.**

Food Service

On Campus

The Elliott University Center, 507 Stirling St., Greensboro, NC 27412 is .1 mile north east of the meeting location and is open from 11:00 a.m. to 6:00 p.m. on weekends. At the EUC are **Papa John's**, **Ghassan's**, **Hissho Sushi**, **Salsarita's**, **Chick-fil-A**, **Wild Greens**, **Subway**, and **Jamba Juice**. The **Barnes and Noble Café** on the main floor offers Starbucks coffee, muffins, and sandwiches.

Off Campus

There are several restaurants within walking distance of the conference. Among these are

Boba House, 332 Tate Street, Greensboro, NC 27403. Features Thai- and Vietnamese-inspired vegetarian and vegan cuisine. Open Saturday, noon to 9:00 p.m. Closed Sunday.

Coffeeology, 423 Tate Street, Greensboro, NC 27403. Features coffee, panini, and gelato. Open Saturday and Sunday, 7:30 a.m. to 10:00 p.m.

Olde Town Draught House, 1205 Spring Garden St., Greensboro, NC 27403. Features salads, pizzas, sandwiches, burgers, and burritos in a casual pub-like atmosphere. Open every day, 11:00 a.m. to 11:00 p.m.

Jack's Corner Mediterranean Deli, 1601 Spring Garden Street, Greensboro, NC 27403. Features Mediterranean platters and sandwiches along with deli sandwiches, burgers, and salads. Open Saturday, 10:30 a.m. to 9:00 p.m. Closed Sunday.

Tate Street Coffee House, 334 Tate St., Greensboro, NC 27403. Features coffee, muffins, and pastries. Open Saturday, 6:30 a.m. to 11:00 p.m., and Sunday, 8:00 a.m. to 11:00 p.m.

Further from campus

Fishbones, **Sticks and Stones**, and the **Filling Station** are all located at the corner of Walker Ave. and South Elam Ave.

Fishbones, 2119 Walker Ave., Greensboro, NC 27403. Casual kitchen and pourhouse featuring modern American food. Open Saturday and Sunday, 11:00 a.m. to late.

Sticks and Stones Clay Oven Pizza, 2200 Walker Ave., Greensboro, NC 27403. Features pizzas, sandwiches, and local beers. Open Saturday and Sunday, 11:00 a.m. to late.

Lindley Park Filling Station, 2201 Walker Ave., Greensboro, NC 27403. Features salads and sandwiches, plus brunch on Sunday. Open Saturday and Sunday, 11:00 a.m. to midnight.

Lucky 32, 1421 Westover Terrace, Greensboro, NC 27408. Features local Southern and American food and an extensive wine list. Open Saturday, 11:30 a.m. to 11:00 p.m., and Sunday, 10:00 a.m. to 9:00 p.m.

The following two restaurants are located in the Westover Gallery of Shops:

Saffron Indian Cuisine, 1500 Mill Street, Ste. 104, Greensboro, NC 27408. Features a lunch buffet and fine Indian cuisine in the evening. Open Saturday and Sunday, noon to 3:00 p.m. and 5:00 p.m. to 10:00 p.m.

Taste of Thai, 1500 Mill Street, Suite 101, Greensboro, NC 27408. Features casual Thai food and a lunch buffet.

Open Saturday, 11:30 a.m. to 3:00 p.m. and 5:00 p.m. to 10:15 p.m., and Sunday, 11:30 a.m. to 3:00 p.m. and 5:00 p.m. to 9:45 p.m.

Registration and Meeting Information

Advance Registration

Advance registration for this meeting will open on **August 1, 2014**. Fees will be US$56 for AMS members, US$78 for nonmembers, and US$5 for students, unemployed mathematicians, and emeritus members.

Onsite Information and Registration

Onsite meeting registration, the AMS Exhibit and Book Sale, and all scientific sessions will take place in the School of Education Building (SOEB)1300 Spring Garden St., Greensboro, NC 27412. Registration will be located in the large lobby on the first floor in the southeast corner of the building. The book exhibit will be adjacent to the registration area in room 102. All Special Sessions and Invited Addresses will be located on the first and second floors of the SOEB. Computer labs will be provided for participants' use. UNCG has wireless Internet access throughout campus and also offers eduroam connectivity.

Fees are US$56 for AMS members, US$78 for nonmembers, and US$5 for students, unemployed mathematicians, and emeritus members. Fees are payable onsite via cash, check, or credit card; advance registration will open on the AMS website on August 1, 2014.

Special Needs

It is the goal of the AMS to ensure that its conferences are accessible to all, regardless of disability. The AMS will strive, unless it is not practicable, to choose venues that are fully accerssible to the physically handicapped.

If special needs accommodations are necessary in order for you to participate in an AMS Section Meeting, please communicate your needs in advance to the AMS Meetings Department by:

Registering early for the meeting

Checking the appropriate box on the registration form

Sending an email request to the AMS Meetings Department at mmsb@ams.org or meet@ams.org.

Other Activities

Book Sales: Stop by the on-site AMS bookstore and review the newest titles from the AMS, enjoy up to 25% off all AMS publications, or take home an AMS t-shirt! Complimentary coffee will be served courtesy of AMS Membership Services.

AMS Editorial Activity: An acquisitions editor from the AMS book program will be present to speak with prospective authors. If you have a book project that you would like to discuss with the AMS, please stop by the book exhibit.

