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Notices

of the American Mathematical Society

June/July 2006

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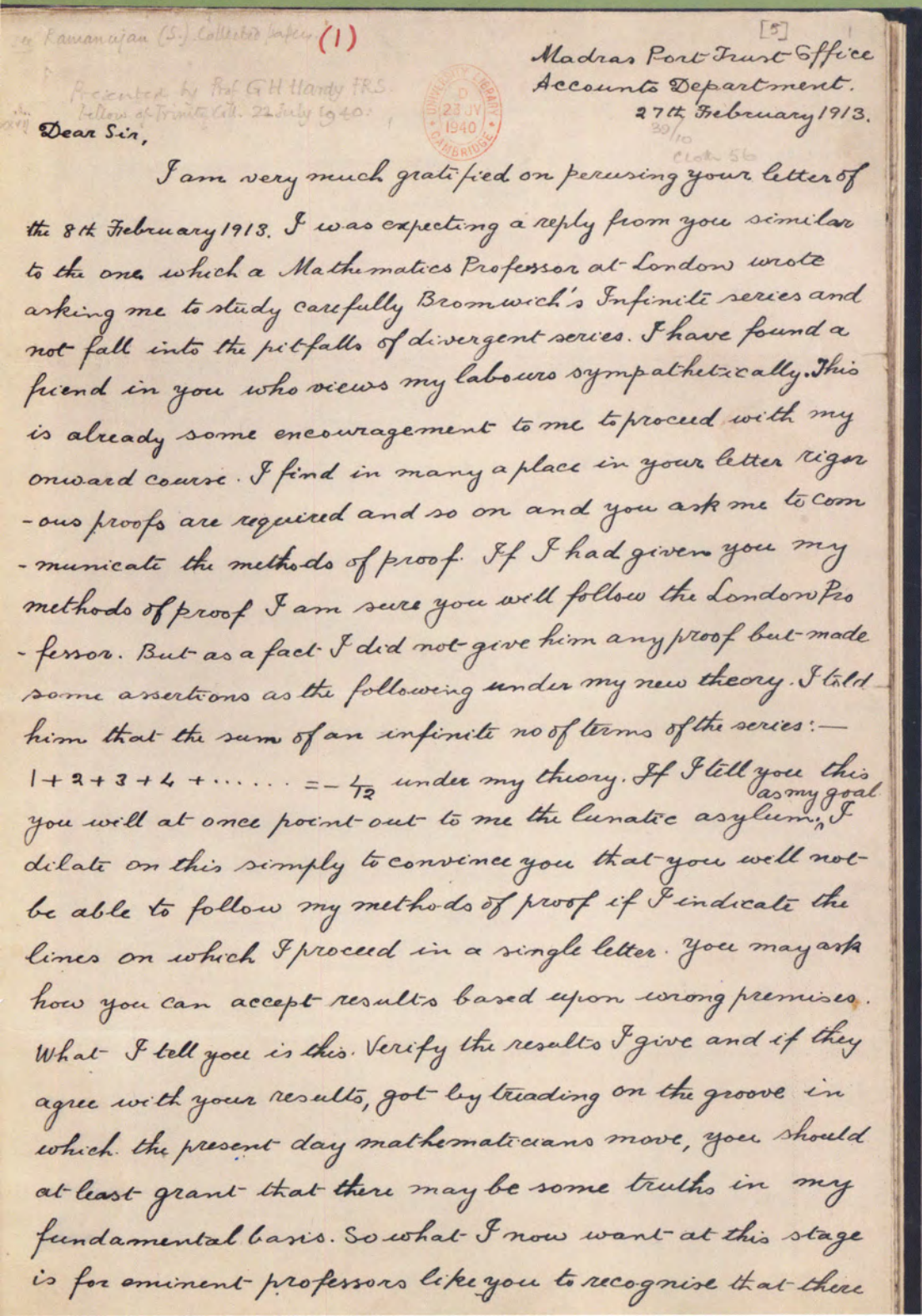

Ramanujan (S.) Collected papers (1)

Presented by Prof G H Hardy FRS. Fellow of Trinity Coll. 22 July 1940.

[5]

Madras Port Trust Office
Accounts Department.
27th February 1913.

Dear Sir,

I am very much gratified on perusing your letter of the 8th February 1913. I was expecting a reply from you similar to the one which a Mathematics Professor at London wrote asking me to study carefully Bromwich's Infinite series and not fall into the pitfalls of divergent series. I have found a friend in you who views my labours sympathetically. This is already some encouragement to me to proceed with my onward course. I find in many a place in your letter rigor-ous proofs are required and so on and you ask me to com-municate the methods of proof. If I had given you my methods of proof I am sure you will follow the London Pro-fessor. But as a fact I did not give him any proof but made some assertions as the following under my new theory. I told him that the sum of an infinite no of terms of the series:—

$1+2+3+4+\cdots\cdots = -\frac{1}{12}$ under my theory. If I tell you this as my goal you will at once point out to me the lunatic asylum. I dilate on this simply to convince you that you well not be able to follow my methods of proof if I indicate the lines on which I proceed in a single letter. You may ask how you can accept results based upon wrong premises. What I tell you is this. Verify the results I give and if they agree with your results, got by treading on the groove in which the present day mathematicians move, you should at least grant that there may be some truths in my fundamental basis. So what I now want at this stage is for eminent professors like you to recognise that there

Out of the groove (page 651)

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of the American Mathematical Society

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Commentary

Features

Notices

of the American Mathematical Society

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Departments

From the AMS Secretary

Business Week Looks at Mathematics

"In past decades, the marriage of higher math and computer modeling transformed science and engineering...But just look at where the mathematicians are now. They're helping to map out advertising campaigns, they're changing the nature of research in newsrooms and biology labs, they're enabling marketers to forge new one-on-one relationships with customers."

—*Business Week*, January 23, 2006

Mathematics landed on the cover of the January 23, 2006, issue of *Business Week* magazine.[1] The article describes how modern business is using mathematics in new ways, most of them centered on mining the vast data sets being created by the Internet, as more and more people work, shop, chat, read, and do many other daily tasks online. The epigraph above comes from one of the article's opening paragraphs. The article actually says little about what mathematicians are doing for "research in newsrooms and biology labs". One quotation in the article holds that "The next Jonas Salk will be a mathematician, not a doctor," but little is said about how mathematics is being used in medical research. Rather, the focus is on the use of mathematics in advertising and marketing.

The article acknowledges the somewhat eerie prospects the new uses of mathematics raise: "The power of mathematicians to make sense of personal data and model the behavior of individuals will inevitably continue to erode privacy." Some hazards of this "mathematical modeling of humanity" are discussed, but for the most part the article paints a cheery, all-systems-go picture of how mathematics is helping to pump up businesses' bottom lines. Google and Yahoo appear as prominent examples of how mathematics helps marketers pinpoint prospective customers by analyzing vast quantities of data about where people click or what words they enter into search engines. Another example is Harrah's Entertainment, which runs casinos. The company gathers information about how long gamblers bet and how much they have won or lost, together with personal information, "to target individuals with offers, from getaway weekends to gourmet dining, calculated to maximize returns." As proof that this really works, the article points out that Harrah's averaged 22 percent annual growth and that its stock price has tripled. "Yes, it's a magnificent time to know math," trumpets the article's final sentence.

Am I the only one who was bothered by this article? I work with the small AMS Public Awareness staff on modest efforts to try to get more coverage of mathematics in the popular press, so one part of me was thrilled to see mathematics as the cover story in a large-circulation magazine like *Business Week*. On the other hand, the article's message, that the new deployments of mathematics in advertising and marketing show that the field has truly *arrived*, left me dispirited. The idealism that is such a strong motivation in the development of mathematics is absent from the article.

The reason for *Business Week's* decidedly *un*idealistic portrait of mathematics is clear enough: *Business Week* reports on business and has little use for idealism. The magazine is certainly right to say that "it's a magnificent time to know math." But if you want to get anywhere near the heart of the subject, you cannot be motivated solely by the bottom line: You must have some sense of idealism, a feeling for truth and beauty. As Roger Penrose put it in his acceptance statement for the 2006 Communications Award from the Joint Policy Board for Mathematics, "one cannot really properly understand mathematics without having some kind of appreciation of its aesthetic qualities."

The *Business Week* piece is one among the nearly 1,200 articles that have been summarized in the AMS website feature "Math Digest". For ten years, the Math Digest has tracked articles and broadcasts about mathematics appearing in the popular media. The early coverage of the Math Digest is somewhat sparse, since initially I was the only one working on it, but today we have four other contributors: AMS Public Awareness Officers Mike Breen and Annette Emerson, and two former AMS Mass Media Fellows, Claudia Clark and Lisa Dekeukelaere. I believe the Math Digest is today the most comprehensive resource tracking English-language coverage of mathematics in the popular media. Over 200 articles and broadcasts appearing in 2005 are summarized in the Math Digest.

The Math Digest is one component of *Math in the Media*, an online magazine provided free on the Web by the AMS. *Math in the Media* carries "Tony's Take", a monthly commentary on coverage of mathematics in the media, written by Tony Phillips of Stony Brook University, as well as a "Reviews" page with pointers to reviews of books, plays, movies, and television shows related to mathematics. Also on the AMS website is the *Feature Column*, which each month provides a lively and accessible introduction to a mathematical topic, aimed at the general public. To find any of these resources, go to the *Math in the Media* webpage, `http://www.ams.org/mathmedia`.

—*Allyn Jackson*

[1] The *Business Week* article is available on the Web at `http://www.businessweek.com/magazine/content/06_04/b3968001.htm`.

Classical Truth

The truth seems more classical than we thought it was!

Without any compelling reason whatsoever, the Copenhageners of the 1920s assumed that the Schrödinger equation would describe a single system. In doing so they threw out the very possibility of having an ensemble statistics for which a universe of discourse could have been established. Ironically, a 1912 calculation by Planck, (*Theory of Heat Radiation*, Dover reprint, 1959, p.141), in which he shows how an ensemble of harmonic oscillators requires an average energy $h\nu/2$ per oscillator to maintain a state of optimal phase disorder, confirms this decision-liability for the Copenhagen doctrine. Planck's counterexample suffices to invalidate any need for calling on a nonclassical statistics, a proposition not really recognized as a valid mathematical concept.

Unlike Copenhagen doctrine, Planck graciously permits us to deal with a free-space not everywhere filled with infinite energy. So, by the grace of God, we are not living in an optimally disordered world of infinite zero-point energy, which is perhaps why not all of us have as yet collapsed under an apocalyptic load of infinite gravity. In the 1930s there arose a movement (Popper, Kemble, J. Groenewold) pleading to replace Copenhagen's single system by an ensemble proposition. Jammer (*Philosophy of Quantum Mechanics*, Wiley, NY, 1974) gave an incisive assessment of this initiative covering the West and Russia; unfortunately the initiative did not quite make the grade, because it left the nonclassical statistics intact.

The following conclusion is now unavoidable. Planck's calculation shows no compelling reason for taking recourse to this notion of a nonclassical statistics. Since that proposition has not found recognition as a basic mathematical concept, its use in basic physics is also undesirable. In light of such serious objections, the Copenhagen doctrine is urgently due for immediate and incisive interpretive revision.

Physical ramifications of the cited mathematical criticism are available in the public domain. Boston-Monograph BSPS 181 is suggested reading as a preliminary guide for removing conceptual wrinkles through a quantum reprogramming (E. J. Post, *Quantum Reprogramming*, Kluwer, Ac. Press, Dordrecht-Boston, 1995, (Springer, 2005); "Quantum reprogramming: A long overdue and least intrusive reality adaptation of the Copenhagen Interpretation", *Ann. Fond. Louis de Broglie*, Vol. 30, nos. 3–4, 2005, p. 325). It would seem more focus is needed in preventing this self-perpetuating nonclassical myth of the past from adversely affecting contemporary physical truth.

—E. J. Post
Westchester, CA
evertpost@aol.com

(Received March 13, 2006)

Don't Facilitate Military, Homeland Security Funding

This is an open letter to the AMS leadership.

We are extremely concerned that the Society not facilitate funding from the Department of Homeland Security to mathematicians. Many of their projects are based on dubious fear-based hypotheses, and some others are geared towards clear violations of personal freedoms.

The Society has no mandate for such activities. On the contrary, the membership voted in a referendum in 1988 on two motions calling on the Society to reduce the profession's dependence on military funding. The turnout was large, and the motions passed by healthy margins. The staff of the Society has never reported to the officers and members on their implementation of this policy, and indeed in recent years it seems to be no longer recognized. It was, however, never repealed, nor should it be.

We urge that military funding be avoided by mathematicians. The reasons are at least as strong now as in 1988: the so-called Anti-Missile Defense has been revealed ever more plainly as incapable of defending anything, and the country's military adventures are ever more flagrantly destructive. We also urge that the profession avoid funding from the Department of Homeland Security, which since its creation has been conspicuously bumbling. It is not defending national security but only spreading alarm and insecurity in the minds of the public.

We urge that the Society's staff and officers never facilitate contacts of mathematicians with military funders nor with the Department of Homeland Security.

In addition to the names below, this letter has also been signed by 49 other mathematicians. A complete list may be found at http://www.math.temple.edu/szyld/AMS_Letter.

—Chandler Davis
University of Toronto
davis@math.toronto.edu

—Mary W. Gray
American University

—Henry Helson
University of California Berkeley

—Michael Shub
University of Toronto

(Received March 20, 2006)

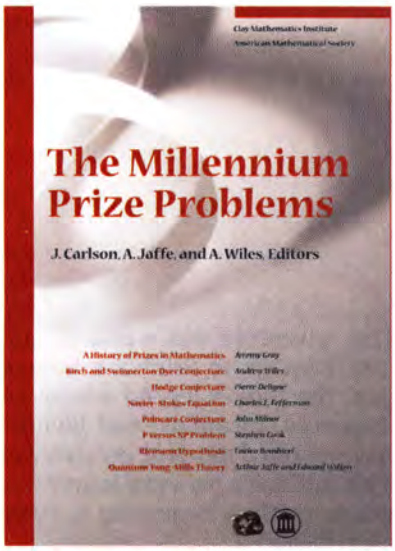
Short Story Set in Oberwolfach

Readers of the *Notices* may be interested in learning that Manil Suri has recently published a short story set in the Mathematics Institute at Oberwolfach. The story, "The Tolman Trick", deals with a Professor Tolman attending a conference at Oberwolfach, whose major result is suspected to be false by a young colleague. The atmosphere at Oberwolfach, the angst of Tolman, and some of the stress of math research, are well presented. In addition there is a lovely ending. The story is published in Issue 1 of a new literary magazine called *Subtropics*, whose website is http://www.english.ufl.edu/subtropics.

—Bruce Kellogg
rbmjk@alltel.net

(Received April 18, 2006)

A NEW JOINT PUBLICATION ARRANGEMENT WITH THE AMS AND THE CLAY MATHEMATICS INSTITUTE



The Millennium Prize Problems

James Carlson, *Clay Mathematics Institute, Cambridge, MA*, **Arthur Jaffe**, *Harvard University, Cambridge, MA*, and **Andrew Wiles**, *Institute for Advanced Study, Princeton, NJ*, Editors

This text describes the seven mathematical problems that represent the most important and challenging issues for mathematicians, and places these problems in a broader historical context. An essay on the history of prize problems in mathematics gives this text broad appeal among those interested in mathematics. The Millennium Prize Problems reflect the sponsoring Clay Mathematics Institute's goal of furthering the beauty and power of mathematical thinking.

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Honoring a Gift from Kumbakonam

Ken Ono

Today was an absolutely glorious day in Madison, Wisconsin. It is Christmas 2005, and everyone in the house is asleep after a long day of enjoying family, opening presents, and eating enormous portions of mashed potatoes and yule log cake. Yet powerful images keep me awake.

Thirty-six hours ago I returned from a six-day whirlwind journey to a far-off place. I spent forty hours on airplanes, and I endured fourteen hours in cars dodging bicycles, rickshaws, cows, goats, and masses of people on roads severely damaged by recent flooding. These floods would be blamed[1] for at least forty-two deaths. Despite these hardships and bad luck, this adventure exceeded my lofty expectations.

Bust of Srinivasa Ramanujan by artist Paul Granlund.

I ostensibly travelled to Kumbakonam with the purpose of giving a lecture on mock theta functions and Maass forms at the International Conference on Number Theory and Mathematical Physics at SASTRA University. I could have offered other worthy pretexts: I wanted to see my student Karl Mahlburg give his first plenary lecture. I wanted to applaud my friends Manjul Bhargava and Kannan Soundararajan (he goes by Sound) as they won a prestigious prize. However, my primary reason was personal, not professional. This adventure was a pilgrimage to pay homage to Srinivasa Ramanujan, the Indian legend whose congruences, formulas, and identities have inspired much of my own work. This fulfilled a personal journey, one with an unlikely beginning in 1984.

The Story of Ramanujan

Ramanujan was born on December 22, 1887, in Erode, a small town about 250 miles southwest of Chennai (formerly known as Madras). He was a *Brahmin*, a member of India's priestly caste, and as a consequence he lived his life as a strict vegetarian.

When Ramanujan was one year old, he moved to Kumbakonam, a small town about 170 miles south of Chennai, where his father Srinivasa was a cloth merchant's clerk. Kumbakonam, which is situated on the banks of the sacred Kaveri River, was (and remains today) a cosmopolitan center of the rural Indian district of Tanjore in the state of Tamil Nadu. Thanks to the area's rich soil and tropical climate, rice and sugar cane crops thrive. In Ramanujan's day, Kumbakonam had a population of fifty thousand.

Kumbakonam is one of India's sacred Hindu towns. It boasts seventeen Hindu temples (eleven honoring the Hindu god Lord Siva, and six honoring the god Lord Vishnu). The town is perhaps most well-known for its Mahamaham Festival, which is held every twelve lunar years when the Sun enters the constellation of Aquarius and Jupiter enters Leo. Nearly one million Hindu pilgrims descend on Kumbakonam for the festival. In a ritual

Ken Ono is the Solle P. and Margaret Manasse Professor of Letters and Science at the University of Wisconsin, Madison. His email address is ono@math.wisc.edu.