Local Activities

There will be a reception in the Cone Ballroom at the Elliott University Center at 6:00 p.m. on Saturday, November 8. Hors d'oeuvres will be served.

Local Information, Maps, and Parking

This meeting will take place on the campus of the University of North Carolina at Greensboro. Maps are available at www.uncg.edu/online-map. Information about the Department of Mathematics and Statistics is available at http://math.uncg.edu.

Paid parking is available at the Oakland Avenue Parking Deck, across Spring Garden St. The cost is US$2 for the first hour, then US$1 per hour up to US$7 per day. Free parking is available in the lots on either side of Oakland Avenue near the parking garage. See the map at http://parking.uncg.edu/access/access.html?id=School of Education.

For additional information about UNCG, visit www.uncg.edu.

Travel

The University of North Carolina at Greensboro is located in Greensboro, NC. The Piedmont Triad Airport (GSO) is located approximately 10 miles north-northwest of the university; the address is 1000 A. Ted Johnson Pkwy., Greensboro, NC 27409. To get to the campus by taxi is a flat rate of US$25 (plus gratuity (Yellow United Taxi).

Driving to Greensboro: Greensboro is located in the center of North Carolina. Interstate 40 connects Greensboro with Raleigh and Asheville. Interstate 85 connects Greensboro to Charlotte and Durham. Customizable driving directions are available at http://parking.uncg.edu/access/access.html.

Driving to campus from the Airport: Exit the airport and follow signs toward Greensboro and Bryan Blvd. Continue approximately eight miles. Turn right on Aycock Street. From Aycock Street, turn left on Spring Garden. Destination is ahead on the left, at the corner of Spring Garden and Stirling. Park on the right in the surface lots or in Oakland Parking deck and walk across Spring Garden Street.

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) **04N30004**. 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$26 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

The month of November is characterized by rapidly falling daily high temperatures, with daily highs decreasing from 65°F to 55°F over the course of the month, exceeding 75°F or dropping below 43°F only one day in ten. Daily low temperatures range from 36°F to 44°F, falling below 25°F or exceeding 55°F only one day in ten. The average probability that some form of precipitation will be observed

in a given day is 37%, with little variation over the course of the month. Throughout November, the most common forms of precipitation are light rain and moderate rain. This information was gathered from weatherspark.com.

Information for International Participants

Visa regulations are continually changing for travel to the United States. Visa applications may take from three to four months to process and require a personal interview, as well as specific personal information. International participants should view the important information about traveling to the U.S. found at http://sites.nationalacademies.org/pga/biso/visas/ and http://travel.state.gov/visa/visa_1750.html. If you need a preliminary conference invitation in order to secure a visa, please send your request to 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.

* 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.

San Antonio, Texas

Henry B. Gonzalez Convention Center and Grand Hyatt San Antonio

January 10–13, 2015

Saturday – Tuesday

Meeting #1106

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: Expired
For abstracts: September 16, 2014

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/national.html.

Joint Invited Addresses

Jordan Ellenberg, University of Wisconsin-Madison, *Title to be announced* (AMS-MAA Invited Address).

Donald G. Saari, University of California, Irvine, *Title to be announced* (MAA-AMS-SIAM Gerald and Judith Porter Public Lecture).

Richard Tapia, Rice University, *Title to be announced* (AMS-MAA Invited Address).

AMS Invited Addresses

Ian Agol, University of California, Berkley, *Title to be announced.*

Henri Darmon, McGill University, *Title to be announced.*

Susan Holmes, Stanford University, *Title to be announced.*

Michael Hopkins, Harvard University, *Title to be announced* (AMS Colloquium Lectures, Lectures I, II, III).

Russell Lyons, Indiana University, *Title to be announced.*

Irena Peeva, Cornell University, *Title to be announced.*

Daniel A. Spielman, Yale University, *Title to be announced* (AMS Josiah Willard Gibbs Lecture).

AMS Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `http://jointmathematicsmeetings.org/meetings/abstracts/abstract.pl?type=jmm`.

Some sessions are cosponsored with other organizations. These are noted within the parenthesis at the end of each listing, where applicable.

Accelerated Advances in Multiobjective Optimal Control Problems and Mathematical Programming Based on Generalized Invexity Frameworks (Code: SS 4A), **N. J. Huang**, Sichuan University, **R. N. Mohapatra**, University of Central Florida, **Ram Verma**, Texas State University, and **Alexander Zaslavski**, Israel Institute of Technology.

Advances in Coding Theory (Code: SS 21A), **Felice Manganiello** and **Gretchen L. Matthews**, Clemson University, and **Judy L. Walker**, University of Nebraska.

Algebraic Combinatorics and Representation Theory (Code: SS 36A), **Zajj Daugherty**, Dartmouth College, and **Ben Salisbury**, Central Michigan University.

Applications of Dynamical Systems to Biological Models (Code: SS 18A), **Yu Jin**, University of Nebraska-Lincoln, and **Xiang-Sheng Wang**, Southeast Missouri State University (AMS-AAAS).

Beyond First-Order Model Theory (Code: SS 55A), **John T. Baldwin**, University of Illinois at Chicago, **Xavier Caicedo**, Universidad de los Andes, **Rami Grossberg**, Carnegie Mellon University, **Jose Iovino**, University of Texas at San Antonio, and **Boris Zilber**, Oxford University (AMS-ASL).

Classification Problems in Operator Algebras (Code: SS 47A), **Arnaud Brothier**, Vanderbilt University, **Ionut Chifan**, The University of Iowa, **Darren Creutz**, Vanderbilt University, **Remus Nicoara**, University of Tennessee, and **David Penneys**, University of Toronto.

Computing Intensive Modeling in Mathematical and Computational Biology (Code: SS 29A), **Timothy D. Comar**, Benedictine University, **Olcay Akman**, Illinois State University, and **Daniel Hrozencik**, Chicago State University.

Continued Fractions (Code: SS 43A), **James Mc Laughlin**, West Chester University, and **Nancy J. Wyshinski**, Trinity College.

Creating Coherence in K–12 Mathematics (Code: SS 50A), **Brigitte Lahme**, Sonoma State University, **William McCallum** and **Cody Patterson**, University of Arizona, **Kristin Umland**, University of New Mexico, and **Ellen Whitesides**, University of Arizona.

Current Trends in Classical Dynamical Systems (Code: SS 25A), **Lennard Bakker** and **Skyler Simmons**, Brigham Young University (AMS-AAAS).

Difference Equations and Applications (Code: SS 3A), **Steven Miller**, Williams College, and **Michael A. Radin**, Rochester Institute of Technology.

Differential Geometry and Statistics (Code: SS 45A), **Susan Holmes**, Stanford University.

Enumerative Combinatorics (Code: SS 30A), **Brian K. Miceli**, Trinity University, and **Jay Pantone** and **Vince Vatter**, University of Florida.

Ergodic Theory and Dynamical Systems (Code: SS 32A), **Mrinal Kanti Roychowdhury**, University of Texas-Pan American.

Factorization Theory and Its Applications (Code: SS 11A), **Nicholas Baeth**, University of Central Missouri, **Scott Chapman**, Sam Houston State University, **Jim Coykendall**, Clemson University, and **Alfred Geroldinger**, Karl Franzens University.

Fixed Point Theory and Applications (Code: SS 13A), **Clement Boateng Ampadu**.

Fractional, Stochastic, and Hybrid Dynamic Systems with Applications (Code: SS 5A), **John R. Graef**, University of Tennessee at Chattanooga, **G. S. Ladde**, University of South Florida, and **A. S. Vatsala**, University of Louisiana at Lafayette.

Frames and Their Applications (Code: SS 33A), **Radu Balan** and **Kasso Okoudjou**, University of Maryland, and **Rachel Ward**, University of Texas.

Geometries Defined by Differential Forms (Code: SS 38A), **Sergey Grigorian**, University of Texas-Pan American, **Sema Salur**, University of Rochester, and **Albert J. Todd**, University of California, Riverside.

Geosystems Mathematics (Code: SS 54A), **Willi Freeden**, University of Kaiserslautern, **Volker Michel**, University of Siegen, and **M. Zuhair Nashed**, University of Central Florida.

Graphs, Matrices, and Related Problems (Code: SS 23A), **Cheryl Grood** and **Thomas Hunter**, Swarthmore College, and **Sharon McCathern**, Azusa Pacific University.

Groups, Algorithms, and Cryptography (Code: SS 2A), **Bren Cavallo** and **Delaram Kahrobaei**, City University of New York Graduate Center.

Heavy-Tailed Distributions and Processes (Code: SS 52A), **U. Tuncay Alparslan** and **John P. Nolan**, American University.

History of Mathematics (Code: SS 24A), **Sloan Despeaux**, Western Carolina University, **Patti Hunter**, Westmont College, **Deborah Kent**, Drake University, and **Adrian Rice**, Randolph-Macon College (AMS-MAA).

Holomorphic Dynamics in One and Several Variables (Code: SS 51A), **Tanya Firsova**, State University of New York at Stony Brook and Kansas State University, and **Thomas Sharland**, State University of New York at Stony Brook.

Hopf Algebras and Tensor Categories (Code: SS 6A), **Susan Montgomery**, University of Southern California, **Siu-Hung Ng**, Louisiana State University and Iowa State University, and **Sarah Witherspoon**, Texas A&M University.

Inequalities and Quantitative Approximation (Code: SS 1A), **Feng Dai**, University of Alberta, and **Mourad E. H. Ismail**, University of Central Florida.

Inverse Problems (Code: SS 49A), **Peter Muller**, Rensselaer Polytechnic Institute, and **Kaitlyn Voccola**, Colorado State University.

Knot Theory (Code: SS 10A), **Tim Cochran** and **Shelly Harvey**, Rice University.

Limits of Discrete Structures (Code: SS 26A), **Peter Diao**, **Dominique Guillot**, **Apoorva Khare**, and **Bala Rajaratnam**, Stanford University.

Math Teachers Circles and the K–20 Continuum (Code: SS 41A), **Brian Conrey**, American Institute of Mathematics, **Michael Nakamaye** and **Kristin Umland**, University of New Mexico, and **Diana White**, University of Colorado at Denver.

Mathematics in Natural Resource Modeling (Code: SS 44A), **Shandelle M. Henson**, Andrews University, and **Catherine A. Roberts**, College of the Holy Cross.