[1] *This was reported in* The Hindu *on December 20, 2005.*

meant to absolve sins, pilgrims bathe in the Mahamaham tank, which symbolizes the waters of India's holy rivers.

As a young boy, Ramanujan was a stellar student. He entered Town High School in 1898, and he would go on to win many awards there. He was a strong student in all subjects, and he stood out as the school's best math student. His life took a dramatic turn when a friend loaned him the Government College library's copy of G. S. Carr's *Synopsis of Elementary Results in Pure Mathematics.* G. H. Hardy, the celebrated Cambridge professor, later described (see page 3 of [17]) the book as

> ...the "synopsis" it professes to be. It contains enunciations of 6,165 theorems, systematically and quite scientifically arranged, with proofs which are often little more than cross-references...

Ramanujan became addicted to mathematics research, and he recorded his findings in notebooks, imitating Carr's format. He typically offered no proofs of any kind. Based on his education, he presumably did not understand the obligation mathematicians have for justifying their claims with proofs.

Thanks to his exemplary performance at Town High School, Ramanujan won a scholarship to Government College. However, by the time he enrolled there in 1904, his addiction to mathematics made it impossible for him to focus on schoolwork. He unceremoniously flunked out. He would later get a second chance, a scholarship to attend Pachaiyappa's College in Madras. However, mathematics again kept him from his schoolwork, and he flunked out a second time.

By 1907, the gifted Ramanujan was an academic failure. There was no room for him in India's system of higher education. Despite his failures, his friends and parents supported him. They must have recognized his genius, for they allowed him to work on mathematics unabated. Vivid accounts portray Ramanujan hunched over his slate on the porch of his house and in the halls of Sarangapani Temple, working feverishly.

> ....Ramanujan would sit working on the pial (porch) of his house on Sarangapani Street, legs pulled into his body, a large slate spread across his lap, madly scribbling, ...When he figured something out, he sometimes seemed to talk to himself, smile, and shake his head with pleasure.
>
> R. Kanigel (see page 67 of [20])

It is said (for example, [3, 20]) that Ramanujan believed that his findings were divine, told to him in dreams by Namagiri, the goddess of Namakkal.

In July 1909, Ramanujan married nine-year-old S. Janaki Ammal; it was an arranged marriage. After a short stay with Ramanujan and his family, Janaki returned to her home to learn domestic skills and pass time until she reached puberty. Ramanujan moved to Madras in 1911 and Janaki joined him in 1912 to begin their married life. To support them, Ramanujan took a post as a clerk in the accounting department of the Madras Port Trust.

Ramanujan continued his research in near isolation. His job at the Port Trust provided a salary and left time for mathematics. Despite these circumstances, his frustration mounted. Although some Indian patrons acknowledged his genius, he was unable to find suitable mentors. Indian mathematicians did not understand his work.

After years of such frustration, Ramanujan boldly wrote distinguished English mathematicians. He first wrote H. F. Baker, and then E. W. Hobson, both times without success. His letters consisted mostly of bare statements of formal identities, recorded without any indication of proof. Due to his lack of formal training, he claimed some known results as his own, and he offered others, such as his work on prime numbers, which were plainly false. In this regard, Hardy would later write (see page xxiv of [16]):

> Ramanujan's theory of primes was vitiated by his ignorance of the theory of a complex variable. It was (so to say) what the theory might be if the Zeta-function had no complex zeroes. ...Ramanujan's Indian work on primes, and on all the allied problems of the theory, was definitely wrong.

Ramanujan's work on Bernoulli numbers, which he presumably included in his letters, also includes an incredible mistake involving explicit numbers. The Bernoulli numbers [23] are the rational numbers $B_2 = 1/6, B_4 = 1/30, \ldots$ defined[2] by

$$x \cot x = 1 - \frac{B_2}{2!}(2x)^2 - \frac{B_4}{4!}(2x)^4 - \frac{B_6}{6!}(2x)^6 - \cdots.$$

Ramanujan falsely conjectured (see equation (14) of [23]) that if n is a positive even number, then the numerator of B_n/n, when written in lowest terms, is prime.[3] This conjecture is false, as is plainly seen by

$$\frac{B_{20}}{20} = \frac{174611}{6600} = \frac{283 \times 617}{2^3 \times 3 \times 5^2 \times 11}.$$

[2] *This is a slight departure from the modern definition of the Bernoulli numbers b_{2n}. These numbers are related by the relation $B_{2n} = (-1)^{n+1} b_{2n}$.*

[3] *Ramanujan obviously considered 1 to be a prime for this conjecture.*

In fact, among the even numbers n less than 2000, Ramanujan's conjecture holds only for the twenty numbers

$$2, 4, 6, 8, 10, 12, 14, 16, 18, 26, 34, 36,$$
$$38, 42, 74, 114, 118, 396, 674, 1870.$$

In view of these facts, it is not surprising that Baker and Hobson dismissed him as a crank.

Then on January 16, 1913, Ramanujan wrote G. H. Hardy, a thirty-five year old analyst and number theorist at Cambridge University. With his letter he included nine pages of mathematical scrawl. C. P. Snow elegantly recounted (see pages 30-33 of [18]) Hardy's reaction to the letter:

> One morning in 1913, he (Hardy) found, among the letters on his breakfast table, a large untidy envelope decorated with Indian stamps. When he opened it...he found line after line of symbols. He glanced at them without enthusiasm. He was by this time...a world famous mathematician, and...he was accustomed to receiving manuscripts from strangers. ...The script appeared to consist of theorems, most of them wild or fantastic... There were no proofs of any kind... A fraud or genius? ...is a fraud of genius more probable than an unknown mathematician of genius? ...He decided that Ramanujan was, in terms of...genius, in the class of Gauss and Euler...

Hardy could have easily dismissed Ramanujan like Baker and Hobson before him. However, to his credit he (together with Littlewood) carefully studied Ramanujan's scrawl and discovered hints of genius. In response to Ramanujan's letter, Hardy invited Ramanujan to Cambridge for proper training. Although Hindu beliefs forbade such travel at the time, we are told that Komalatammal, Ramanujan's mother, had a vision from the Hindu Goddess Namagiri giving Ramanujan permission to accept Hardy's invitation. Ramanujan accepted, and he left his life in south India for Cambridge, home of some of the world's most distinguished scientists and mathematicians. He arrived on April 14, 1914.

Over the course of the next five years, Ramanujan would publish extensively on a wide variety of topics: the distribution of prime numbers, hypergeometric series, elliptic functions, modular forms, probabilistic number theory, the theory of partitions and q-series, among others. He would write over thirty papers, including seven with Hardy. After years of frustration working alone in India, Ramanujan was finally recognized for the content of his mathematics. He was named a Fellow of Trinity College, and he was elected a Fellow of the Royal Society (F.R.S.), an honor shared by Sir Isaac Newton. News of his election spread quickly, and in India he was hailed as a national hero.

Ramanujan grew ill towards the end of his stay in England. One of the main reasons for his declining health was malnutrition. He was a vegetarian living in World War I England, a time when almost no one else was a vegetarian. Ramanujan also struggled with the severe change in climate; he was not accustomed to English weather. He did not have (or did not wear) appropriate clothes to protect himself from the elements. These conditions took their toll, and Ramanujan became gravely ill. He was diagnosed with tuberculosis. More recently, hepatic amoebiasis [4, 29], a parasitic infection of the liver, has been suggested as the true cause of his illness.

Hardy would visit the bedridden Ramanujan at a nursing home in Putney, a village a few miles from London on the south bank of the Thames.

> It was on one of those visits that there happened the incident of the taxi cab number...He went into the room where Ramanujan was lying. Hardy, always inept about introducing a conversation, said, probably without a greeting, and certainly as his first remark: "I thought the number of my taxi cab was 1729. It seemed to me rather a dull number." To which Ramanujan replied: "No, Hardy! No, Hardy! It is a very interesting number. It is the smallest number expressible as the sum of two cubes in two different ways."
>
> C. P. Snow (see page 37 of [18])

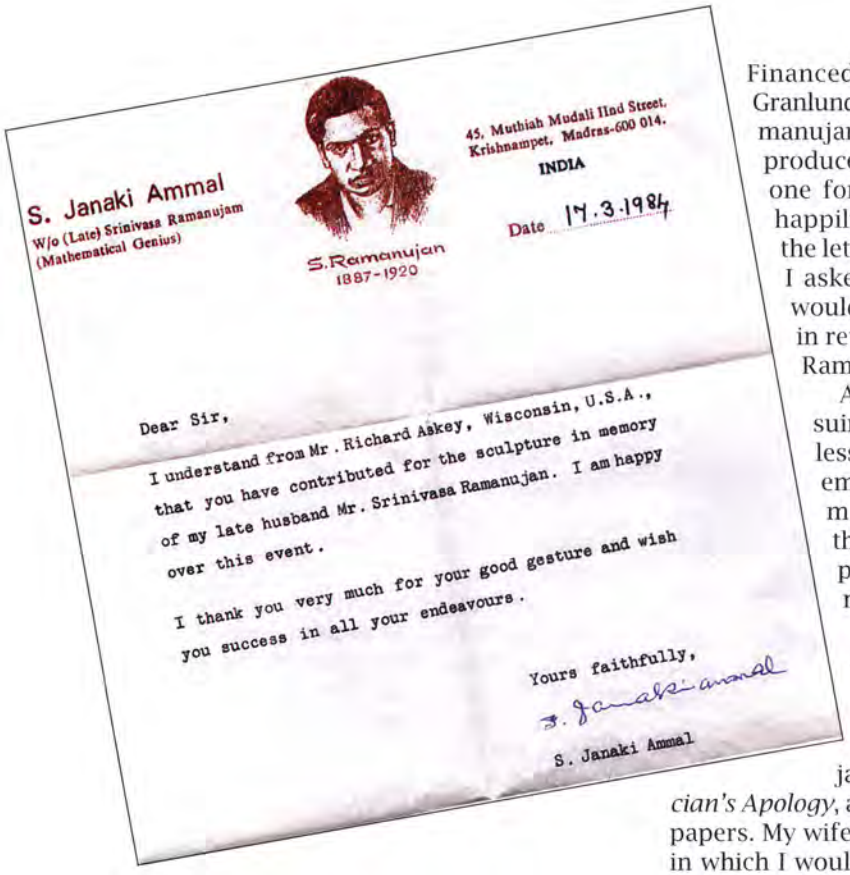
Indeed, we have

$$1729 = 1^3 + 12^3 = 10^3 + 9^3.$$

In the spring of 1919, Ramanujan returned to south India where he spent the last year of his life seeking health care and a forgiving climate. His health declined over the course of the following year, and he died on April 26, 1920, in Madras, with Janaki by his side. He was thirty-two years old.

My Pilgrimage

I first heard the story of Ramanujan when I was a reticent teenager obsessed with bicycle racing. It was a beautiful spring day in 1984, and my mind was on an important bicycle race in Washington D.C. when a letter adorned with Indian stamps arrived. The letter was dated 17-3-1984, and it was carefully typewritten on delicate rice paper. My father, Takashi Ono, a number theorist at Johns Hopkins University, was deeply moved by the letter which read [22]:



S. Janaki Ammal
W/o (Late) Srinivasa Ramanujam
(Mathematical Genius)

S.Ramanujan
1887-1920

45, Muthiah Mudali IInd Street,
Krishnampet, Madras-600 014.
INDIA

Date 14.3.1984

Dear Sir,

I understand from Mr. Richard Askey, Wisconsin, U.S.A., that you have contributed for the sculpture in memory of my late husband Mr. Srinivasa Ramanujan. I am happy over this event.

I thank you very much for your good gesture and wish you success in all your endeavours.

Yours faithfully,

S. Janaki Ammal

S. Janaki Ammal

Dear Sir,

I understand from Mr. Richard Askey, Wisconsin, U.S.A., that you have contributed for the sculpture in memory of my late husband Mr. Srinivasa Ramanujan. I am happy over this event.

I thank you very much for your good gesture and wish you success in all your endeavours.

Yours faithfully,

Signed S. Janaki Ammal

My father explained that Dick Askey, a mathematician at the University of Wisconsin at Madison, had organized an effort, on behalf of the mathematicians of the world, to commission a sculpture of Ramanujan. This initiative was in response to an interview[4] with Janaki Ammal, Ramanujan's widow. She lamented,

> They said years ago a statue would be erected in honor of my husband. Where is the statue?

[4] *From the article "Where is the statue?" in the June 21, 1981, issue of the* Hindu.

Financed by Askey's efforts, artist Paul Granlund rendered a sculpture based on Ramanujan's 1919 passport photo, and he produced eleven bronze casts, including one for Ramanujan's widow. My father happily contributed US$25, and hence the letter. Upon hearing this explanation, I asked, "Who was Ramanujan?" "Why would you give $25 expecting nothing in return?" That was when I first heard Ramanujan's story.

At the time, I had no plan of pursuing a career in mathematics, much less one involving Ramanujan's mathematics. As it was, the romantic tale made a lasting impression, and, thanks to my choice of career and the passage of time, has become one of my favorite stories.

Seven days ago I eagerly boarded a flight from Madison beginning my pilgrimage to Kumbakonam. In anticipation, I reread Kanigel's popular biography of Ramanujan [20] and Hardy's *A Mathematician's Apology*, among countless other articles and papers. My wife Erika gave me a beautiful journal in which I would go on to record pages of notes. Despite these preparations, I was unsettled. The long flights amplified these feelings. What was I looking for? After all, I did not expect to find a lost notebook, or acquire divine inspiration allowing me to prove famous open conjectures. I struggled with this question, and I ultimately decided that I should not ask it. I was content with the idea of simply paying homage to a great mathematician, one whose legend and work had become intertwined with the fabric of my life.

Despite my resolution, I was still bothered by two quotes from Hardy's 1936 Harvard tercentenary lectures on Ramanujan. He asserted (see page 4 of [17]),

> I am sure that Ramanujan was no mystic and that religion, except in a strictly material sense, played no important part in his life.

Could this be true? He also proclaimed (see page 5 of [17]),

> There is quite enough about Ramanujan that is difficult to understand, and we have no need to go out of our way to manufacture mystery.

Is it possible to rationally explain the legend of Ramanujan?

I arrived in Chennai at 8:45 a.m. on December 19, 2005, on a flight from Mumbai. The effects of several days of heavy rain were inescapable. South

The highway from Chennai to Kumbakonam.

India was devastated by severe flooding. How would these conditions impact the 170-mile drive from Chennai to Kumbakonam that was scheduled for the afternoon?

I was shuttled across town to a local hotel where many of the invited speakers and their guests had gathered. There I enjoyed a quick lunch and a refreshing hot shower. Around 1:30 p.m. we departed for Kumbakonam in a minivan kindly provided by SASTRA University. The other mathematicians on board were Krishnaswami Alladi, Alexander Berkovich, Manjul Bhargava, Mira Bhargava (Manjul's mother), and Evgeny Mukhin.

The first hour of our journey was uneventful. In steady rain, we barely poked along in Chennai traffic snarled by auto-rickshaws, bicycles, livestock, and masses of people (many without footwear). Then out of the blue we found ourselves on India's celebrated national highway. Begun in 1991, the national highway program is a component in India's plan to advance its economy by improving infrastructure. The highway is distinctly Indian. Goats and cows appear at regular intervals, and people cross lanes of traffic on foot without fear. Imagine cows feeding on the grass on the median of a divided highway! Our speed rarely exceeded 45 miles per hour. The section of highway was quite short (perhaps 30 miles), and the balance of the route covered brutally rough roads. Some sections were so savage that we literally bobbed from rut to rut. I did my best to enjoy the sight of the beautiful lush green rice paddies and sugar cane fields as we bounced down the flood-ravaged road. Needless to say, the Sterling Resort, a rustic Indian-style hotel, was a welcome sight when we arrived at 9:00 p.m. The warm hotel staff draped lovely garlands around our necks and imprinted red *tilaks* on our foreheads. The glasses of rose water and foot massages which followed were perfect elixirs for such a grueling ride.

Arabinda Mitra (Indo-U.S. Forum Chair), Kannan Soundararajan, Manjul Bhargava, and Krishnaswami Alladi after the prize ceremony.

The next morning, after an exquisite breakfast of masala dosa, one of my favorite south Indian dishes, we boarded the minivan for the short drive to SASTRA University, the site of the International Conference on Number Theory and Mathematical Physics and home of the Srinivasa Ramanujan Centre. The day began with the awarding of the first SASTRA Ramanujan Prize, a prestigious international award recognizing research by young mathematicians (under the age of 32) working in areas influenced by Ramanujan. Arabinda Mitra, the executive director of the Indo-U.S. Science and Technology Forum, and Krishnaswami Alladi, the chair of the prize committee, jointly awarded Manjul Bhargava (Princeton University) and Kannan Soundararajan (University of Michigan) the prize for their respective works in number theory. The dazzling ceremony included the lighting of a stunning brass lamp, traditional Indian songs, and a passionate speech by Mitra announcing new scientific Indo-U.S. ventures. The majestic ceremony was a fitting amalgamation of Indian tradition with promising visions of the future. The spectacle was breathtaking: two young stars lauded in the name of Ramanujan in his hometown.

After a full slate of lectures, we were driven to two sacred sites: Ramanujan's childhood home and Sarangapani Temple. We first visited Ramanujan's home on Sarangapani Sannidhi Street. The one-story stucco house, which sits inconspicuously among a row of shops, is a source of national pride. In 2003, Abdul Kalam, the president of India, named it the "House of Ramanujan", and he dedicated it as a national museum.

The house does not possess any striking features. In the front there is a small porch, one of Ramanujan's favorite places to do mathematics. We took many photos of the porch, and we tried to imagine the sight of Ramanujan calculating power series there as a young boy. I spent the next half hour pacing through the tiny house which consists

Manjul Bhargava, left, and Ken Ono in front of Ramanujan's house.

of two rooms and a kitchen. The very small bedroom is immediately on your left as you enter through the front door, and its only distinguishing features are a window facing the street, and an old-fashioned bed occupying nearly half of the floor space. The exhibits in the museum are modestly displayed in the main room, and they include a bust of Ramanujan decorated with garlands. There was a beautiful *kolam* in front of the bust, an intricate floral-like symmetric design on the floor fashioned out of rice flour. These designs are replaced by careful hands daily, and they are meant to distract one's attention from beautiful objects thereby minimizing *dhrishti*, the effect of jealous eyes. Behind Ramanujan's house there is a tiny courtyard with an old well.