Mathematics in Poland: Interbellum, World War II, and Immediate Post-War Developments (Code: SS 42A), **Mohammad Javaheri** and **Emelie A. Kenney**, Siena College.

Model Theory and Applications (Code: SS 48A), **David Marker**, University of Illinois at Chicago, **Sergei Starchenko**, University of Notre Dame, and **Carol Wood**, Wesleyan University.

Noncommutative Function Theory (Code: SS 16A), **Paul S. Muhly**, University of Iowa, and **Gelu F. Popescu**, University of Texas at San Antonio.

Operator Algebras and Their Applications: A Tribute to Richard V. Kadison (Code: SS 40A), **Robert S. Doran** and **Efton Park**, Texas Christian University.

Partitions, q-Series, and Modular Forms (Code: SS 37A), **Atul Dixit**, Tulane University, **Tim Huber**, University of Texas-Pan American, **Amita Malik**, University of Illinois, and **Ae Ja Yee**, Pennsylvania State University.

Positivity and Matrix Inequalities (Code: SS 35A), **Dominique Guillot**, **Apoorva Khare**, and **Bala Rajaratnam**, Stanford University.

Probability and Applications (Code: SS 34A), **Rick Kenyon**, Brown University, and **Russell Lyons**, Indiana University.

Progress in Multivariable Operator Theory (Code: SS 20A), **Ron Douglas**, Texas A&M University, and **Constanze Liaw**, Baylor University (AMS-AAAS).

Quantum Markov Chains, Quantum Walks, and Related Topics (Code: SS 7A), **Chaobin Liu**, Bowie State University, **Takuya Machida**, University of California, Berkeley, **Salvador E. Venegas-Andraca**, Tecnologicó de Monterrey, Campus Estado de México, and **Nelson Petulante**, Bowie State University.

Recent Advances in Discrete and Intuitive Geometry (Code: SS 31A), **Andras Bezdek**, Auburn University, **Ted Bisztriczky**, University of Calgary, and **Wlodek Kuperberg**, Auburn University (AMS-AAAS).

Recent Advances in the Analysis and Applications of Modern Splitting Methods (Code: SS 14A), **Abdul Q. M. Khaliq**, Middle Tennessee State University, **Qin Sheng**, Baylor University, and **Bruce Wade**, University of Wisconsin-Milwaukee.

Recent Developments in Algebraic Number Theory (Code: SS 9A), **Wen-Ching Winnie Li**, Pennsylvania State University, **Tong Liu**, Purdue University, and **Ling Long**, Iowa State University and Louisiana State University.

Research in Mathematics by Undergraduates and Students in Post-Baccalaureate Programs (Code: SS 17A), **Darren A. Narayan**, Rochester Institute of Technology, **Tamas Forgacs**, California State University Fresno, and **Jobby Jacob**, **Carl V. Lutzer**, and **Tamas Wiandt**, Rochester Institute of Technology (AMS-MAA-SIAM).

Ricci Curvature for Homogeneous Spaces and Related Topics (Code: SS 8A), **Megan Kerr**, Wellesley College, and **Tracy Payne**, Idaho State University.

Selmer Groups (Code: SS 53A), **Mirela Ciperiani**, University of Texas, and **Henri Darmon**, McGill University.

Set-Valued Optimization and Variational Problems with Applications (Code: SS 22A), **Akhtar A. Khan**, Rochester Institute of Technology, **Mau Nam Nguyen**, Portland State University, **Miguel Sama**, Universidad Nacional de Educacion a Distancia, Madrid, and **Christiane Tammer**, Martin-Luther-University of Halle-Wittenberg.

Studies in Interconnections among Parameters in Graph Theory, Combinatorics, and Discrete Geometry (Code: SS 39A), **Cong X. Kang** and **Eunjeong Yi**, Texas A&M University at Galveston.

Successes and Challenges in Teaching Mathematics (Code: SS 46A), **Ellina Grigorieva**, Texas Woman's University, and **Natali Hritonenko**, Prairie View A&M University.

Syzygies (Code: SS 27A), **Giulio Caviglia**, Purdue University, **Jason McCullough**, Rider University, and **Irena Peeva**, Cornell University.

The Scottish Book (Code: SS 15A), **Krystyna Kuperberg**, Auburn University, **R. Daniel Mauldin**, University of North Texas, and **Jan Mycielski**, University of Colorado.

Theory and Application of Reaction Diffusion Models (Code: SS 12A), **Jerome Goddard II**, Auburn University Montgomery, and **Ratnasingham Shivaji**, University of North Carolina Greensboro.

Topological Measures of Complexity: Inverse Limits, Entropy, and Structure of Attractors (Code: SS 28A), **Loribeth M. Alvin**, University of Denver, **Jan P. Boroński**, National Supercomputing Centre IT4Innovations, Ostrava, **James Keesling**, University of Florida, **Olga Lukina**, University of Illinois at Chicago, and **P. Oprocha**, AGH University of Science and Technology, Krakow.

What's New in Group Theory? (Code: SS 19A), **Arturo Magidin**, University of Louisiana at Lafayette, and **Elizabeth Wilcox**, Oswego State University.

Washington, District of Columbia

Georgetown University

March 7–8, 2015

Saturday – Sunday

Meeting #1107

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: January 2015
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: March 2015
Issue of *Abstracts*: Volume 36, Issue 2

Deadlines

For organizers: August 7, 2014
For abstracts: January 20, 2015

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Frederico Rodriguez Hertz, Pennsylvania State University, *Title to be announced.*

Nancy Hingston, The College of New Jersey, *Title to be announced.*

Simon Tavaré, Cambridge University, *Title to be announced* (Einstein Public Lecture in Mathematics).

Yitang Zhang, University of New Hampshire, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Conceptual Mathematical Models in Climate Science (Code: SS 5A), **Hans Engler** and **Hans Kaper**, Georgetown University.

Crossing Numbers of Graphs (Code: SS 3A), **Paul Kainen**, Georgetown University.

Qualitative Behavior of Solutions of Partial Differential Equations (Code: SS 7A), **Junping Shi**, College of William and Mary, and **Jiuyi Zhu**, John Hopkins University.

Quantum Algebras, Representations, and Categorifications (Code: SS 2A), **Sean Clark** and **Weiqiang Wang**, University of Virginia.

Spatial Evolutionary Models and Biological Invasions (Code: SS 6A), **Judith Miller**, Georgetown University, and **Yuan Lou**, Ohio State University.

Topology in Biology (Code: SS 4A), **Paul Kainen**, Georgetown University.

Within-Host Disease Modeling (Code: SS 1A), **Stanca Ciupe**, Virginia Polytechnic Institute, and **Sivan Leviyang**, Georgetown University.

East Lansing, Michigan

Michigan State University

March 14–15, 2015

Friday – Sunday

Meeting #1108

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: January 2015
Program first available on AMS website: January 29, 2015
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Volume 36, Issue 2

Deadlines

For organizers: August 26, 2014
For abstracts: January 20, 2015

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Philippe Di Francesco, University of Illinois, *Title to be announced.*

Alexander Furman, University of Illinois at Chicago, *Title to be announced.*

Vera Mikyoung Hur, University of Illinois at Urbana-Champaign, *Title to be announced.*

Mihnea Popa, University of Illinois at Chicago, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Approximation Theory in Signal Processing and Computer Science (Code: SS 5A), **Mark Iwen**, Michigan State University, **Rayan Saab**, University of California San Diego, and **Aditya Viswanathan**, Michigan State University.

Arithmetic of Hyperelliptic Curves (Code: SS 3A), **Tony Shaska**, Oakland University.

Complex Analysis in Several Variables and its Applications (Code: SS 11A), **Debraj Chakrabarti**, Central Michigan University, and **Yunus Zeytuncu**, University of Michigan at Dearborn.

Fractals and Tilings (Code: SS 10A), **Sze-Man Ngai**, Georgia Southern University, **Erin Pearse**, California Polytechnic State University, **Yang Wang**, Hong Kong University of Science and Technology, and **Yimin Xiao**, Michigan State University.

Fractional Calculus and Nonlocal Operators (Code: SS 1A), **Mark M. Meerschaert** and **Russell Schwab**, Michigan State University.

Groups and Representations (Code: SS 9A), **Amanda Schaeffer Fry** and **Jonathan Hall**, Michigan State University, and **Hung Nguyen**, University of Akron.

Homotopy Continuation Methods and Their Applications to Science and Engineering (Code: SS 6A), **Tianran Chen**, Michigan State University, and **Dhagash Mehta**, North Carolina State University.

New Developments in Stochastic Analysis, Stochastic Control and Related Fields (Code: SS 7A), **Chao Zhu**, University of Wisconsin-Milwaukee.

Phase Retrieval in Theory and Practice (Code: SS 8A), **Matthew Fickus**, Air Force Institute of Technology, **Mark Iwen**, Michigan State University, and **Dustin Mixon**, Air Force Institute of Technology.

Random Fields and Long Range Dependence (Code: SS 2A), **Mark M. Meerschaert** and **Yimin Xiao**, Michigan State University.

Stochastic Partial Differential Equations and Applications (Code: SS 4A), **Leszek Gawarecki**, Kettering University, and **Vidyadhar Mandrekar**, Michigan State University.

Huntsville, Alabama

University of Alabama in Huntsville

March 27–29, 2015

Friday – Sunday

Meeting #1109

Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: January 2015
Program first available on AMS website: February 11, 2015
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Volume 36, Issue 2

Deadlines

For organizers: August 20, 2014
For abstracts: February 4, 2015

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Eva Bayer-Fluckiger, EPFL, *Title to be announced.*

M. Gregory Forest, University of North Carolina at Chapel Hill, *Title to be announced.*

Dan Margalit, Georgia Institute of Technology, *Title to be announced.*

Paul Pollack, University of Georgia, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `http://www.ams.org/cgi-bin/abstracts/abstract.pl`.

Fractal Geometry and Ergodic Theory (Code: SS 1A), **Mrinal Kanti Roychowdhury**, University of Texas-Pan American.

New Developments in Population Dynamics and Epidemiology (Code: SS 4A), **Jia Li**, University of Alabama in Huntsville, **Maia Martcheva**, University of Florida, and **Necibe Tuncer**, Florida Atlantic University.

Recent Trends in Mathematical Biology (Code: SS 3A), **Wandi Ding** and **Zachariah Sinkala**, Middle Tennessee State University.

Stochastic Processes and Related Topics (Code: SS 2A), **Paul Jung**, University of Alabama at Birmingham, **Erkan Nane**, Auburn University, and **Dongsheng Wu**, University of Alabama in Huntsville.