Two blocks away, the Sarangapani Temple towers over Ramanujan's neighborhood. There Ramanujan and his family regularly offered prayers to the Hindu god Lord Vishnu. There are accounts of Ramanujan working on mathematics in its great halls.

> Here, to the sheltered columned coolness, Ramanujan would come. Here, away from the family, protected from the high hot sun outside, he would sometimes fall asleep in the middle of the day, his notebook, with its pages of mathematical scrawl, tucked beneath his arm, the stone slabs of the floor around him blanketed with equations inscribed in chalk.
>
> R. Kanigel (see pages 29-30 of [20])

The brilliant orange hue of the sun's rays encircling the colossal structure, like the corona of the sun, beckoned us from the porch of Ramanujan's house. The temple, built mostly between the 13th and 17th centuries, is a twelve-storied superstructure constructed from stone brought from the north by elephants. The temple is tetragonal, and its outer walls are completely covered with colorful ornate carvings depicting countless Hindu legends.

After we passed beneath the *gopuram*, the temple gate, dozens of bats circled above us against the dim lit sky. A few steps away, there were several cows chomping on hay. The interior of the temple is a stunning labyrinth of sculptures, stone columns, brass walls, flickering lights and candles, and brass pillars. The walls are completely covered with ornate metalwork and stone carvings. Honoring Hindu tradition, we stepped barefoot over the stone floor in a clockwise direction. Along our path we passed dozens of *kolam* floor designs. The air was warm and muggy, and heavy with the scent of incense. The main central shrine is a monolith resembling a chariot drawn by horses and elephants.

Beyond the monolith lies the inner sanctum, protected by a pair of ancient bulky wooden doors covered with bells. The inner sanctum, bursting with silver and bronze vessels, is the bronze-walled resting place of Lord Vishnu. Krishnaswami Alladi and his wife, Mathura, called us into the inner sanctum and made offerings of coconuts and vegetables to Lord Vishnu via the Hindu priests. I understood that Alladi arranged for us to be blessed in an impassioned *pooja*, or prayer ceremony.

As we made our way out of the temple, I came upon a small set of steps that led to a stone cubbyhole containing the statue of a Hindu god flanked

Sarangapani Temple.

Portrait of a young Ramanujan at Town High School.

by melted candles. This nook took my breath away; its stone walls were covered by numbers scrawled in charcoal. I was so pleased; how appropriate for Ramanujan's temple to be covered with numbers! Sound's father, Soundararajan Kannan, explained that it is not unusual for Hindus to etch important numbers when making offerings. Some numbers were birthdates, while others appeared to be telephone numbers. As I surveyed the numbers, I excitedly searched for 1729, the taxi cab number. I never spotted it, but to my amazement I found

$$2719$$

prominently etched at eye level. For me this number plays a special role in the lore of Ramanujan, not only as a permutation of the digits of 1729, but for its connection to his work on quadratic forms. In 1997 Sound and I proved [21], assuming the Generalized Riemann Hypothesis, that 2719 is the largest odd number not represented by Ramanujan's ternary quadratic form

$$x^2 + y^2 + 10z^2.$$

I was delighted to see it near where Ramanujan worked a century ago.

The next day provided another full slate of talks. My student Karl gave a superb talk on his research on the Andrews-Garvan-Dyson "crank" and its role in describing Ramanujan's partition congruences. I gave my lecture on mock theta functions and Maass forms. Later we boarded the minivan for further sightseeing. We visited Town High School, where Ramanujan excelled before his addiction to mathematics, and Government College, the first college to flunk Ramanujan.

Just before I had left the U.S., I spoke with Bruce Berndt, a professor at the University of Illinois and acclaimed Ramanujan expert. From him I learned that I could see the original copy of Carr's book, the one that Hardy said (see page 3 of [17]) "awakened his [Ramanujan's] genius". When Berndt last visited Kumbakonam, the book was on display in the library at Government College. After this conversation, I imagined flipping through the pages (if allowed) for evidence of Ramanujan's handiwork. Perhaps I would discover elegant formulas delicately noted in the margin of the book.

Shortly after we set foot on campus, I heard the devastating news. The book was lost. My disappointment quickly turned to anger. How does one lose such a prominent artifact, one which is central to the story of Ramanujan? As I write this, I now prefer to think that the book is not lost, but borrowed by a connoisseur who adores it, much like an art collector might cherish masterpieces bought on the black market. When it reappears, I hope it finds its way to the House of Ramanujan.

After the short visit to Government College, we made our way to Town High School, site of Ramanujan's first academic successes. We arrived after classes had ended for the day. The school is an impressive two-story building with arched balconies and a lush tropical courtyard. My spirits were quickly lifted by A. Ramamoorthy and S. Krishnamurthy, two of the school's teachers. They kindly gave us an entertaining tour of campus, which included a stop in *Ramanujam Hall*,[5] a cavernous room dedicated to the memory of Ramanujan. The teachers also proudly displayed copies of awards that Ramanujan won as a top student. I was deeply moved by the pride with which they shared their campus and revelled in the story of Ramanujan. Their passion confirms that Ramanujan's status as a national hero endures today.

Near the end of our visit, Ramamoorthy revealed that he teaches English, and as a student was never very good at math. He timidly asked whether I could explain any of Ramanujan's work to him, and based on his facial expression it was clear he expected a negative answer. I was thrilled by the challenge, and I found a chalkboard and explained Ramanujan's partition congruences. A *partition* of an integer n is any nonincreasing sequence of positive integers that sum to n, and the partition function $p(n)$ counts the number of partitions of n. There are five partitions of four, namely

$$4,\ \ 3+1,\ \ 2+2,\ \ 2+1+1,\ \ 1+1+1+1,$$

and so $p(4) = 5$. The simplest examples of Ramanujan's congruences assert that

$$\begin{aligned} p(5n+4) &\equiv 0 \pmod 5, \\ p(7n+5) &\equiv 0 \pmod 7, \\ p(11n+6) &\equiv 0 \pmod{11} \end{aligned}$$

for every integer n. As is common in number theory, the problems and theorems are often easy to explain (but hard to prove). My new friends were delighted by the simplicity of the congruences,

[5] *The teachers explained that Ramanujan can be spelled Ramanujam due to transliteration.*

K. Ono, left, and A. Ramamoorthy at Town High School.

and they promised to share them with the students the next day, Ramanujan's birthday.

The conference also concluded the next day. Manjul Bhargava closed the conference by delivering the Ramanujan Commemorative Lecture, a captivating talk on his recent work with Jonathan Hanke (Duke University). His topic came as a surprise; I had been expecting to hear him lecture on the Cohen-Lenstra heuristics, and generalizations of Gauss' composition laws. Instead, he announced new theorems about integral quadratic forms.

The study of integral quadratic forms, which dates to classic works of Jacobi, Lagrange, Fermat, and Gauss, plays an important role in the history of number theory. Indeed, Lagrange's Theorem that every positive integer is a sum of four squares is a classic result that number theory students learn early on. Revisiting earlier work of John H. Conway (Princeton University) and William Schneeberger, Manjul and Hanke have proven delightful results establishing finite tests for determining whether a quadratic form represents all positive integers. Consequences of their work are easy to state. For instance, they show that a positive-definite integral quadratic form represents all positive integers if and only if it represents the integers

$$1, 2, 3, 5, 6, 7, 10, 13, 14, 15, 17, 19, 21,$$
$$22, 23, 26, 29, 30, 31, 34, 35, 37, 42, 58,$$
$$93, 110, 145, 203, \text{ and } 290.$$

As a corollary, they determine the complete list[6] of all the positive-definite integral quadratic forms in four variables that represent all positive integers. This resolved a problem first studied by Ramanujan in his classic 1916 paper [24] on quadratic forms.

Bhargava has obtained even more general results. He shows that for every subset S of the positive integers, there is a unique minimal finite subset of integers, say T, with the property that such a form represents all the integers in S if and only if it represents the integers in T. Manjul concluded his lecture with a discussion of the following open problem: Determine T when S is the set of positive odd numbers. This problem is open due to deep questions in analytic number theory, most prominently the ineffectivity of Siegel's lower bound for class numbers, and to a lesser extent, a case of the Ramanujan-Petersson Conjectures. The celebrated effective solution of Gauss' general class number problem due to the work of Goldfeld, Gross, and Zagier, which provides an effective lower bound for class numbers, unfortunately falls short for this problem.

Manjul noted that Ramanujan, in his 1916 paper [24], had already anticipated these difficulties when he proclaimed (see page 14 of [24]):

> ...the even numbers which are not of the form $x^2 + y^2 + 10z^2$ are the numbers
>
> $$4^{\lambda}(16\mu + 6),$$
>
> while the odd numbers that are not of that form, viz.,
>
> $$3, 7, 21, 31, 33, 43, 67, 79, 87, 133,$$
> $$217, 219, 223, 253, 307, 391, \ldots$$
>
> do not seem to obey any simple law.

In the 1980s Duke and Schulze-Pillot [14, 15] used deep results of Iwaniec [19] on the Ramanujan-Petersson Conjecture for half-integral weight modular forms to prove that there are *only finitely many* odd numbers that are not this form, guaranteeing that there is a "simple law" that they obey. However, the catch is that the proof is ineffective, meaning that it cannot be used to deduce the finite list of rogue exceptions. This sort of predicament explains the nature of Manjul's open problem.

On one of his final slides, Manjul recalled my result with Sound which brightened the picture:

Assuming the Generalized Riemann Hypothesis, the only odd numbers not of this form are

$$3, 7, 21, 31, 33, 43, 67, 79, 87, 133,$$
$$217, 219, 223, 253, 307, 391, 679, \text{ and } \mathbf{2719}.$$

This was a poetic conclusion to my pilgrimage: the number

$$\mathbf{2719}$$

echoing from a small cubbyhole in the great hall of Ramanujan's temple.

Ramanujan's Mathematical Legacy

To properly appreciate the legend of Ramanujan, it is important to assess his legacy to mathematics. For this task, we recall the thoughts (see page

[6] *Lagrange's form $w^2 + x^2 + y^2 + z^2$ is one of them.*

xxxvi of [16]) Hardy recorded shortly after Ramanujan's death in 1920:

> Opinions may differ about the importance of Ramanujan's work, the kind of standard by which it should be judged, and the influence which it is likely to have on mathematics of the future. ...He would probably have been a greater mathematician if he could have been caught and tamed a little in his youth. On the other hand he would have been less of a Ramanujan, and more of a European professor, and the loss might have been greater than the gain....

Sixteen years later, on the occasion of Harvard's tercentenary, Hardy revisited this quote, and he retracted (see page 7 of [17]) the last sentence as "ridiculous sentimentalism".

In light of what we know now, perhaps we should revisit this decision. With the passage of time, it should be much simpler to assess Ramanujan's legacy. Indeed, we enjoy the benefit of reflecting on eighty-five years of progress in number theory. However, the task is complicated at many levels. It would be unfair to assess his legacy based on his published papers alone. The bulk of his work is contained in his notebooks. This is underscored by the fact that the project of editing the notebooks remains unfinished, despite the tireless efforts of Bruce Berndt over the last thirty years, adding to the accumulated effort of earlier mathematicians such as G. H. Hardy, G. N. Watson, B. M. Wilson, and R. A. Rankin. The task is further complicated by the fact that modern number theory bears little resemblance to Ramanujan's work. It is safe to say that most number theorists, unfamiliar with his notebooks, would find it difficult to appreciate the pages of congruences, evaluations, and identities, of strangely named functions, as they are presented in the notebooks. To top it off, these results were typically recorded without context, and often without any indication of proof. Our task would be far simpler had Ramanujan struck out and developed new theories whose fundamental results are now bricks in the foundation of modern number theory. But then he would have been "less of a Ramanujan".

Despite these challenges, it is not difficult to paint a picture that reveals the breadth and depth of Ramanujan's legacy. Instead of concentrating on examples of elegant identities and formulas, which is already well done in many accounts by mathematicians such as Berndt and Hardy (for example, see [5, 6, 7, 8, 9, 17, 25]), we adopt a wider perspective that illustrates Ramanujan's influence on modern number theory.

Number theory has undergone a tremendous evolution since Ramanujan's death. The subject is now dominated by the arithmetic and analytic theory of automorphic and modular forms, the study of Diophantine questions under the rubric of arithmetical algebraic geometry, and the emergence of computational number theory and its applications. These subjects boast many of the most celebrated achievements of twentieth century mathematics. Examples include: Deligne's proof of the Weil Conjectures, the effective solution of Gauss' general Class Number Problem (by Goldfeld, Gross, and Zagier), Wiles' proof of Fermat's Last Theorem, and Borcherds' work on the infinite product expansions of automorphic forms. At face value, Ramanujan's work pales in comparison. However, in making this comparison we have missed an important dimension to his genius: his work makes contact with all of these notable achievements in some beautiful way. Ramanujan was a great anticipator; his work provided examples of deeper structures and suggested important questions that now permeate the landscape of modern number theory.

To illustrate this, consider Ramanujan's work on the single function

$$\begin{aligned}\Delta(z) &= \sum_{n=1}^{\infty} \tau(n)q^n := q\prod_{n=1}^{\infty}(1-q^n)^{24} \\ &= q - 24q^2 + 252q^3 - 1472q^4 + \cdots,\end{aligned} \tag{1}$$

where $q := e^{2\pi i z}$ and z is a complex number with $\mathrm{Im}(z) > 0$. Viewing this function as a formal power series in q, one would not suspect its important role. This function is a prototypical *modular form*, one of weight 12. As a function on the upper half of the complex plane, this essentially means that

$$\Delta\left(\frac{az+b}{cz+d}\right) = (cz+d)^{12}\Delta(z)$$

for every matrix $\left(\begin{smallmatrix} a & b \\ c & d \end{smallmatrix}\right) \in \mathrm{SL}_2(\mathbb{Z})$. Ramanujan was enraptured by its coefficients $\tau(n)$, the values of the so-called tau-function.

Although nothing about their definition suggests such properties, Ramanujan observed and conjectured (see page 153 of [25]) that

$$\tau(nm) = \tau(n)\tau(m)$$

for every pair of coprime positive integers n and m, and that

$$\tau(p)\tau(p^s) = \tau(p^{s+1}) + p^{11}\tau(p^{s-1})$$

for primes p and positive integers s. Although Mordell would prove these conjectures, those with knowledge of modular forms will recognize them as by-products of a grand theory that would be developed in the 1930s by E. Hecke. The modern theory of automorphic and modular forms and their L-functions, which dominates much of modern number theory, is a descendant of Hecke's theory.

In addition to studying their multiplicative properties, Ramanujan studied the size of the numbers

$\tau(n)$. For primes p he conjectured (see pages 153-154 of [25]), but could not prove, that

$$|\tau(p)| \leq 2p^{\frac{11}{2}}. \tag{2}$$

This speculation is the first example of a family of conjectures now referred to as the Ramanujan-Petersson Conjectures, among the deepest problems in the analytic theory of automorphic and modular forms. This conjectured bound was triumphantly confirmed [13] by Deligne as a deep[7] corollary of his proof of the Weil Conjectures, work that earned him the Fields Medal in 1978. Although it would be ridiculous to say that Ramanujan anticipated the Weil Conjectures, which includes the Riemann hypothesis for varieties over finite fields, he correctly anticipated the depth and importance of optimally bounding coefficients of modular forms, the content of the Ramanujan-Petersson Conjectures.

As another example of Ramanujan the anticipator, we reflect on the many congruences he proved for the tau-function, such as (see page 159 of [25]):

$$\tau(n) \equiv \sum_{d|n} d^{11} \pmod{691}. \tag{3}$$

Although this congruence is not difficult to prove using q-series identities, it provides another example of a deep theory. About thirty-five years ago, Serre [26] and Swinnerton-Dyer [28] wrote beautiful papers interpreting such congruences in terms of certain two dimensional ℓ-adic representations of $\mathrm{Gal}(\overline{\mathbb{Q}}/\mathbb{Q})$, the absolute Galois group of the algebraic closure of $\mathbb{Q}$. At the time, Deligne had just proven that such representations encode the coefficients of certain modular forms as "traces of the images of Frobenius elements". Armed with this perspective, Serre and Swinnerton-Dyer interpreted Ramanujan's tau-congruences, such as (3), as the first nontrivial examples of certain "exceptional" representations. In the case of Ramanujan's $\Delta(z)$, for the prime $\ell = 691$, there is a (residual) Galois representation

$$\rho_{\Delta,691} : \mathrm{Gal}(\overline{\mathbb{Q}}/\mathbb{Q}) \longrightarrow \mathrm{GL}_2(\mathbb{Z}/691\mathbb{Z})$$

which, for primes $p \neq 691$, satisfies

$$\rho_{\Delta,691}(\mathrm{Frob}(p))) = \begin{pmatrix} 1 & * \\ 0 & p^{11} \end{pmatrix},$$

where $\mathrm{Frob}(p) \in \mathrm{Gal}(\overline{\mathbb{Q}}/\mathbb{Q})$ denotes the "Frobenius element at p". Congruence (3) then follows from Deligne's prescription, for primes $p \neq 691$, that

$$\mathrm{Tr}(\rho_{\Delta,691}(\mathrm{Frob}(p))) \equiv \tau(p) \pmod{691}.$$

This theory of modular ℓ-adic Galois representations, which provides Galois-theoretic interpretations of Ramanujan's tau-congruences, has subsequently flourished over the years, and famously is the "language" of Wiles' proof of Fermat's Last Theorem.