Las Vegas, Nevada

University of Nevada, Las Vegas

April 18–19, 2015

Saturday – Sunday

Meeting #1110

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: February 2015
Program first available on AMS website: March 5, 2015
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Volume 36, Issue 2

Deadlines

For organizers: September 18, 2014
For abstracts: February 24, 2015

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Joel Hass, University of California, Davis, *Title to be announced.*

Ko Honda, University of California, Los Angeles, *Title to be announced.*

Brendon Rhoades, University of California, San Diego, *Title to be announced.*

Bianca Viray, Brown University, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `http://www.ams.org/cgi-bin/abstracts/abstract.pl`.

Data Analysis and Physical Processes (Code: SS 4A), **Hanna Makaruk**, Los Alamos National Laboratory, and **Eric Machorro**, National Security Technologies.

Inverse Problems and Related Mathematical Methods in Physics (Code: SS 1A), **Hanna Makaruk**, Los Alamos National Laboratory, and **Robert Owczarek**, University of New Mexico, Albuquerque.

Stochastic Analysis and Rough Paths (Code: SS 2A), **Fabrice Baudoin**, Purdue University, **David Nualart**, University of Kansas, and **Cheng Ouyang**, University of Illinois at Chicago.

Topics in Graph Theory: Structural and Extremal Problems (Code: SS 3A), **Jie Ma**, Carnegie Mellon University, **Hehui Wu**, Simon Fraser Univerisy, and **Gexin Yu**, College of William & Mary.

Porto, Portugal

University of Porto

June 10–13, 2015

Wednesday – Saturday

Meeting #1111

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 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

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/internmtgs.html.

Invited Addresses

Rui Loja Fernandes, University of Illinois at Urbana-Champaign, *Title to be announced*.

Irene Fonseca, Carnegie Mellon University, *Title to be announced*.

Annette Huber, Albert-Ludwigs-Universität, *Title to be announced*.

Mikhail Khovanov, Columbia University, *Title to be announced*.

André Neves, Imperial College London, *Title to be announced*.

Sylvia Serfaty, Université Pierre et Marie Curie Paris 6, *Title to be announced*.

Gigliola Staffilani, Massachusetts Institute of Technology, *Title to be announced*.

Marcelo Viana, Instituto de Matemática Pura e Aplicada, Brasil, *Title to be announced*.

Chicago, Illinois

Loyola University Chicago

October 3–4, 2015

Saturday – Sunday

Meeting #1112

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: June 2015
Program first available on AMS website: August 20, 2015
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Volume 36, Issue 4

Deadlines

For organizers: March 10, 2015
For abstracts: August 11, 2015

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Julia Chuzhoy, Toyota Technological Institute at Chicago, *Title to be announced*.

Andrew Neitzke, The University of Texas at Austin, *Title to be announced*.

Sebastien Roch, University of Wisconsin-Madison, *Title to be announced*.

Peter Sarnak, Princeton University, *Title to be announced* (Erdős Memorial Lecture).

Memphis, Tennessee

University of Memphis

October 17–18, 2015

Saturday – Sunday

Meeting #1113

Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: August 2015
Program first available on AMS website: September 3, 2015
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Volume 36, Issue 3

Deadlines

For organizers: March 17, 2015
For abstracts: August 25, 2015

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Mark van Hoeij, Florida State University, *Title to be announced*.

Vaughan Jones, Vanderbilt University, *Title to be announced*.

Mette Olufsen, North Carolina State University, *Title to be announced*.

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Computational Analysis (Code: SS 1A), **George Anastassiou**, University of Memphis.

Fractal Geometry and Dynamical Systems (Code: SS 2A), **Mrinal Kanti Roychowdhury**, University of Texas-Pan American.

Fullerton, California

California State University, Fullerton

October 24–25, 2015

Saturday – Sunday

Meeting #1114

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: August 2015
Program first available on AMS website: September 10, 2015
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: Volume 36, Issue 4

Deadlines

For organizers: March 27, 2015
For abstracts: September 1, 2015

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Mina Aganagic, University of California, Berkeley, *Title to be announced.*

John Lott, University of California, Berkeley, *Title to be announced.*

Eyal Lubetzky, Microsoft Research, Redmond, *Title to be announced.*

Zhiwei Yun, Stanford University, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Geometric Analysis (Code: SS 1A), **John Lott**, University of California, Berkeley, and **Aaron Naber**, Northwestern University.

New Brunswick, New Jersey

Rutgers University

November 14–15, 2015

Saturday – Sunday

Meeting #1115

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: September 2015
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: November 2015
Issue of *Abstracts*: Volume 36, Issue 4

Deadlines

For organizers: April 14, 2015
For abstracts: September 22, 2015

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Lee Mosher, Rutgers University, *Title to be announced.*

Jill Pipher, Rutgers University, *Title to be announced.*

David Vogan, Massachusetts Institute of Technology, *Title to be announced.*

Wei Zhang, Columbia University, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at http://www.ams.org/cgi-bin/abstracts/abstract.pl.

Applications of CAT(0) Cube Complexes (Code: SS 1A), **Sean Cleary**, City College of New York and the City University of New York Graduate Center, and **Megan Owen**, Lehman College of the City University of New York.

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

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.

Eastern Section: **Steven H. Weintraub**, Department of Mathematics, Lehigh University, Bethlehem, PA 18105-3174; e-mail: steve.weintraub@lehigh.edu; telephone: 610-758-3717.

Southeastern Section: **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:

2014

June 16–19	Tel Aviv, Israel	p. 809
September 20–21	Eau Claire, Wisconsin	p. 810
October 18–19	Halifax, Canada	p. 813
October 25–26	San Francisco, California	p. 817
November 8–9	Greensboro, North Carolina	p. 821

2015

January 10–13	San Antonio, Texas Annual Meeting	p. 825
March 7–8	Washington, DC	p. 827
March 14–15	East Lansing, Michigan	p. 828
March 27–29	Huntsville, Alabama	p. 829
April 18–19	Las Vegas, Nevada	p. 829
June 10–13	Porto, Portugal	p. 830
October 3–4	Chicago, Illinois	p. 830
October 17–18	Memphis, Tennessee	p. 830
October 24–25	Fullerton, California	p. 831
November 14–15	New Brunswick, New Jersey	p. 831

2016

January 6–9	Seattle, Washington Annual Meeting	p. 831

Important Information Regarding AMS Meetings

Potential organizers, speakers, and hosts should refer to page 99 in the January 2014 issue of the *Notices* for general information regarding participation in AMS meetings and conferences.

Abstracts

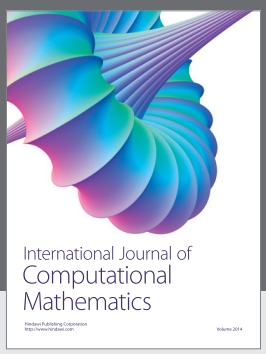
Speakers should submit abstracts on the easy-to-use interactive Web form. No knowledge of LaTeX is necessary to submit an electronic form, although those who use LaTeX may submit abstracts with such coding, and all math displays and similarily coded material (such as accent marks in text) must be typeset 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.

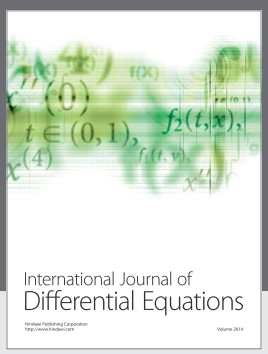
Conferences in Cooperation with the AMS: (see http://www.ams.org/meetings/ for the most up-to-date information on these conferences.)

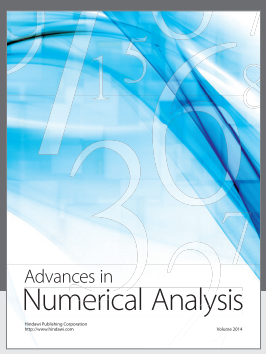
November 7–9, 2014: 7th International Conference on Science and Mathematics Education in Developing Countries, Mandalay University, Myanmar.

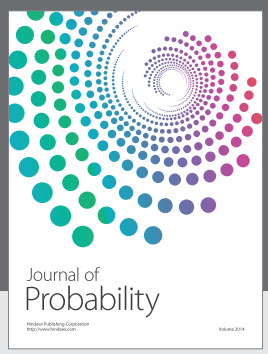
November 24–28, 2014: ICPAM-Goroka 2014: International Conference on Pure and Applied Mathematics, University of Goroka, Papua, New Guinea.

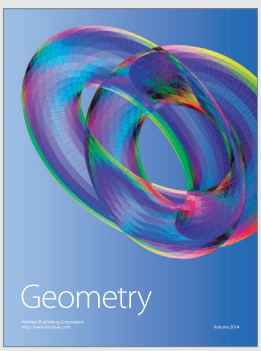
April 2–5, 2015: The Second International Conference on Mathematics and Statistics (AUS-ICMS '15). American University of Sharjah, United Arab Emirates.