As one readily sees, Ramanujan's work on the tau-function anticipated deep theories long before their time. Similar remarks apply to much of Ramanujan's work. Over the last few years, largely due to work of Zagier and Zwegers [30, 31],[8] a clear picture has begun to emerge concerning the *mock theta functions*, the focus of Ramanujan's work while he was bedridden in his last year of life. These strange q-series, such as

$$\begin{aligned} f(q) &:= 1 + \sum_{n=1}^{\infty} \frac{q^{n^2}}{(1+q)^2(1+q^2)^2 \cdots (1+q^n)^2} \\ &= 1 + q - 2q^2 + 3q^3 - \cdots, \end{aligned}$$

are related to *Maass forms*, a type of nonholomorphic modular form that would not be defined until the 1940s, twenty years after Ramanujan's death. Thanks to these new connections, several longstanding open problems about mock theta functions and partitions have recently been solved (for example, [11, 12]). Research in this direction is presently advancing at a rapid rate, and although the details have not yet been fully worked out, it should turn out that mock theta functions will also provide examples of automorphic infinite products. These products were introduced by Borcherds in his 1994 lecture at the International Congress of Mathematicians [10]. These products, combined with his work on Moonshine, earned Borcherds a Fields Medal in 1998.

In other areas of number theory, Ramanujan's legacy and genius stand out further in relief. He was a pioneer in probabilistic number theory, in the theory of partitions and q-series, and in the theory of quadratic forms, and together with Hardy he gave birth to the "circle method", a fundamental tool in analytic number theory (for example, see [5, 6, 7, 8, 9, 16, 25]). His work in these subjects, combined with the deep theories he anticipated, paints a breathtaking picture of his mathematical legacy.

As a final (crude) measure of Ramanujan's legacy, simply consider the massive list of mathematical entities that bear his name:

- The Dougall-Ramanujan identity
- The Landau-Ramanujan constant
- Ramanujan's theta-function
- Ramanujan's class invariants g_n and G_n
- Ramanujan's ${}_1\psi_1$ identity
- Ramanujan's τ-function

[7] *Earlier works by Eichler, Ihara, Sato, and Shimura play an important role in reducing (2) to a consequence of the Weil Conjectures.*

[8] *This research comprises Zwegers' Ph.D. thesis written under the direction of Don Zagier.*

- Ramanujan's continued fraction
- Ramanujan graphs
- Ramanujan's mock theta functions
- The Ramanujan-Nagell equation
- The Ramanujan-Petersson Conjectures
- Ramanujan sums
- Ramanujan's theta-operator
- The Rogers-Ramanujan identities
- among many others...

If Hardy knew what we know now, perhaps he would again alter his 1920 quote. Rather than dismissing the last sentence as "ridiculous sentimentalism", perhaps he would agree that it rings true now more than it originally had at the time of Ramanujan's death.

Reflections

I am compelled to return to the quotes by Hardy which prompted me to consider whether it is possible that religion was not an important part of Ramanujan's life, and whether one can rationally explain the legend of Ramanujan's mathematics.

I certainly cannot resolve the question of whether religion was an important part of his life. Obviously, I also cannot truly speculate on whether he believed his research was divine in origin. That would be romantic fiction. However, based on my experiences, particularly my visit to Sarangapani Temple, it is difficult to imagine that religion did not play some role. From a western perspective, it is hard to overstate the importance and relevance of Hindu beliefs on all aspects of daily life in Kumbakonam. Hinduism permeates daily life. After all, Kumbakonam is a holy city, one where ninety percent of its citizens today are observant Hindus, a fact that was certainly true in Ramanujan's day. It is also difficult to ignore the well-documented fact that Komalatammal, Ramanujan's mother, was deeply religious and that his voyage to England was dependent on her dream from the goddess Namagiri. Therefore whether Ramanujan was deeply religious or not, it is certainly true that everything about him and his world view was heavily influenced by religion.

For me, there is a poetic resolution to the question of whether one can rationally explain the legend of Ramanujan: this true story is one of magic. Ramanujan was an untrained mathematician, toiling largely in isolation, whose work was born entirely out of imagination. He was a pioneer and a self-taught anticipator of great mathematics, and this is indeed magical. After all, great mathematics is magic, something we can understand but whose inspiration we cannot comprehend. Ramanujan was a gift to the world of mathematics.

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About the Cover

Out of the Groove

Madras Port Trust Office
Accounts Department.
27th February 1913.

Dear Sir,

I am very much gratified on perusing your letter of the 8th February 1913. I was expecting a reply from you similar to the one which a Mathematics Professor at London wrote asking me to study carefully Bromwich's Infinite Series and not fall into the pitfall of divergent series. I have found a friend in you who views my labours sympathetically. This is already some encouragement to me to proceed with an onward course. I find in many a place in your letter rigourous proofs are required and so on and you ask me to communicate the methods of proof. If I had given you my methods of proof I am sure you will follow the London Professor. But as a fact I did not give him any proof but made some assertions as the following under my new theory. I told him that the sum of an infinite number of terms in the series $1 + 2 + 3 + 4 + \cdots = -1/12$ *under my theory. If I tell you this you will at once point out to me the lunatic asylum as my goal. I dilate on this simply to convince you that you will not be able to follow my methods of proof if I indicate the lines on which I proceed in a single letter. You may ask how you can accept results based upon wrong premises. What I tell you is this. Verify the results I give and if they agree with your results, got by treading on the groove in which the present day mathematicians move, you should at least grant that there may be some truths in my fundamental basis. So what I now want at this stage is for eminent professors like you to recognize that there is some worth in me. I am already a half starving man. To preserve my brain I want food and this is now my first consideration. Any sympathetic letter from you will be helpful to me here to get a scholarship either from the University or from Government.*

With respect to the mathematics portion of your letter...

This is the beginning of the second letter from Ramanujan to G. H. Hardy. The first, one of the most famous of all documents in the history of mathematics, had been written on January 16, and Hardy had replied from Trinity College, Cambridge, on February 8. The beginning of the first letter seems unfortunately to have disappeared, although its content has been preserved. Hardy commented in a note written July 23, 1940, "I have looked in all likely places, and can find no trace of the missing pages of the first letter, so I think we must assume that it is lost. This is very natural since it was circulated to quite a number of people interested in Ramanujan's case."

Both letters as well as other relevant items can be read in Bruce Berndt's account in *Ramanujan—Letters and Commentary*, published by the AMS. The idea of making this cover came from Ken Ono's article in this issue (pp. 640–51).

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

The Millennium Grand Challenge in Mathematics

Arthur M. Jaffe

On May 24, 2000, Arthur Jaffe, then president of the Clay Mathematics Institute, announced the Millennium Grand Challenge in Mathematics towards the end of a meeting held at the Collège de France in Paris. The proof or a counterexample to seven important old mathematical conjectures would earn a US$7 million dollar reward—with US$1 million dollars for each answer. This challenge brought instant, world-wide recognition to the Institute, an organization conceived and founded by Jaffe and Landon Clay, a Boston philanthropist, just twenty months earlier. In 2006 a spotlight shines on the Poincaré conjecture, the first of these questions which may have been resolved. This essay presents a personal perspective on the background to the Challenge, as well as the founding of the Institute, a private non-profit foundation dedicated to furthering "the beauty, power, and universality of mathematical thought".

—*A.M.J.*

Evolution

The idea for the millennium grand challenge in mathematics cannot be separated from dreams of creating a new organization to support mathematical research. That vision came to fruition with the meeting of the initial three members of the Board of Directors of the Clay Mathematics Institute (CMI), just minutes after their election by the three members of CMI, on the morning of 10 November 1998.[1] The setting lent a dignified and uplifting feeling to the occasion. We met in a small, private dining room on the second floor of the Harvard Faculty Club, aptly named the "Presidents' Room" for its decoration with pictures of past Harvard presidents on the walls.

Two significant outcomes at that meeting were the election of the officers of CMI as well as constituting the Scientific Advisory Board (SAB). Attending were the three original members of the Board of Directors: Landon T. Clay, his wife Lavinia D. Clay, and the author—along with recordkeeper, Barbara Drauschke. The directors elected the author as president and as chair of the SAB, and then elected Alain Connes, Andrew Wiles, and Edward Witten as further SAB members, all without limit of time.

The agenda that morning included discussion of the first ten scientific projects to be pursued by CMI. To the best of my recollection, number eight in the list of projects read:

> **"Problems for the millennium, initial project:** Select 50 problems for publication in a book volume for the millennium, with the award of US$1,000 to the author of each manuscript. Select afterward a small number of special problems (maximum 12)."

This item received approval after minimal discussion, along with the other nine projects.

About one month afterward, I returned to the prize problem project while working in another inspirational setting—the loft in a vacation house located in New Hampshire, north of Cambridge. There the mood flowed from the view past the cathedral ceiling and through a picture window to the rolling

Arthur M. Jaffe is professor of mathematics and theoretical science at Harvard University and past president of the AMS (1997-98). His email address is jaffe@math.harvard.edu.

[1] *See the "Epilogue" toward the end of this essay for a few further details on the formation of CMI, and how its history intertwines with that of the millennium challenge.*

Ossipee hills in the west. Was it possible to transmit this uplifting spirit to a text soliciting potential problems? I began to prepare a single page of text that CMI could circulate by mail and email. Perhaps it would be posted on mathematics department bulletin boards and on internet web sites. It might also be spread by word-of-mouth at scientific meetings. I had also just been invited to attend one of many conferences the following summer that were scheduled to review the progress of mathematics at the turn of the century and millennium. This and other similar meetings could be excellent forums for input.

Setting out the mechanism and procedures for the solicitation of fifty problems and the subsequent selections was a priority. I drafted a process to select the fifty manuscripts for publication, a second one to narrow the focus to a small number of special problems, and even went as far as drafting a letter that might be used by individual SAB members to solicit input. After several revisions, the plans appeared to be on track. I was in contact with Connes about other matters, so I asked him to critique the texts.

I then discussed the proposed details with Wiles, and this led to another point of view. He convinced me that the original approach might generate difficulties I had not anticipated; basically he questioned whether a completely open process would be best. Was it possible that powerful mathematicians who felt that their opinions were not sufficiently heeded would object and attempt to undermine the project? Wiles urged me to revise the plan in order to avoid "mathematical politics", by focusing immediately on the selection of the smaller number of special problems and omit the competition as an initial step. This also meant that the process would be more secretive than open. I went back to discuss this with Connes, who on reconsideration agreed that it was wise to modify the original plan.

But I realized that whatever plan we pursued ran the risk of controversy, and enough did arise later. So I decided that the SAB should scrap its plan to announce an open competition for fifty questions. The discussions would go outside the SAB only through individual members seeking advice from their trusted colleagues in the mathematics community.

Getting to Seven

The SAB now had to choose the problems, and this began in earnest only during the fall of 1999. No preconceived number of questions had been fixed. The upper limit of twelve seemed a reasonable bound—small enough to focus attention onto the project, yet large enough to be fairly broad. But the exact number of questions would depend upon the process, and we had no idea where the selection would lead us.

As a first step, I requested that each SAB member submit a personal list of top questions. Each of these questions should be difficult and important—a time-tested challenge on which mathematicians had worked without success. This exercise indicated some initial direction and set the background for further discussion. As I recall, everyone's list included the Riemann hypothesis and the Poincaré conjecture. So it seemed assured that these questions had common approval and would appear on the SAB's final list.

However, even in terms of these common questions we still needed to decide in what form they should be posed as challenges. Should the Riemann hypothesis be linked with some form of the Langlands' program? Should the Poincaré conjecture be linked with Thurston's more general geometrization program? This precipitated discussion of whether the millennium questions should be posed in their simplest form, or in general form. After some discussion by telephone, we arrived at a rule-of-thumb: we would prefer the simplest form of a question, at least whenever that choice seemed sensible on mathematical and general scientific grounds.[2]

From then on, the process of choice evolved through a series of telephone discussions separated by consultation and reflection. We added questions to the list one by one. With each new question we asked whether the list should be expanded or whether it might be improved by substituting a new question.

Here is one concrete example of the process: how we approached the P versus NP question. This problem arose on several lists, and the question also seemed to be "in the air" at the time. Nevertheless the SAB felt that it needed guidance from outside experts both about the relevance and difficulty of this question. And did this question represent the central thinking of the experts? After some external consultation, the SAB came to the conclusion that computer scientists regarded the P versus NP question as the most important open question in their field. At the same time, consulting some experts in mathematical logic led us to the conclusion that they regarded the same question as the outstanding open problem in logic. These opinions assured P versus NP a place on our list.

While each problem on the list was central and important, I want to stress that the SAB did not envisage making a definitive list, nor even a

[2] *I planned that the uniformity of the seven final manuscripts from this point of view, each written by different authors, would be reviewed and discussed by the SAB. For nonscientific reasons too lengthy to elaborate here, such a discussion by the SAB became impractical, and in fact it never took place.*

One can give many answers to the question, "Why pose a grand challenge in mathematics?" Three themes dominated my own thought. Focusing attention on difficult, significant, and time-tested mathematical questions emphasizes a lofty goal: strive for major, long-term satisfaction in mathematics rather than for immediate gratification. Communicating awareness to the public that important—yet unresolved—problems permeate mathematics illustrates the message that mathematics—like science—is a dynamic, complicated, and living organism. Possibly one can also inspire young students—opening new mathematical vistas for a few—while motivating them to attack major challenges in the future.

—*A.M.J.*

representative set of famous unsolved problems. Rather, personal taste entered our choices; a different scientific advisory board undoubtedly would have come up with a different list. The persons we consulted were experts, but they were chosen under pressure of time. However, the spirit of the selection transcends these decisions: the resulting list represents an honest attempt to convey some excitement about mathematics. We do not wish to address the question, "Why is Problem A not on your list?" Rather we say that the list highlights seven historic, important, and difficult open questions in mathematics.

The list grew after further conversations. As each problem was added the SAB began to have greater and greater difficulty—either to add a new problem, or to substitute a different one. By the end of 1999 seven questions had been chosen. At this point the SAB declared the list tentatively closed, but left open the possibility of later changes.

The report from the president to the directors' meeting on 6 January 2000 included a progress report on the project. It stated that CMI plans to offer a major financial award for the solution of particular mathematics problems, and to announce the plan publicly only after the selection of prize problems. The directors reaffirmed the project in principle, but had little new information at that point, except that the list included the Riemann hypothesis.

Even two months later—with the May 2000 announcement of the prize problems close at hand—the SAB had a further discussion about whether it might expand the list of problems. But the SAB decided to keep the list intact with the seven chosen problems. The members voted on 10 April 2000 to recommend to the directors that these seven questions be approved, as well as the US$7 million prize.

A Monetary Prize

The intention to offer some monetary prize for the solution of one of the millennium problems was always part of the picture. The reasoning behind this contained several components, each of which stands on its own, and all of which taken together remain very persuasive. But the idea to attach a fixed, US$7 million sum to the challenge came as an afterthought. It occurred during April 2000.

The original plan involved creating a prize fund within the CMI endowment. I expected that a substantial sum would be allocated each year for use of this fund in the event of an award. At the time that CMI recognized a solution to one of its problems, one would divide the amount of money in the fund by the number of remaining problems to determine the size of the award. With this plan, a solution that came shortly after the announcement of the competition would yield a modest prize. But a problem that remained unsolved over a long period after the announcement would bring a very substantial award—potentially much larger than the present US$1 million offer. A large award for an entire life's work would be fitting, and the size of the award would certainly raise public interest in mathematics.

The change in thinking on this question resulted from a couple of factors; one important event was an article in *The Times* of London detailing an offer made by the publisher Faber & Faber in an attempt to raise interest in a new book. Faber offered a US$1 million prize for the solution to the Goldbach conjecture, a question in number theory formulated in 1742. Details of the Faber offer contrasted markedly with those of the planned millennium prize. The key difference was that the CMI plan had no time limit for solving the prize problems, while the Faber offer imposed an unrealistic, two-year time limit for solving the Goldbach conjecture. This time limit allowed Faber to back its prize by insurance from Lloyd's, rather than by cash. And of course, the insurance turned out to be completely unnecessary.

But the Faber offer had already captured attention both in the printed press and on the Internet. I worried that if CMI proceeded as had been planned, the Faber news would surface and it could undermine attention to the CMI millennium challenge. The general public does not make fine distinctions. Mathematicians themselves are also unpredictable.

After reflection, my reaction was to suggest that CMI offer a US$7 million challenge from the start. This was bound to attract attention. On the other hand, the millennium challenge problems were sufficiently difficult that there was little worry that many of them would be solved in the near (or even the foreseeable) future. The Clays accepted my formulation, so I began to discuss it with the other directors and of course with the SAB.

I also believed that the US$7 million should be segregated so the prize would grow over time along with the endowment (and with inflation). The

Boston attorney for CMI argued that such a decision could be made in the future, so it would be best to wait and see the reaction. We did not segregate the prize.

A paraphrase of my letter of 12 April 2000 to the SAB and the Board of Directors illustrates the time-line. This letter requested a written vote on the problems, the rules, and the financial award; this would leave little to be reviewed by the directors at their 23 May 2000 meeting in Paris.

> The SAB has selected seven problems, following numerous conversations within and outside the SAB over the course of the past months. The SAB also considered possible experts to make a precise statement and to give background for each problem. We expect to have these descriptions available at the Paris meeting, and to publish a pamphlet with these problem write-ups and the enclosed rules....
>
> Below you find a popular name for each problem (alphabetically), and the experts who have agreed to prepare the descriptions. Presently we have three preliminary versions of these write-ups in hand, and for your interest I enclose copies:
>
> 1. The Birch-Swinnerton-Dyer conjecture (Andrew Wiles)
>
> 2. The Hodge conjecture (Pierre Deligne)
>
> 3. The Navier-Stokes equation has smooth solutions (Charles Fefferman)
>
> 4. P is not NP (Stephen Cook)
>
> 5. The Poincaré conjecture (John Milnor)
>
> 6. Quantum Yang-Mills theory exists with a mass gap (Arthur Jaffe and Edward Witten)
>
> 7. The Riemann hypothesis (Enrico Bombieri)

The SAB voted unanimously in a telephone meeting on 10 April 2000:

- To accept these seven problems as the list of Millennium Prize Problems and to recommend to the directors their approval of this selection.
- To recommend to the directors that the attached rules would be announced on 24 May 2000 (with minor refinement between now and 23 May).
- To recommend to the directors that the prize be announced as "a US$7 million prize for mathematics", with details to be given in a list of problems and in rules that would be made public on 24 May 2000.
- To request that the directors authorize to encumber US$7 million of the CMI endowment ... to back this prize.

The directors confirmed this request by written ballot; it later had reconfirmation with minor changes to the proposed rules during a telephone conference on 15 May 2000.

The rules for the prize resulted from a fair amount of thought. Some features evolved from the original 1998 proposal described in the "Epilogue" below. One major safeguard involved the importance of publication of a solution. Implied is an initial review of correctness of the work by expert colleagues. In addition the rules specify a two-year waiting period after publication to ensure acceptance of the work by the mathematics community, before the CMI will even solicit expert opinions about the validity or attribution of a presumed solution to a problem.

Of course there can always be unforeseen circumstances. For example, an author of a solution may not write it down completely or might opt for self-publication, rather than for publication in an established journal. Traditional publication could change in the future, with relaxed standards of review. These and other circumstances are left for recommendation from a future scientific advisory board.

Paris

Sometime during November 1999, during the course of selection of the problems, another fact dawned upon the members of the SAB. Of course we should have been well aware of this from the start. But sometimes one needs to reflect before understanding the obvious.

Most mathematicians know that the famous set of twenty-three Hilbert problems were announced in a lecture at the 1900 Congress of Mathematicians, in Paris. So it was only natural that our list of millennium problems should be made public during the year 2000, and in Paris!

This meant that we needed to speed up everything. We had not even finished selecting the problems. But we also had to organize a meeting, to make specific preparations for the announcement, and to plan for the reaction! Fortunately we realized these time pressures only toward the end of 1999, really too late for us to worry about their consequences. In fact, at that point I was thankful that we had abandoned the original plan to proceed through fifty questions. Following that path would have made an announcement during the year 2000 totally impractical.

Alain Connes represented our Paris connection, and he graciously offered to host the CMI meeting at the Collège de France. Unfortunately some other mathematicians in Paris did not realize how positively the public would react to this challenge, and

Alain Connes (left) and Arthur Jaffe at the ceremony announcing the Millennium Prizes at the Collège de France in Paris, May 2000.

in the beginning several minor obstacles had to be overcome. In the first half of 2000, Alain made a substantial investment of time and energy, and his dedication and enthusiasm became an essential factor in the formula for the success of the meeting in Paris. Ultimately most of the organizational burden fell on the two of us. We had the indispensable assistance of a large number of enthusiastic and dedicated staff and supporters on both sides of the Atlantic.

Because of various constraints, both on the use of the Amphithéâtre Marguerite de Navarre at the Collège de France, as well as the schedule of other meetings in the Paris region, we chose 24–25 May 2000 for the millennium meeting, one day later than originally anticipated. And certainly any date seemed to pose conflicts. For example, we hoped to have both R. Bott and J.-P. Serre attend the meeting; but in February we learned that these two mathematicians had been chosen to receive the Wolf Prize. That award ceremony overlapped our meeting and affected the plans of other mathematicians as well.

CMI was fortunate that Gilbert Dagron, the distinguished Byzantine historian and administrator of the Collège (the equivalent of the president in other organizations), played another key role. Dagron became captivated by the idea of the millennium meeting and not only lent his personal support to CMI, using many resources of the Collège, but also gave a great deal of personal assistance. His deputy, Jacques Glowinski, had overseen the construction of the new amphitheater where we met; he too helped and enjoyed seeing the splendid site put to good use.

Through the good graces of Dagron, CMI also had access to the indispensable assistance of Véronique Lemaître. This extraordinary woman had the responsibility at the time for external relations at the Collège. Not only was she expert in her work, but she was also both dedicated and enthusiastic, spending long evening hours outside normal working time to make plans or telephone calls. Véronique knew and was respected by a substantial fraction of the scientific journalists representing both national and international publications and media in the Paris area. So when Véronique organized a briefing for the press on the morning of the meeting, over thirty Paris journalists appeared in person for discussion and lunch.

The Meeting

Expectations for the meeting at the Collège had mounted over the days leading up to it. The auditorium was vast—on the scale of mathematics meetings—although we had no idea how many persons would want to attend. As Paris represents a substantial mathematics community, and we had little advance idea of interest from the general scientific community or from the public, Alain Connes decided not long before the meeting that he needed to assign a ticket with a specific seat number for each attendee.

This plan created the enormous new burden of communicating with as many individuals as possible, as well as attempting to ensure that some elder mathematical statesmen (including Henri Cartan and Laurent Schwartz) would not have difficulty attending. While this caused a logistical nightmare and incredible pressure on Connes and his helpers, the plan succeeded. The audience flowed in smoothly, and every seat in the vast auditorium was filled at the start of the meeting. And for the overflow we had arranged closed-circuit video in a nearby room.

The meeting itself went splendidly, with the one exception—the newly appointed Minister of Research arrived late, causing an unintended wait and rearrangement in the schedule. The research awards to L. Lafforgue and A. Connes proceeded smoothly. The general talk on the "Importance of Mathematics" by Timothy Gowers presented an inspirational story of interaction between different disciplines and ideas within mathematics. The presentations of the seven problems by Michael Atiyah and John Tate presented a vast interwoven tapestry of mathematics.

One can review and reconsider this day, as four videos bring the proceedings to life. The French documentary filmmaker François Tisseyre worked tirelessly to present an interesting and comprehensible account of the meeting. The first video frames the day with interviews with participants as well as excerpts from various lectures. The other three videos present the main talks of Gowers, Atiyah, and Tate in their entirety, enhanced by graphical

effects that make them approachable and appealing. The publisher Springer Verlag distributes these videos.

Immediate Reaction

The immediate reaction came swiftly, as if it were the spirit of the times. Undoubtedly this was also linked to announcing the challenge in Paris, for in France the image of mathematics remains strong in the populace. In Paris it is easy to discover street names, public portraits, and busts of historic figures with mathematical significance.

Leading up to the meeting, Alain Connes had two interviews that captured the imagination of science reporter Jean-François Augereau, who eventually wrote four different articles in the 25 May issue of *Le Monde*. As is customary, the paper appeared on the previous afternoon, just as the participants were leaving the millennium meeting for dinner on 24 May. We bought a number of copies to hand out at that occasion; the paper carried a front-page photo of the SAB and CMI directors that the newspaper had discovered on the Internet.

Véronique Lemaître also had arranged for Jocelyn Gecker, a new, young, Paris-based science reporter for the Associated Press, to interview me two days before the meeting. The extensive article that she ultimately wrote appeared on 25 May in several hundred U.S. newspapers. Many of the other reporters present at the Collège also wrote stories.

The British magazine *Nature* even published an editorial on 25 May entitled: *Values of the Abstract: A new set of prizes is an apt celebration of the significance and wonder to be found in pure mathematics*, and reflecting: "It's an excellent way for a private foundation to recognize the eternal fascination that mathematics holds for people such as Hardy, and for the rest of us." This widespread positive reaction eventually led to thousands of articles appearing in other papers and magazines around the world, as well as interest by radio and television programs and on the Internet.

Just months before the meeting, the CMI had launched a website. We carefully prepared material about the millennium challenge, and made it possible for someone in Cambridge (USA) to push one button that resulted in posting the material on the Web exactly at the time the actual announcement took place in Paris.

All this precipitated a deluge of reaction far beyond what had been expected. Once the announcement became public, reaching the CMI website became totally impossible. Demand swamped the capacity of the server of the web hosting company. We had not anticipated that problem!

At this point I telephoned from Paris to John Ewing, the executive director of the American Mathematical Society based in Providence. John had served as a trusted advisor in designing the administrative structure of CMI, and he immediately offered his assistance. He was extremely happy to see so much attention being paid to mathematics and disappointed that a technical glitch frustrated so much curiosity.

Timeline: A Few Significant Dates

April 15, 1998. Over lunch at the Harvard Faculty Club, LTC asks AMJ his opinion about previously expressed ideas for a software foundation.

May 9, 1998. Alain Connes agrees while visiting Harvard that if a mathematics-oriented foundation is formed, he would be willing to become involved.

June 4, 1998. AMJ and LTC meet at the Harvard Club in Boston, and LTC mentions that his prior ideas have evolved and that he would now like to create an independent foundation devoted to fundamental mathematics. At this point, the formation of such an entity appears likely.

June 24, 1998. AMJ faxes to LTC an outline of several proposed mathematics projects, including "Prize 2000".

June 28, 1998. AMJ returns from travel four days earlier than planned in order to continue the discussions of a possible foundation with LTC.

August 19, 1998. During the International Congress of Mathematicians in Berlin, AMJ and Andrew Wiles dine together. They discuss the probable creation of a new foundation for mathematics, and in that event AMJ invited Wiles to serve on an advisory board.

September 25, 1998. The CMI becomes a corporate entity, registered in the state of Delaware.

October 27, 1998. LTC transfers shares of stock to a CMI account in Boston, creating the CMI endowment.

October 28, 1998. Edward Witten, while visiting Harvard, agrees to serve on an advisory board for CMI.

November 10, 1998. The members of CMI meet to elect the CMI directors. The directors meet to elect officers of CMI and the historic members of the Scientific Advisory Board.

May 10, 1999. A set of public lectures at MIT marks the formal opening of CMI.

January 6, 2000. The CMI directors approve the initial plans for a millennium challenge and for the meeting in Paris, tentatively set for 23–24 May 2000.[3]

April 10, 2000. The SAB formally approves the seven problems and the US$7 million millennium challenge; two days later the details are mailed to the directors with a request to confirm these decisions.

May 15, 2000. The plan is reconfirmed during a telephone conference of the CMI Board of Directors.

May 24, 2000. CMI announces the millennium challenge problems at the Collège de France. Simultaneously the website of CMI posts news of the challenge, and *Le Monde* publishes a front-page photograph and story. Worldwide reaction follows immediately.

—*A.M.J.*

[3] *Scheduling difficulties resulted in shifting the Paris meeting to one day later than the original plan.*

John's plan was to mirror the CMI website on the AMS web server, and to redirect requests for the CMI web address to the Society. The AMS server not only hosts mathematical news, but provides many electronic journals and other services to a worldwide community of mathematicians; its capacity and bandwidth was far greater than the server run by the web hosting company that CMI used. This solution would be temporary, until the CMI could make arrangements for a more robust host; but it would solve the problem. We implemented this plan immediately, with several phone calls between Cambridge and Providence to assist in transferring the files to mirror.

Not long afterward I returned from Paris to Cambridge, where I was greeted by a telephone call from John Ewing. There was a new problem: the volume of requests to view the CMI web pages threatened to crash the entire AMS website—including the AMS journals and the bookstore! This was unacceptable, and it looked like John would have to disconnect the CMI.

We discussed the numbers. Although the traffic redirected to the AMS address was still increasing, one saw a bit of leeway for it to stabilize before disaster hit. So we agreed to wait a day or two before John made his decision. We expected that the traffic would die down to a more manageable level after the initial reaction, and one week had already passed. Luckily the internet traffic did quickly come to equilibrium, and eventually CMI found a web host that offered more substantial bandwidth. It may be a while before internet activity related to mathematics again reaches the fever pitch of May 2000; hopefully that will arise from a mathematical discovery that fascinates the world.

Many amateurs who learned of the challenge did not realize the difficulty or subtlety of the challenge problems. Less than a year after the announcement, the CMI had received over six hundred letters, emails, and manuscripts from persons claiming that they could understand and solve one (and sometimes all) of the problems. A few of these individuals even sent their manuscripts to established journals in the hope of publication. While amateurs have always found an attraction in famous open problems, the publicity of the millennium challenge seemed to focus their attention.

The *Boston Globe* ran an interesting account by David Appell on 27 March 2001. For background the reporter interviewed some mathematicians who edit professional journals. David Goss of the *Journal of Number Theory* recounted, "They're really coming out of the woodwork. At times I am almost getting more crank stuff than legitimate stuff." Some of these amateur authors even complain their work received unfair treatment because editors summarily rejected their submissions, without explicitly pointing to flaws in their logic. In fact frequent submissions do pose undue burden on the editor and reviewers for a journal. However, to my knowledge the short-term anomaly of many amateur submissions has declined over time.

Reflection

Can one give an assessment of the millennium challenge five years after its launch? Cause and effect in life cannot easily be quantified into a mathematical law. But clearly the existence of the challenge has had a resounding impact on the number of papers, lectures, courses, conferences, manuscripts, and summer schools devoted to important, fundamental questions in mathematics. Within the community of research mathematicians the challenge has had profound impact.

It also catalyzed an enormous peak in public awareness of mathematics outside the research community. It affected the Internet, radio, television, as well as newspapers, magazines, and books. In fact the number of popular books about mathematics has increased substantially in the past five years; some recent books describe individual challenge problems, others discuss the challenge more broadly. Again this may not all be attributed to a single cause, but the overall effect is striking. Clearly the level of popular interest in recent mathematical work on the Riemann hypothesis and the Poincaré conjecture has been much greater than what one might expect without the climate generated by the challenge.

Some anecdotal evidence gathered from conversations with undergraduates suggests that the millennium problems have already had substantial impact within the student world —although limited experience can only suggest such effectiveness.

Presumably the most profound consequences of the millennium challenge project lie in the future. I hope that it will inspire mathematics and encourage potential mathematicians in a positive way for years to come.

Epilogue: Brief Background on CMI

Although I was dogged for some years by early-morning thoughts about forming an entity like CMI, it was only during 1997 that these dreams began to crystallize into something concrete, and about a year later they became a reality. In order to understand how this happened, let's backtrack.

After George Mackey retired from the Harvard mathematics department in 1985, the dean designated me the successor to his named chair. As a result, I began to lunch on a regular basis with the donor, a Boston businessman named Landon T. Clay (LTC) whom I had met casually some fifteen years earlier. He had been a generous benefactor to Harvard in the past, including the endowment of two chairs in different departments, as well as

the donation of a substantial fund to assist the dean in recruiting new faculty.

These lunches were generally quite interesting; we often discussed the activity in the mathematics department. A fundamental boost in activity resulted from the opening up of travel between Eastern Europe and the West. Those events began in 1988, during my term as department chair, and served as a precursor to the dramatic political changes soon to take place in that part of the world.

With the blessing, a small amount of money, and a great deal of encouragement from Harvard president Derek Bok, as well as a grant to the Harvard mathematics department from the Sloan Foundation, we invited a handful of young Russians to visit the following year as "Harvard Prize Fellows". In addition, I. Gelfand and A. Schwarz visited jointly between Harvard and MIT. Ultimately many of the friends of these fellows visited as well, producing a virtual invasion. During the academic year 1989–90, approximately twenty-five Russians spent time at Harvard!

LTC liked this activity; he also expressed his opinion based on his experience on various Harvard committees that the university administration did not appreciate the department's value. As a result of our interaction and discussion, he offered to establish a fund to invite visitors and to enable research projects in the department. In 1990 he directed over US$4 million income (over twenty years) from a trust in his name into the mathematics department. He also helped me establish a group of "Friends" of the mathematics department who ultimately assisted in many other ways.

Seven years later during 1997 he related at one of our lunches that many factors led him to contemplate establishing an "operating foundation". Sometime afterward he advised me that he had formulated a plan to create such a foundation devoted to software. I made no comments on these plans; at the time, my opinion had not been solicited.

Eventually LTC did seek my views; again it happened over lunch during the following year on 15 April 1998 at the Harvard Faculty Club. I recall answering this query as best I could, and shortly afterward writing a letter to him. I suggested that a foundation devoted to software would have difficulty competing with large existing corporate entities which had enormous financial resources at their disposal. In my mind it made scientific sense, and would be cost-effective, to consider creating a foundation devoted to mathematics. I also offered my counsel and assistance, in case he decided to follow that alternative path. Without making any commitments, that topic recurred on at least two other occasions over the next six weeks, including once during a scientific meeting held at Harvard.

After this lunch, and anticipating the possible founding of a mathematics organization, I began to turn over in my mind what persons might be suited to work together in a friendly and compatible atmosphere, were relatively accessible for consultation, and would have impeccable judgment and reputation. Among those I met with privately over the next six months were Alain Connes (at a conference in Cambridge on 9 May), Andrew Wiles (over dinner on 19 August preceding his lecture to the International Congress of Mathematicians in Berlin), and Edward Witten (during his visit on 28 October to lecture at Harvard). Each agreed in principle to participate.

Let's return to the chronology. On 4 June 1998, the morning of the graduation ceremony at Harvard, I met LTC for several hours in the Boston Harvard Club. He had invited me for breakfast that we ate in the dining room, after which we retired to a small upstairs meeting room for an extended discussion. That day LTC projected the attitude that he had made up his mind to start a mathematics organization, although the details were up in the air. He requested some written guidelines from me about what I might propose to do, both in the way of structure and the purpose of such an organization. He wanted it to be independent from Harvard, but possibly located on Harvard land. I responded by letter on 12 June 1998, summarizing our conversation. This letter included a brief outline of a possible plan for the structure of such an organization and reiterated that from 15 June to 2 July I planned to travel abroad. Later I would formulate and communicate further ideas.

Twelve days afterward on 24 June, I followed up this letter with a fax from a scientific meeting in Les Houches, France. During that meeting I also had the opportunity to consult with A. Connes, L. Faddeev, and J. Fröhlich. This fax of 24 June included a list of potential initial projects for the mathematics foundation. Among these, the millennium problem project appeared as the following proposal:

> "**Prize 2000:** In association with the millennium, I recommend a monetary prize for the solution of one of a small number of outstanding, long-range mathematics problems. These problems will be formulated by the Scientific Board and published in the year 2000. The problems will be published in a special article that also outlines procedures to determine a winner. In order to be eligible for consideration for this prize, the solution of the prize problem must be published in a refereed mathematics journal .... The correctness of the solution must be accepted by the leaders of

the mathematics community. For establishing questions of priority, members of the Scientific Board will investigate or have experts investigate. In case of lack of agreement by the mathematics community about the correctness or completeness of a published solution or about the proper attribution of a solution, the Scientific Board has discretion not to award a prize. An author may bring his or her own published work to the attention of the Foundation for consideration. Only an individual or individuals (as distinct from an organization, department or other group of persons) may receive this prize.