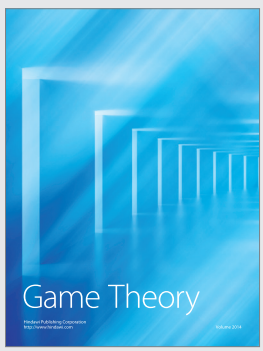


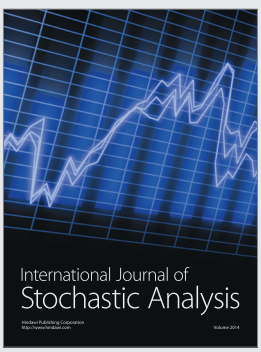


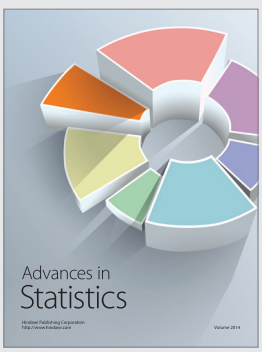


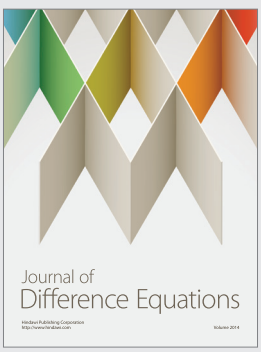


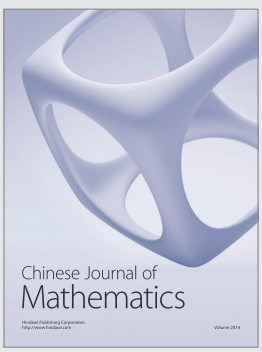


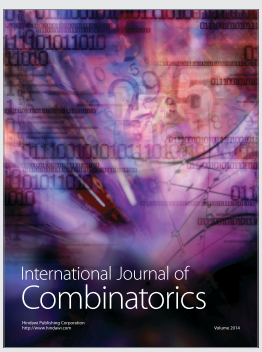


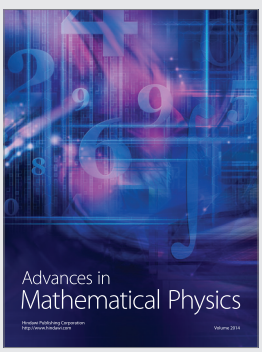


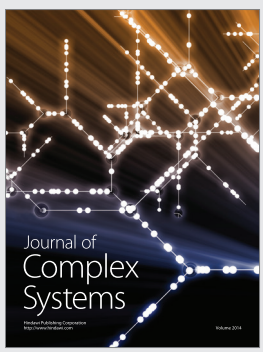












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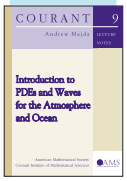
Book Releases in Fluid Mechanics

Applied Mathematics



Introduction to PDEs and Waves for the Atmosphere and Ocean

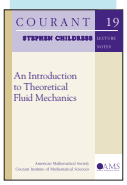
Andrew Majda, *New York University-Courant Institute of Mathematical Sciences, New York*

This book is written by a leading specialist at the Courant Institute of Mathematical Sciences, a world-renowned mathematical institute in applied atmosphere/ocean (AOS) science. The topic is extremely important in weather forecasting, a popular area of study. The book offers students an excellent introduction to partial differential equations and their applications to AOS for students, researchers, and applied mathematicians.

Titles in this series are co-published with the Courant Institute of Mathematical Sciences at New York University.

Courant Lecture Notes, Volume 9; 2003; 234 pages; Softcover; ISBN: 978-0-8218-2954-7; List US$36; AMS members US$28.80; Order code CLN/9

Applied Mathematics



An Introduction to Theoretical Fluid Mechanics

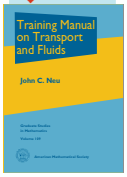
Stephen Childress, *New York University, Courant Institute of Mathematical Sciences, NY*

This overview of classical topics in fluid dynamics highlights the mathematical methods that have their origin in fluid theory. Areas discussed include the kinematics and dynamics of incompressible inviscid and Newtonian viscous fluids, as well as compressible flow. The notes are designed to prepare the reader for more specialized courses in fluid mechanics.

Titles in this series are co-published with the Courant Institute of Mathematical Sciences at New York University.

Courant Lecture Notes, Volume 19; 2009; 201 pages; Softcover; ISBN: 978-0-8218-4888-3; List US$31; AMS members US$24.80; Order code CLN/19

Applied Mathematics
TEXTBOOK



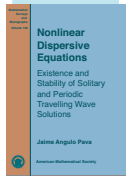
Training Manual on Transport and Fluids

John C. Neu, *University of California, Berkeley, CA*

This text presents elementary models of transport in continuous media and a corresponding body of mathematical technique. There is a strong emphasis on dimensional analysis and scaling, including a systematic process of scaling-based reductions that is not covered in other books on this subject. The book's problems are followed by detailed solutions emphasizing process and craftsmanship.

Graduate Studies in Mathematics, Volume 109; 2010; 265 pages; Hardcover; ISBN: 978-0-8218-4083-2; List US$59; AMS members US$47.20; Order code GSM/109

Applied Mathematics



Nonlinear Dispersive Equations

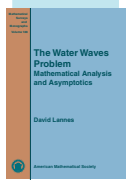
Existence and Stability of Solitary and Periodic Travelling Wave Solutions

Jaime Angulo Pava, *IME-USP, São Paulo, Brazil*

This book provides a self-contained presentation of classical and new methods for studying wave phenomena that are related to the existence and stability of solitary and periodic travelling wave solutions for nonlinear dispersive evolution equations. The author brings the reader to the forefront of knowledge about some aspects of the theory and motivates future developments in this fascinating and rapidly growing field.

Mathematical Surveys and Monographs, Volume 156; 2009; 256 pages; Hardcover; ISBN: 978-0-8218-4897-5; List US$79; AMS members US$63.20; Order code SURV/156

Applied Mathematics



The Water Waves Problem

Mathematical Analysis and Asymptotics

David Lannes, *Ecole Normale Supérieure et CNRS, Paris, France*

In spite of recent intense activity surrounding the water waves equations, there exists no self-contained reference dealing with the basic theory of these equations. The present volume admirably fills this gap in the literature by proposing a simple and robust framework that allows readers to address important issues raised by the water waves equations.

Mathematical Surveys and Monographs, Volume 188; 2013; 321 pages; Hardcover; ISBN: 978-0-8218-9470-5; List US$98; AMS members US$78.40; Order code SURV/188

Notices is Going Green!

So long, plastic wrapper! We are going green, which means you no longer have to unwrap and discard the plastic wrapper from your *Notices* copy. The *Notices* will now be mailed unwrapped (except if co-mailed with the *Bulletin*).

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