"Since the prize will be awarded only on rare occasion, a substantial prize fund may accumulate; this would focus great importance on solving these problems, and give substantial publicity to the prize. Both the principal and income to this principal will accumulate with other annual increments until the solution of all prize problems.

"However, in case the Foundation ceases to exist at some time in the Future, the prize fund will be transferred to another entity that agrees to administer the prize under the same conditions as if it had been under the auspices of the Foundation...."

I had planned to give a mathematics lecture at the University of Geneva at the beginning of July. However, communications with Boston led me to cut short the trip and return to Cambridge four days early on 28 June, in order to continue discussions about the foundation. While on the airplane, I began to prepare a document that summarized further thoughts about the scientific goals of the organization, and even proposed some twenty alternative names. It detailed the purpose as:

"to provide conditions to stimulate outstanding original research; to educate mathematicians or scientists about new discoveries; to encourage gifted students to pursue mathematical or scientific careers; and to recognize and reward unusual achievements in mathematical research."

These words ultimately became the first draft of the statement of purpose that would appear in the Bylaws of the CMI.

The official organization of CMI waited until September, when LTC outlined his intention to create a foundation to W. Warren and J. Olivieri of the firm Dewey Ballantine in New York. At that meeting he also chose the name CMI, and four days later on 25 September 1998, the CMI became a nonprofit Delaware corporation. Many details evolved over the next few months, and while they are central to CMI, they are peripheral to the millennium challenge.

The public recognition of CMI as an organization took place at a series of lectures at MIT on 10 May 1999, followed by a dinner to honor the donor. Speakers included M. Atiyah, LTC, H. Ferguson, D. Gergen, D. Herschbach, AMJ, B. Mazur, W. Odom, C. Vest, and E. Witten, with A. Wiles as keynote speaker. In addition, J.-P. Bourguignon, W. Browder, F. Caspersen, R. Colwell, L. Faddeev, D. Mumford, and K. Osterwalder made remarks after dinner.

Book Review

The Road to Reality: A Complete Guide to the Laws of the Universe

Reviewed by Brian Blank

The Road to Reality: A Complete Guide to the Laws of the Universe
Roger Penrose
Alfred A. Knopf, 2005
ISBN 0-679-45443-8
$40.00, 1,099 pages

For the title of his latest epic, *The Road to Reality*, Roger Penrose has selected a metaphor that appears frequently in popular expositions of physics. It is no wonder that the phrase has become a favorite among physicists, for it suggests a single-minded pursuit of the ultimate destination: an understanding of all the underlying principles that govern the behavior of our universe. Perhaps that may seem to be an ambitious program. After all, it was not so very long ago that Eugene Wigner asserted, "The great success of physics is due to a restriction of its objectives." Since that sober assessment, however, stunning progress has changed the outlook of physics so greatly that several of its leading proponents have been emboldened to suggest that a complete grasp of the laws of nature lies just ahead of us.

As Penrose asserts, the voyage of discovery has lasted more than two and a half millennia and has been profoundly difficult. At the start of the journey, around 500 B.C.E., Heraclitus identified the major stumbling block: *Nature is wont to conceal herself.* Mathematical advances aside, the first significant steps on the road to reality were achieved in the period between 1543, the year Copernicus published his heliocentric theory of planetary motion, and 1687, the year Newtonian mechanics was introduced. This era, the first Scientific Revolution, culminated in a working awareness of the solar system, a basic framework for studying dynamics, and a mathematical formulation of one of Nature's interactions, gravity.

Many of the hallmarks of progress along the road to reality can already be discerned in the first Scientific Revolution. Because Nature so deftly hides her secrets, a crazy theory is often a prerequisite for making any headway. Copernicus, for example, defied not only established authority but also the common sense of every observer who, under the illusion of being at rest, watched the sun move across the sky. Other necessities for progress—mathematics for formulating and developing a theory and a physical apparatus for testing it—were also essential components of the revolution. The improved instruments for measurement devised by Tycho Brahe permitted Kepler to refute the orbits of Copernicus's system. Newton's calculus allowed him to extend Galilean dynamics and explain the laws that Kepler had observed. The road to reality had taken its now familiar course of revolution followed by successive approximation.

The nineteenth century witnessed the second Scientific Revolution. Between 1850 and 1865, fundamental notions such as energy and entropy were introduced. At first, many scientists deprecated energy as a mathematical abstraction. By the end of the century, however, energy was replacing force as the preferred attribute of reality around which to organize physical theories. Several new branches of physics—thermodynamics, statistical mechanics, the kinetic theory of gases—arose accordingly. The second revolution in physics culminated in a working awareness of our solar system's place in the Milky Way, the concept of a "disembodied" field, the mathematical description of a second fundamental interaction, namely electromagnetism, the discovery of an elementary particle (the electron), and, by virtue of the second law of thermodynamics, a stark new aspect of reality: the thermodynamic arrow of time.

Brian Blank is professor of mathematics at Washington University. His email address is brian@math.wustl.edu.

For all the successes of the second revolution, physics faced several challenges at the beginning of the twentieth century. The debate over the wave versus particle nature of light, which had erupted during the first revolution, was not definitively settled by the second, Maxwell's characterization of light as electromagnetic radiation notwithstanding. All experiments to detect a medium through which light propagated, the hypothetical luminiferous aether, failed. Newton's law of gravitation remained a useful scorecard of gravity, but it neither explained the mechanism by which gravity is effected nor permitted time to play any role in gravity's action. The new theories of the second revolution presented even more troublesome paradoxes, chief among which was the prediction of blackbody radiation having arbitrarily large energy. From an evolutionary point of view, our understanding of reality seems to have advanced not by a march down an orderly road but by an alternating sequence of leaps between the frying pan and the fire.

Historians of science often state that the twentieth century witnessed two revolutions in physics: quantum theory and general relativity. The first rescued physics from the ultraviolet catastrophe of blackbody radiation and resolved the dilemmas posed by the properties of light. By blurring the distinction between wave and particle, quantum theory presented counterintuitive insights into the nature of matter and energy. The second revolution, general relativity, combined space and time to provide a theory of gravity that is deeper than a mere bookkeeping formula. Both revolutions profoundly changed our conceptions of physical reality.

The twentieth century was, indeed, a productive one for physicists; two revolutions may not give them their due. A second elementary particle, the photon, was detected in 1923. By 1932 both the proton and the neutron had also been discovered. These nucleons led physicists to an additional two interactions: the strong and weak nuclear forces. Within a few decades, a large menagerie of subatomic particles had been assembled: positrons and muons in the 1930s, pions and kaons in the 1940s, Pauli's long-conjectured neutrino in the 1950s, and a great many others. The ever increasing particle zoo became ever more perplexing. Once, after having given a speculative lecture at Columbia, Wolfgang Pauli admitted, "This is a crazy theory." From the audience Niels Bohr called out, "Unfortunately, it is not crazy enough!" In 1963 Murray Gell-Mann and, independently, George Zweig proposed a theory of fractionally charged elementary particles (christened *quarks* by Gell-Mann) that proved to be just crazy enough. In the next decade and a half, the so-called *Standard Model* of elementary particles and their interactions arose. It is a theory that experimental physicists have repeatedly confirmed to exacting standards. Particles continue to be discovered—notably the top quark in 1995 and the τ-neutrino in 2000—but they fit into the theory the way the man-made synthetic elements fit into the periodic table.

During the same time span in which high energy physicists probed the smallest bits of reality, astronomers and astrophysicists revolutionized our understanding of the largest objects of reality, including our universe itself. By 1923 astronomers had confirmed the existence of galaxies beyond the Milky Way. Observations of distant celestial bodies coupled with general relativity gave rise to a new branch of physics, cosmology, that tells us much about how our universe came to be and how it will cease to be. Though elementary particle physics and cosmology deal with objects at diametrically opposite ends of reality, the two fields have come to be intricately intertwined. Knowledge gained from the study of subatomic processes is the basis for understanding the physics of stars and the synthesis of heavy elements in the universe. In return, the exotic constituents of the universe provide important tests of particle theory.

The whirlwind tour we have just concluded represents only a tiny fraction of what *The Road to Reality* covers in its 1,100 pages. Anyone who casually flips through a few of those pages will recognize immediately that more than length distinguishes *The Road to Reality* from other expositions that target a roughly similar audience. Here, uniquely so far as I am aware, we find an author presenting sophisticated concepts of physics by invoking sophisticated concepts of mathematics. Even an experienced mathematician who happens upon a page illustrated with diagrammatic tensor notation might shy away from Penrose's *Road*. As the author explains in his preface, "What I have to say cannot be reasonably conveyed without a certain amount of mathematical notation and the exploration of genuine mathematical concepts." Do not take this declaration to be a contemporary version of Copernicus's *Mathemata mathematicis scribuntur*: Penrose's idea is that mathematics should be written not only for mathematicians but also for anyone willing to learn. To that end, remedial lessons begin in the preface, where rational numbers are defined as equivalence classes.

The first sixteen chapters of *The Road to Reality* are primarily devoted to the mathematics needed to express modern physical theory. By the time page 383 is reached, the intrepid reader will have been introduced to a large number of topics in analysis, algebra, and geometry. Of these, the demands of analysis are comparatively modest: calculus, Fourier series, hyperfunctions, Riemann surfaces, and enough complex function theory to state the Riemann mapping theorem. The necessities

from algebra include quaternions, Clifford and Grassmann algebras, linear algebra, transformation groups, and enough Lie theory to discuss the classical groups and their Lie algebras and representations. The topics from differential geometry are the most arduous: parallel transport, geodesics, curvature, the exterior derivative, calculus on manifolds, connections, and fibre bundles. All told, Penrose has condensed the outline of a quite respectable education in undergraduate mathematics into the first third of his book. When he states, "I am an optimist in matters of conveying understanding," we are inclined to believe him.

As a coping mechanism for the reader who turns off whenever a mathematical formula presents itself, Penrose suggests "skipping all the formulae and just reading the words." Such advice surely transcends well-founded optimism for there is scarcely a page on which mathematics and prose are not thoroughly interwoven. Readers who shun mathematics would do far better seeking out the many excellent works that target a more general audience and that can be assembled to cover similar ground. Even those who do not flee from mathematical symbols may prefer explanations of science in the style of Brian Greene or Stephen Hawking. Mathematicians who are interested in physics, however, should give Penrose's book more serious consideration. Some will choose to cut the book down to size by passing over the first sixteen chapters entirely. Others who want to brush up on a few topics will find that Penrose's synopses provide a useful background for the physics that lies ahead.

With 382 pages of mathematical preliminaries out of the way, Penrose turns his attention to the various scientific revolutions that transformed physics in the twentieth century. The second part of his book comprises 352 pages that are devoted to general relativity, quantum theory, elementary particle physics, and cosmology. The transition from mathematics to physics is nearly seamless. In part, that is because Penrose does not rigidly compartmentalize the two subjects. Quantum numbers are introduced in the chapter on the geometry of complex numbers, gauge connections appear in the chapter on fibre bundles, and, in the other direction, Hilbert spaces, unitary operators, and spherical harmonics are found in a chapter on quantum theory. Another reason for the smooth integration of mathematics and physics is that Penrose speaks with the voice of a mathematical physicist: even when topics from physics are not entirely familiar to us, the method and language of presentation are. For the selective reader, navigation between mathematics and physics is facilitated by the extensive collection of forward and backward references. The reader who has skipped over a bit of mathematics to speed ahead to the physics will find the backward references helpful. The forward references may strengthen the incentives of some readers to slog through seemingly abstract mathematics.

Those who reach the chapters on special relativity, general relativity, and quantum mechanics will find excellent treatments that are filled with physical insights and mathematical context. In particular, the four consecutive chapters that begin with the quantum particle and conclude with Paul Dirac's theoretical discovery of antiparticles are especially enlightening. In the last of these chapters, Penrose shows how the integration of special relativity and quantum theory gives rise to the prediction of antiparticles. Starting with the relativistic Hamiltonian of a quantum particle of rest mass μ, Penrose develops the Klein-Gordon equation $(\Box + (\mu/\hbar)^2)\,\psi = 0$ for the wavefunction ψ. He shows us how Dirac, by rediscovering Clifford algebras, factored the Klein-Gordon equation into what we now call the Dirac and anti-Dirac equations. Exposure to this mathematical background provides the reader with genuine insights into Dirac's prediction of the positron, the antiparticle of the electron, which was discovered only one year after its conjectured existence.

Dirac's theory of the electron is a natural point of departure for the Standard Model of elementary particles and their interactions, a subject that does not lend itself well to popular exposition. One of the difficulties is that the Standard Model is filled with jargon, much of which is whimsical rather than intuitive. Even more problematic for the novice is the overlapping of terms, as illustrated by the following sentence from *The Road to Reality*: "The family of hadrons includes those fermions known as 'baryons' and also those bosons referred to as 'mesons'." Hundreds of different particles—enough to make your head spin or your eyes glaze over, to quote Brian Greene—abound, all governed by a complicated theory of debatable mathematical consistency. In short, an author who attempts to explain the Standard Model to a general audience faces many pitfalls; Penrose does not sidestep all of them. Consider, for example, the discussion of hadrons in *The Road to Reality*. Hadrons are, by definition, the particles that interact through the strong nuclear force. On page 101, Penrose introduces them in this way: "...the modern viewpoint [is] that the 'strongly interacting' particles known as *hadrons* (protons, neutrons, π-mesons, etc.) are taken to be composed of *quarks*." It is a short excerpt that is laced with trouble for the newcomer:

- Commas should delimit the participial clause; as rendered, Penrose's statement implies that the set of hadrons does not contain the set of strongly interacting particles. This confusion is not entirely resolved 500 pages later when Penrose's next description of hadrons allows them

to be a proper subset of the strongly interacting particles.

- Including the π-mesons in a list of familiar particles intended to anchor the concept of hadrons is counterproductive: the quoted extract is the only indexed entry for π-mesons. The problem propagates when, without explanation, Penrose uses the alternative terminology, *pions*, the next four times he mentions π-mesons (pages 436, 437, 494, and 628). The definition of *meson* finally appears on page 646, but it is not indexed.
- The subatomic particles represented by "etc." are not revealed until 500 pages later.
- The use of the phrase "are taken to be composed of" rather than the more concrete "are composed of" is baffling. The sentence has begun not with "the *fact* is" but with the equivocating "the modern viewpoint is". Why is further hedging necessary?
- The assertion of the quoted excerpt, repeated on page 645 as "All hadrons are taken to be composed of *quarks*," is contradicted when Penrose later states that each meson is composed of one quark and one antiquark. Additionally, *glueballs*, which are believed to have been detected at BNL, CERN, and DESY, are quarkless hadrons comprising only gluons.

The problems highlighted by the preceding discussion are neither isolated nor uniquely Penrose's: several well-regarded elementary treatments of the Standard Model, such as [3] and [10], are, in places, just as exasperating. Where Penrose bests other popularizers is that he gets the reader closer to the underlying mathematical structure. By discussing gauge connections and symmetry groups in a nontrivial way, he alone allows his readers to understand why the Standard Model is also called the $SU(3) \times SU(2) \times U(1)$ theory.

With the chapter called *The Big Bang and its thermodynamic legacy*, Penrose concludes the second part of *The Road to Reality* by sketching our present knowledge of cosmology. In outline, the Big Bang theory of an expanding universe originated when Alexander Friedmann (1922) and, independently, Georges Lemaître (1927), solved Einstein's equations of gravitation without adopting Einstein's initial hypothesis of a static universe. Edwin Hubble's discovery (1929) of the recession of galaxies provided early experimental evidence for the Friedmann-Lemaître model. Nevertheless, the Big Bang explanation for the expansion of the universe seemed to be just one more crazy theory—the name itself originated in the 1950s from a sarcastic barb that was uttered by a dissenting cosmologist. Beginning in 1964 when the cosmic microwave background radiation predicted by Big Bang cosmology was detected, an overwhelming body of observational evidence has confirmed the theory. Conventional treatments of cosmology flesh out this summary with a great deal of additional detail. Penrose, on the other hand, dispenses with these matters in a mere two paragraphs, which he finally presents more than one-third of the way into the chapter. Standard expositions of the Big Bang walk the reader through the stages of the cooling universe from Planck time to the present. Penrose does not. The notion of "freezing out" appears briefly in his chapter on the Standard Model but its role in the evolution of the early universe is not made clear. For that matter, neither nucleosynthesis nor star formation finds its way into *The Road to Reality*. There *is* a brief discussion of stellar evolution but it serves only to describe the creation of black holes. By and large, the chapter focuses on the thermodynamic puzzles of Big Bang cosmology that Penrose has raised and studied since the 1970s. While it is good to have an expert present mysteries of the universe that have occupied his thoughts for three decades, the downside is that readers will have to look elsewhere if they want to understand how the reality we now experience emerged from a plasma of elementary particles.

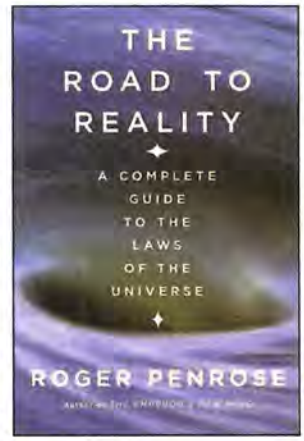
As I have suggested, *The Road to Reality* comprises three books in one. The third part, which is nearly as long as each of the first two, concerns the road ahead. It is here that Penrose fully lives up to his reputation as a recusant among physicists. According to an idea of cosmology that is now generally accepted, at some instant of time no later than 10^{-12} seconds "after the bang", the universe underwent an "inflationary" period of exponential growth in which its size increased by a factor of at least 10^{30}. The theory was conceived in 1979 by Alan Guth as an answer to the magnetic monopole problem that signaled a conflict between Big Bang cosmology and grand unified theories. At first, inflationary cosmology appeared to be yet another crazy theory. However, inflation resolved so many significant difficulties of conventional Big Bang theory that it gained serious consideration in short order. Inflation has also won over skeptics by being a predictive theory that has not been refuted by the observations that have been made since its formulation. Additionally, inflation, if correct, would indicate the presence of the long-sought hypothetical Higgs field at an earlier time of the universe. As Leon Lederman, one of the leading particle hunters, declared, "The astrophysicists have discovered a Higgs thing!" Against this cheery backdrop, Penrose will seem to be a killjoy when he demurs that "there are powerful reasons for doubting the very basis of inflationary cosmology."

The controversy over inflation might have been avoided, but it fits into the theme of the final portion of Penrose's book. His thesis is that there are too many inadequately explained phenomena for

us to be near the end of the road to reality. Most pressing is the provisional nature of the Standard Model. Because this theory requires fundamental constants of nature as *input* parameters, it describes the reality of a different universe just as contentedly as it describes our own. That the values of the fundamental constants now seem arbitrary and not prescribed is, presumably, a defect of our present knowledge. Of even greater concern is the conflict between quantum theory and general relativity in those realms where they should both apply. Until some verifiable theory of quantum gravity appears, we must consider ourselves far from the road's end. Indeed, there is now a fork in the road that has caused an often contentious debate over the correct continuation. Penrose devotes a chapter to each of three possible paths to quantum gravity: string theory, loop variables (LQG), and his own twistor theory. (These approaches are also discussed, at a more elementary level, by Lee Smolin, a proponent of LQG, in *Three Roads to Quantum Gravity* [8]. Given that string theorist Brian Greene's recent book [1] has a section titled *Roads to Reality*, we infer that there is at least agreement about the metaphor that is to be used.)

Penrose may have taken off his gloves in the chapter on inflationary cosmology, but it is in the string theory chapter that bare-knuckle fisticuffs break out. In the first paragraph of the chapter, Penrose writes, "Very few [physicists] appear to anticipate that there will be fundamental changes in the framework of quantum mechanics. Instead, they argue for strange-sounding ideas like the need for extra dimensions to spacetime, or for point particles to be replaced by extended entities known as 'strings'." Five sections later, the rhetoric escalates: "To its most extreme detractors, [string theory] has achieved absolutely nothing, physically so far, and has little chance to play any significant role in the physics of the future." Although the reader may suspect that Penrose is not putting words in *other* detractors' mouths, he allows only that he is "less than positive about a good many aspects of the current string-theory programme". Unlike the theoretical objections to string theory that Penrose raises, many physicists object on principle: their tradition is to dismiss theories not tested by experiment as either philosophy or religion or mathematics. In his recent book on particle physics [10, p. 308], Nobel laureate Martinus Veltman expresses his justification for omitting string theory and supersymmetry with language that is as blunt as Penrose's: "The fact is that this book is about physics, and this implies that the theoretical ideas discussed must be supported by experimental facts. Neither supersymmetry nor string theory satisfy this criterion. They are figments of the theoretical mind. To quote Pauli: they are not even wrong."

Expounding the creation of the universe and its ultimate fate invariably turns an author's mind to philosophy, theology, or some other contemplative outlet. Penrose neither ponders why there is something rather than nothing nor engages in what science journalist Timothy Ferris terms God-mongering. Instead, *The Road to Reality* concludes with a chapter in which Penrose muses upon beauty and miracles, mathematically driven physics, the function of falsifiability in scientific theory, and the role of fashion in physical theory. In the last of these topics, Penrose addresses the stampede that is taking place along the string theory road to quantum gravity. Bandwagon effects, he worries, are drawing an ever increasing number of theorists down a path he suspects to be a dead end. Penrose is also troubled by the curious jawboning that marks the landscape. If you have already investigated string theory, then it is likely that you are acquainted with the slogan, "String theory is the only game in town." One well-known string theory textbook, quoted by Penrose, dismissively pronounces, "There are no alternatives...all good ideas are part of string theory." Similarly, the author of a new book on string theory declares [9, p.357], "As much as I would very much like to balance things by explaining the opposing side, I simply can't find that other side." Overwhelmingly outnumbered, Penrose can do no more than remind us that, "With ideas that are as far from the possibility of experimental confirmation or refutation as those in quantum gravity, we must be especially cautious in taking the popularity of an approach as any real indication of its validity." The mathematician who peers in, unable to take sides, will begin to appreciate the hard-liner's position: *This is what comes of debating philosophy.*



A very long book is almost certain to generate some annoyances. For me, the professionally compiled yet abysmal index of *The Road to Reality* proved to be an enduring irritant. The electron neutrino's rest mass $m(\nu_e)$ makes a good case in point. Determining the value of this parameter, and, in particular, establishing that it is nonzero, is of great current interest. Penrose introduces neutrino mass on pages 636 and 637 and then provides an upper bound for $m(\nu_e)$ on page 872. However, this second discussion has no index entry and the first is indexed only under the misspelled *nutrino*. Another source of frustration is the haphazard handling of the physicists behind the physics. Many of their given names are reduced to initials, and some physicists are not even accorded that much: James Cronin, Val Fitch, John Clive Ward, and George Zweig rate neither a first name,

nor an initial, nor an index entry. Other physicists are *entirely* invisible. Thus, we learn about the Stern-Gerlach apparatus, but we do not encounter the two eponymous pioneers of quantum theory, Otto Stern and Walther Gerlach. Indeed, when a prominent physicist is mentioned, it is often only by chance. Eugene Wigner, for example, makes two tangential entrances, but not in the chapter that contains the circle of ideas once known as Wignerism.

Though these cited complaints are genuine, they do seem niggling when considered alongside the astonishing scope of Penrose's endeavor. The relatively few lapses that have been mentioned are not evidence of general carelessness. Given its length, breadth in both mathematics and physics, and its eight year gestation, *The Road to Reality* must be deemed extraordinarily accurate and coherent. If any nontrivial grievance is to be found, then I think we must look to an imbalance between the mathematical description of physical law and the presentation of observational support for it. Figments of the theoretical mind are part and parcel of mathematics, but when it comes to separating the crazy theories that represent physical reality from the crazy theories that are just plain crazy, we rely on empirical facts for conviction. Even Dirac, antielectron equation in hand, hesitated to predict antimatter. (As he later said, "The equation was smarter than I was.") Penrose's concentration on theory is perhaps best illustrated by his omission of CERN's Large Hadron Collider, which is scheduled to begin operations in 2007, from the chapter titled *Where lies the road to reality?* To obtain viewpoints drawn from the experimental side of physics, readers can supplement *The Road to Reality* with the excellent books ([4], [5]) of Leon Lederman and Don Lincoln, both of Fermilab. Reference [2] is an especially valuable resource containing articles written by many of the experimental and theoretical physicists who contributed to the Standard Model.

The Road to Reality was published in Great Britain and discussed by critics prior to the release of the American edition. Before Penrose's *Road* came into my hands, I was familiar with several reviews that damned it with faint praise. Typical of the bottom-line assessments is this one from Nobel laureate Frank Wilczek [11]: "There's much to admire and profit from in this remarkable book, but judged by the highest standards *The Road to Reality* is deeply flawed." With such criticism in mind, I approached my reviewing task apprehensively. As I progressed through the first few hundred pages, unconvinced by Penrose's conception, I found myself thinking nothing kinder than *The Road to Reality is paved with good intentions.* And yet, all my misgivings eventually yielded to the sheer quantity of Penrose's valuable insights and the unity with which he conveys the essential developments of twentieth century physics. In his review, Wilczek cites "serious blunders", drawing attention to three. These problems, perceptible only to sophisticates of physics, should be placed in perspective with a particular audience in mind. If Penrose brings his typical reader to the level of understanding the concepts that compose the disputed statements, then he has done a service in comparison to which the impact of his occasional miscues pales.

For mathematicians with a general interest in physics, Penrose's book will be self-recommending. Other mathematicians may find it useful to scan *The Road to Reality*, if only to glimpse the extent to which mathematical constructs infuse theoretical physics. There are a great many competing books that seek to explain the state of the art in fundamental physics. If you compare Penrose's work to any of the recent ones ([6], [7], [9], for example), then you will understand a reviewer's inclination to hold *The Road to Reality* up to the highest standards, for it is, indeed, *sui generis*. And that makes my bottom-line recommendation a cinch. For anybody who wants to learn up-to-date physics at a level between standard popularization and graduate text, *The Road to Reality* is the only book in town.

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WHAT IS . . .

a Coarse Space?

John Roe

Imagine a new student of analysis. In Calculus I, she hears about *limits* and *continuity*, probably at first in a quite informal way: "the limit is what happens on the small scale". Later, this idea is formalized in terms of the classical ϵ-δ definition, and soon it becomes apparent that the natural domain of this definition is the world of metric spaces. Then, perhaps in the first graduate course, the student takes the final step in this journey of abstraction: she learns that what really matters in understanding limits and continuity is not the numerical value of the metric, just the *open sets* that it defines. This realization leads naturally to the abstract notion of *topological space*, but it also enhances understanding even in the metrizable world—for instance, there is only one natural topology on a finite-dimensional (real) vector space, though there are many metrics that give rise to it.

The notion of *coarse space* arises through a similar process of abstraction starting with the informal idea of studying "what happens on the *large* scale". To understand this idea, consider the metric spaces $\mathbb{Z}^n$ and $\mathbb{R}^n$. Their small-scale structure—their topology—is entirely different, but on the large scale they resemble each other closely: any geometric configuration in $\mathbb{R}^n$ can be approximated by one in $\mathbb{Z}^n$, to within a uniformly bounded error. We think of such spaces as "coarsely equivalent".

Formally speaking, a *coarse structure* on a set X is defined to be a collection of subsets of $X \times X$, called the *controlled* sets or *entourages* for the coarse structure, which satisfy some simple axioms. The most important of these states that if E and F are controlled then so is

$$E \circ F := \{(x, z) : \exists y, (x, y) \in E, (y, z) \in F\}.$$

The other axioms require that the diagonal should be a controlled set, and that subsets, transposes, and (finite) unions of controlled sets should be controlled. The appearance of subsets of $X \times X$, rather than of X itself, is related to the word "uniformly" in our informal description of coarse equivalence at the end of the previous paragraph. In fact, it is more accurate to say that a coarse structure is the large-scale counterpart of a *uniformity* than of a topology.

These axioms are modeled on the behavior of the fundamental example, the *bounded coarse structure* on a metric space, where we say that a set is controlled if and only if the distance function $d: X \times X \to \mathbb{R}^+$ is bounded on it. A *coarse space* is a set with a coarse structure, and a *coarse map* is a proper map that sends controlled sets to controlled sets. Finally, two coarse spaces X and Y are *coarsely equivalent* if there exist coarse maps $f: X \to Y$ and $g: Y \to X$ such that the graphs of $f \circ g$ and $g \circ f$ are controlled subsets of $Y \times Y$ and $X \times X$ respectively. The reader can easily check that the inclusion $\mathbb{Z}^n \to \mathbb{R}^n$ and the "integer part" function $\mathbb{R}^n \to \mathbb{Z}^n$ implement a coarse equivalence between $\mathbb{Z}^n$ and $\mathbb{R}^n$. As another exercise, say that a coarse space X is *bounded* if $X \times X$ is controlled. Verify that this corresponds to metric boundedness, and that if X is bounded and nonempty, the inclusion of any point into X is a coarse equivalence.

Here are some more examples of coarse spaces underlying classical constructions in algebra, geometry, and topology.

► Let G be a locally compact topological group. The sets $\bigcup_{g \in G} gK$, as K ranges over compact subsets of $G \times G$, generate a canonical translation-

John Roe is professor of mathematics at Pennsylvania State University. His email address is jxr57@psu.edu.

invariant coarse structure on G. When G is discrete and finitely generated, this coincides with the bounded coarse structure coming from any word-length metric on G. Thanks to the work of Gromov and others, geometric group theorists know that many interesting properties of infinite discrete groups depend only on the large-scale properties of their word-length metrics: that is, on their coarse structure. For instance, it can be shown that such a group is coarsely equivalent to $\mathbb{Z}^n$ if and only if it actually contains $\mathbb{Z}^n$ as a subgroup of finite index.

► More generally let G act on a space V, with compact quotient; for instance, V might be the universal cover of a compact manifold M, and G the fundamental group of M. The sets $\bigcup_{g\in G} gK$, K compact in $V \times V$, generate a coarse structure on V; in the example of a universal cover, this is the coarse structure associated to the lift to V of any Riemannian metric on M. It is not hard to see that if the action is *proper*, then the map $g \mapsto gx$ (for any fixed $x \in V$) gives a coarse equivalence $G \to V$. This is the abstract form of an old result of Milnor and Svarc, which states that the orbit map $g \mapsto gx$, from the fundamental group G of a compact manifold M to its universal cover V, is a coarse equivalence. Taking M to be a torus, we recover our original example of the inclusion $\mathbb{Z}^n \to \mathbb{R}^n$.

► Let X be a dense open subset of a compact metrizable topological space Y. One can define a coarse structure on X by declaring that a subset $E \subseteq X \times X$ is controlled if, whenever (u_n, v_n) is a sequence in E and one of the sequences u_n, v_n converges to a point of $Y \setminus X$, the other sequence converges also to the same point. (To see where this curious definition comes from, think of X as $\mathbb{R}^n$ and Y as the compactification of X by the "sphere at infinity". Then every boundedly controlled set has the property indicated.) It can be shown that this *continuously controlled coarse structure* is not (except in trivial cases) the bounded structure associated to any metric.

We have already mentioned the importance of the canonical coarse structure on an infinite discrete group. A different application occurs in *controlled topology*, a method for addressing homeomorphism questions about manifolds that is rooted in the work of Quinn and others. A typical controlled construction on a manifold will carry out infinitely many of the basic "moves" of differential topology (connected sums, surgeries, handle attachments, and so on). This infinite process must be "controlled" in such a way that the result converges in the topological, although perhaps not in the differentiable category. One way to achieve this is to keep track of the sizes of the moves performed by parameterizing them over a coarse space, called the *control space*. Typically, the construction can be carried out provided that some algebraic invariant vanishes: an invariant that lies in an obstruction group depending on the control space. Continuously controlled coarse spaces $X \subseteq Y$ are particularly useful as parameter spaces here, because the relevant obstruction groups can be shown to be generalized homology groups of $Y \setminus X$.

Not unrelated to the previous example, coarse spaces have appeared in the *index theory* of elliptic partial differential operators on noncompact complete Riemannian manifolds. An elliptic operator D on a compact manifold has the Fredholm property: the kernel has finite dimension, the range has finite codimension, and the *index*

$$\mathrm{Index}(D) = \dim\ker D - \mathrm{codim}\,\mathrm{im}\, D$$

is a topological invariant of D. On a noncompact manifold the Fredholm property does not hold in the usual form. Nevertheless, one can define an "index group" (actually the K-theory of a certain C^*-algebra), which only depends on the coarse structure and which allows the index of D to be well-defined as an element of this group. (Any compact manifold is coarsely equivalent to a point, so the index group for all compact manifolds is the same. In fact it is $\mathbb{Z}$, and one recovers the ordinary index.) This construction allows the Atiyah-Singer index theorem and its applications to be generalized to noncompact manifolds. An important task remains, however: to compute the index group in particular cases.

Such computations have applications to differential topology, in particular to the question of which characteristic numbers are invariants of homotopy type (the *Novikov conjecture* proposes an answer to this question). A very general theorem of Yu computes the index group for a manifold that can be *coarsely embedded* in a Hilbert space. It follows that the Novikov conjecture is true for a compact manifold whose fundamental group coarsely embeds into Hilbert space. This is a very large class of groups, including all hyperbolic groups, all linear groups, and all amenable groups. In fact, any discrete group that acts amenably on a compact space must coarsely embed into Hilbert space.

It is now natural to ask whether every metric space, or every discrete group, can be coarsely embedded into Hilbert space. Unfortunately, the answer is negative: some counterexamples are furnished by expander graphs. A systematic understanding of all possible counterexamples and their connection with geometry and index theory remains elusive.

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What Symmetry Groups Are Present in the Alhambra?

Branko Grünbaum

On the occasion of the approaching International Congress of Mathematicians (ICM) (Madrid 2006) it is appropriate to renew the enjoyment of the arts—modern as well as historical—that grace many locations in Spain. The cover of the February 2006 issue, and the article by Allyn Jackson (starting on p. 218) are helpful, as is the note of Bill Casselman (on p. 213). Two sentences in the latter made me curious. Casselman states that "The geometric nature of Islamic design, incorporating complex symmetries, has been well-explored from a mathematical point of view. A fairly sophisticated discussion, referring specifically to the Alhambra, can be found in the book *Classical Tessellations and Three-manifolds* by José Maria Montesinos." I had visited the Alhambra more than twenty years ago and had seen Montesinos' book soon after it appeared; that's a long time ago, and I had forgotten the details. I was about to get the book from our library, but before that I checked the *Math Reviews*. There I found an assertion that ran counter to my memories; so I eagerly started looking at the book itself and recovering old papers and notes on the topic.

The question which of the seventeen wallpaper groups[1] are represented in the fabled ornamentation of the Alhambra has been raised and discussed quite often, with widely diverging answers. The first to investigate it was Edith Müller in her 1944 Ph.D. thesis at the Universität Zürich, written under the guidance of Andreas Speiser.[2] In her thesis [7] Müller documents the appearance of twelve wallpaper groups among the ornaments of the Alhambra.[3] (She also investigates other kinds of groups, but this is not relevant for our discussion at this time.) Due to a misunderstanding of Müller's comment that minor changes would have yielded two additional groups, several writers claimed that she found examples of fourteen groups. Some later

Branko Grünbaum is professor emeritus at the University of Washington in Seattle. *He gratefully acknowledges the help given by Bill Casselman and John Jaworski to the genesis of this note.* *The author can be reached at* `grunbaum@math.washington.edu`*; he will be happy to supply references for all statements in this note.*

[1] *Classes of discrete groups of isometries, with two independent translations.*

[2] *Speiser's 1922 text on the theory of groups deals extensively with the investigation of symmetry groups of ornaments and illustrates the topic with several patterns from ancient Egypt. His rather biased opinion about Egyptian decorations is best seen from his assertion that "...Egypt, which is the source of all later ornamentation" ("...Ägypten, denn hier is the Quelle aller späteren Ornamentik"). He also quotes approvingly (in the original English) the opinion of Flinders Petrie that "Practically it is very difficult, or almost impossible, to point out decoration which is proved to have originated independently, and not to have been copied from the Egyptian stock." More on this topic can be found in [2].*

[3] *She also investigated other kinds of groups as well, in particular the eighty groups of the two-sided Euclidean plane. These are the topic of a short note by Müller [8], which includes also illustrations of mosaics from the Alhambra representing nine different wallpaper groups. Despite her mathematical beginnings, Müller became a well-known astronomer, and was for several years the General Secretary of the International Mathematical Union. In a letter from 1984 she mentioned that there is continuing interest in her thesis and that there is a plan to republish it. Regrettably, this seems not to have happened.*

writers gave examples they claimed show the presence of one or the other of the missing groups, while others just stated that all seventeen are present in the Alhambra. This latter phenomenon can be most readily explained as authors copying from authors who copied from others—all without any actual investigation. An exception to this is part of José Maria Montesinos' book [6], in which he argues that the photos he presents show the appearance of all seventeen groups in the Alhambra. This was stressed in the review of [6] by Roger Fenn [1] that startled me: "...Incidentally, for the benefit of Hispanophiles, this book produces photographic evidence once and for all that all seventeen plane symmetry patterns appear in the Alhambra." But does it really? My memory contradicts this.

Before justifying my standpoint, let us briefly consider the situation in which one is asked to count the number of trees in a forest. Clearly, for the effort to mean anything one needs to know where to count them—in the whole forest, or a certain square mile, or some other part. But it also has to be decided

1. What kinds of trees to count;
2. What is a tree? Is a sapling a tree? Should a minimum of 3 inches diameter be required? If so, where is it to be measured (just above ground, 3 feet above ground or some other way)?
3. What about dead but standing trees? What about fallen trees, possibly decomposed to the extent that no visual examination can determine their kind?

In the light of this metaphor we may accept that Montesinos considers all mosaics, paintings, and plasterworks present in the whole Alhambra complex. But then we encounter problems:

There is no explanation concerning what is being considered in any particular ornament: Do we count the symmetries of the underlying tiling, without taking into account the colors of the tiles, or do we insist on color-preserving symmetries? (Similar questions about interlaces. The interlace in Figure 1[4] has 4-fold rotational symmetries with no reflections if the interlacing is considered, but has mirrors if it is not.) In fact, Montesinos counts whatever he finds convenient. In one case he replaces all non-white colors by black in order to find an example with 3-fold rotational symmetry and no reflections (see Figure 2). But one could equally well abstract color altogether and get an example with 6-fold symmetry. In another case (not illustrated) he does disregard colors altogether.

There is no explanation as to what is the size or extent of an ornament that is sufficient to accept it as a representative of a certain group. In one case a single decorated tile is considered, while in another case miniature copies of the pattern shown in Figure 3 are claimed to represent the group with 3-fold rotations and mirrors through all the rotation centers—although the sets of four triangles are in a pattern with 4-fold symmetry, and these are again arranged in a larger pattern with 4-fold symmetry, the whole just part of a decoration on the back of a chair.

Figure 1.

Figure 2.

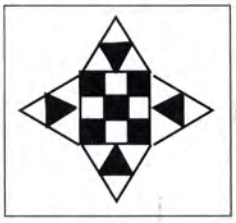

Figure 3.

Several of the ornaments shown are deteriorated to such an extent that it is impossible to see the pattern. Montesinos states that for several of these ornaments better examples can be found within the Alhambra, but does not show them.

As pointed out in a private communication from John Jaworski, it is easy to verify that by assigning appropriate colors, just two of the Alhambra mosaics could yield all seventeen groups. The

[4] *All photos were taken by the author in 1983, during a visit to the Alhambra while on a sabbatical from the University of Washington and with the support of a Guggenheim fellowship.*

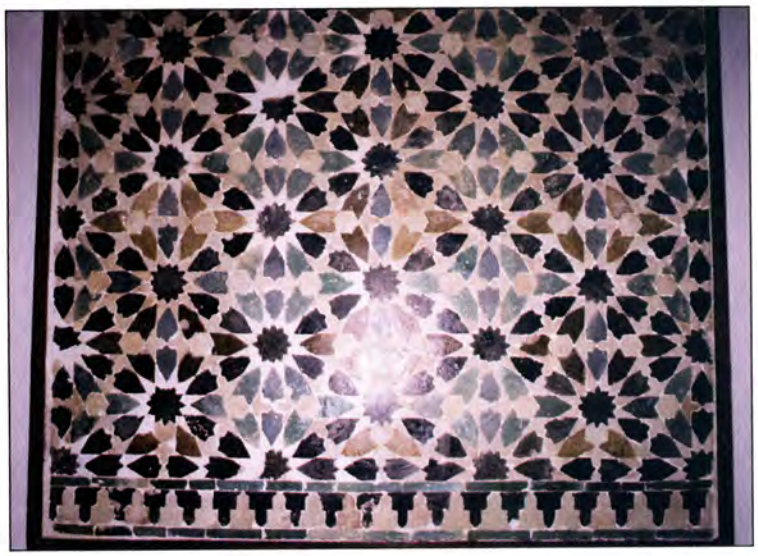

Figure 4.

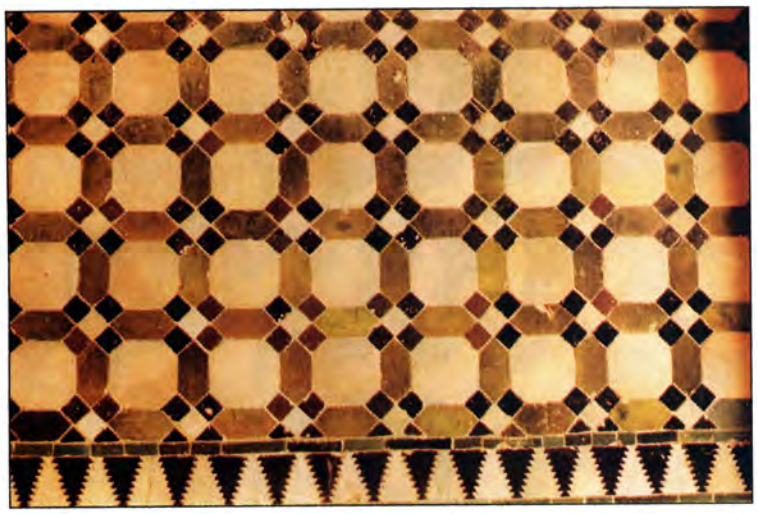

Figure 5.

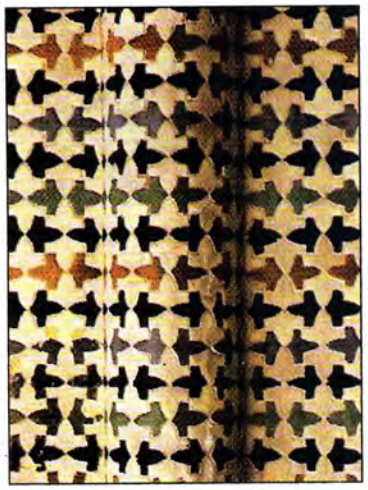

Figure 6.

ornaments shown in Figures 4 and 5 are suitable for that purpose; photos of the same ornaments have been used by Jaworski in his very interesting work [5].

Due to these objections, and similar ones that could be made concerning some other publications, Fenn's enthusiasm seems premature. Moreover, during several days in 1983 of examining the decorations in the Alhambra, I found representatives of the twelve wallpaper groups listed by Müller and one she missed; it is illustrated in Figure 6 (part of which is Montesinos' #4). A more detailed consideration of the difficulties in consistently counting the groups in the Alhambra, and what other kinds of groups (color symmetry, interlace symmetry, ...) might be more appropriate for some of the ornaments, appears in [4].

In view of the above discussion, one might wonder whether it is at all possible to arrive at a final, generally accepted count of the groups present in the Alhambra. The answer must be affirmative, but only if the counting is based on actual examination of the ornaments, presented in a consistent and well-explained manner, and following explicit criteria. It is possible that the presence of thousands of mathematicians at the International Congress may lead some of them to visit the Alhambra and be sufficiently taken by its splendor to invest their time and energy in such a count.

On the other hand, one may well ask why anybody would wish to do this, and what—if anything—would be the significance of the result. It seems to me that there is no more meaning to the determination of that number than, say, to the parity of the number of attendees of the ICM. *Groups* of symmetry had no relevance to artists and artisans who decorated the Alhambra. They certainly could have produced equally attractive ornamentation in any of the symmetry groups had anybody wished them to do so. Naturally, nobody did, since nobody knew about symmetry groups for the next five centuries. Thus it is only our infatuation with the idea that any attractive ornamentation must be explained in group-theoretic terms that leads us to try to find them there. It is probably worth mentioning that the analogous infatuation of crystallographers with groups crashed with the discovery of quasicrystals.

Does this mean that there is no role for mathematics in the study of ornaments, in the Alhambra or anywhere else? I feel very strongly that there is, provided we approach the task in a way consistent with the culture we are trying to understand and interpret. Thus, we have to think, or at least try to think, in terms that people creating the artifacts would understand and follow.

As an example, there is a lot of what could be called symmetry in the tiling in Figure 6. Given the shape of the tiles, they are arranged in the only possible way; it entails periodicity. On this, the designer imposed coloration rules: Half the tiles are white; of the other half, half are black and the remainder are equally divided between green, blue, and brown tiles. This is a way of looking that would have been understood by the Moorish artisans and may well have been their intention. We could say that we find there an example of color symmetries (some horizontal mirrors preserve the white, black, and green tiles, while interchanging blue and brown ones, while other mirrors and glide axes lead to other permutations of colors)—but this would have been totally extraneous to the thinking of people

500 years ago, hence it is entirely irrelevant. There are many additional examples of similar assignments of colors, in the Alhambra as well as in the ornamentation of other cultures. For example, Figure 7 shows an example in which one half of the tiles are white, one quarter black, and the last quarter evenly divided between tan and green. A mathematical investigation of the possibilities would appear to be both interesting and doable and possibly even useful to anthropologists. On the other hand, in many cases there is no such orderliness in the colors of the tiles; one has the feeling that the artists destroyed the symmetries to make the tilings less monotonous.

In decorations on pottery, as well as other surfaces, patterns that are not discrete often appear. Circles around pots and vases, straight lines and strips on flat surfaces, are examples of (admittedly rather minimal) decorations. They are not approachable through the study of discrete groups—but their historic development within a culture still can be of interest.

In the study of the exquisite textiles from ancient Peru discrete patterns are common, and quite orderly. The motifs in some of them form one orbit under isometric symmetries, but in others this is not the case; often the colors "spoil" any symmetry. Moreover, just as in the case of Moorish ornamentation, investigation of the symmetry *groups* of the patterns is totally irrelevant. On the other hand it can be shown that taking into account the structure of the "fabric plane" in which the patterns are imbedded, one can devise (see [3]) an explanation for the orderliness of the patterns that could have been understood and transmitted among the illiterate weavers of long ago. As it turns out, there is only a finite number of possibilities.

There are probably many other situations in which a more flexible approach of mathematical interpretation would be not only more productive but also more relevant. In particular, this applies to the beautiful ornamentation in the Alhambra, but also to those in Sevilla and other locations.

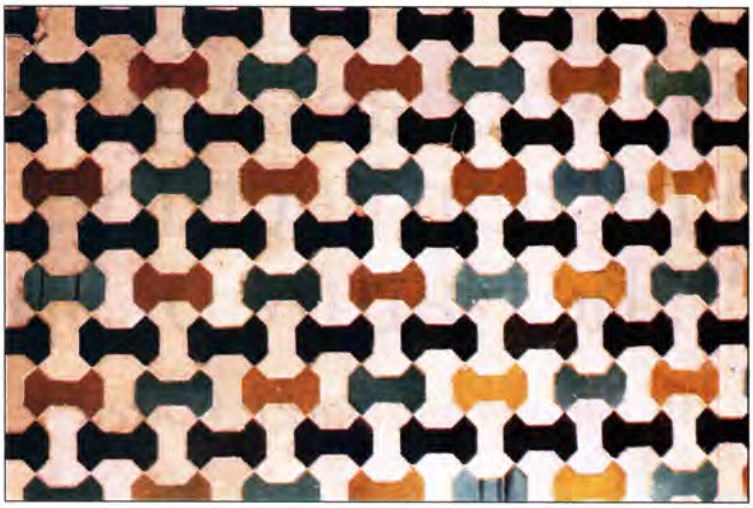

Figure 7.

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[5] *This interdisciplinary journal, with a blue-ribbon Advisory Board, was started after meticulous preparations, and its first issue contained contributions by A. L. Mackay, A. L. Loeb, M. J. Wenninger, C. A. Pickover, V. Vasarely, and others. The publication of the journal was cancelled after the first issue, by its publisher VCH Publishers, due to low rate of subscriptions. So much for investment in the interdisciplinary approach.*

[6] *Unfortunately, the dedication of the paper to Heinrich Heesch was omitted, and the colored illustrations have been rendered in black-and-white.*

Sir Michael Atiyah's Einstein Lecture: "The Nature of Space"

G. W. Johnson and Mark E. Walker

Sir Michael Atiyah, winner of both a Fields Medal and an Abel Prize, delivered the first annual Einstein Public Lecture at the University of Nebraska-Lincoln.[1] The smashing success of Atiyah's talk inspired the local student newspaper, *The Daily Nebraskan*, to quip "Usually Mick Jagger is the only petite Brit who can entertain a sold-out, adoring American audience. But on Friday afternoon, the renowned English mathematician Sir Michael Atiyah showcased both his uncanny sense of humor and genius while delivering a lecture on 'The Nature of Space' to a full-capacity crowd at the University of Nebraska-Lincoln's Kimball Recital Hall."

Sir Michael's lecture was intended for the general public. Indeed, the general public came: Over 850 people filled the lecture hall and many others had to be turned away at the door. Probably well over 400 people in the audience were not part of the conference itself, but rather consisted of a mix of students, from high-school on up, faculty from physics, philosophy, and other disciplines, and other members of the community. Sir Michael offered something for everyone in this diverse crowd. He discussed the major themes of 20th century science while hinting at the technical details. His lecture touched on issues in mathematics, physics, philosophy, and even evolution and neurophysiology. One part of his lecture concerned recent research on the human brain and how it might affect our understanding of mathematics and physics as well as long-standing philosophical issues.

Gerald W. Johnson is professor of mathematics at the University of Nebraska-Lincoln. His email address is gjohnson@math.unl.edu.

Mark Walker is associate professor of mathematics at the University of Nebraska-Lincoln. His email address is mwalker@math.unl.edu.

[1] *Atiyah's talk was delivered on October 21 as part of the 2005 AMS Fall Central Sectional Meeting, hosted by the Department of Mathematics at the University of Nebraska-Lincoln.*

Einstein's *Annus Mirabilis*

The year 2005 is well suited to begin the Einstein Lectures as it marks both the 100th anniversary of Einstein's *annus mirabilis* (miraculous year) and the 50th anniversary of Einstein's death. We expand somewhat upon Atiyah's remarks concerning Einstein.

Einstein submitted four articles to *Annalen der Physik* in the year 1905, three of which are regarded as masterpieces. One of these concerned Brownian motion (the first of five papers Einstein wrote on this topic), and it represented an important contribution to the molecular-kinetic theory of heat, providing support for the atomic theory at a time when it was still in doubt. Einstein's 1905 paper on the photo-electric effect was an early and major contribution to quantum theory. Einstein was never satisfied, however, with the way that probability theory enters into quantum mechanics; this was the source of his famous assertion that "God does not play dice." These two contributions alone would be enough to make Einstein an important figure in the history of physics, but his work on Special Relativity, which was also written in 1905 and which was followed by General Relativity (in 1916), certainly

place him at or near the top of anyone's list of the creative geniuses of physics. It has been claimed that each of these three 1905 papers was worthy of a Nobel Prize in physics, although only his work on the photo-electric effect was so honored, in 1921.

Here are some easily stated consequences of relativity theory:

1. The velocity of an object may appear different to different observers, but the velocity of light, c, is the same for all observers.
2. Energy and mass are related by the equation $E = mc^2$.
3. Space and time are not independent of one another—rather, motion through space influences an observer's measurement of time.
4. The geometry of space—in particular, its relationship with mass—is drastically different from what was believed prior to general relativity.

While being a creative genius in physics, Einstein was a consumer of mathematics, but his work, especially in relativity theory, has had a tremendous impact on mathematics.

It is amazing that the accomplishments of Einstein's *annus mirabilis* occurred while he was a twenty-six-year-old clerk in the patent office in Bern, Switzerland. As Atiyah pointed out, despite Einstein's excellent training in physics, he along with many other new graduates found it difficult to obtain an academic job.

Fundamental Philosophical Questions

Sir Michael touched on not only many areas of mathematics and physics, but also topics in philosophy, neuro-physiology, the nature of the human brain, and the theory of evolution. He asserted that understanding space is the fundamental problem of physics, and his talk focused extensively on the relationship between mathematics and physics, particularly with regard to the nature of space.

Plato believed that the world of ideal forms exists apart from the world perceived by our senses, whereas David Hume held that all knowledge is derived from sensory experience. Your point of view on this subject tends to influence your view of the role of mathematics and whether, in particular, you think mathematics is discovered or invented. Atiyah proposed that many (perhaps most) mathematicians hold the former view. Nearly everyone would agree that the integers were discovered and not invented. While Kronecker held the extreme view that "God made the integers, all else was made by man," most of us would likely accept that the rational numbers and even the real numbers were discovered. Some might point to the complex numbers, by contrast, as a convincing example of invention. Complex numbers are now known, however, to be fundamental in the real world of quantum mechanics. Similarly, although non-Euclidean

Sir Michael Atiyah.

geometry was "invented" before Einstein, it plays an important role in general relativity.

The orthodox view among physicists is that mathematics was invented as a language and a tool to deal with the physical world. Eugene Wigner, however, has pointed out the "unreasonable effectiveness of mathematics in the natural sciences"—that is, if mathematics is merely invented, how is it that mathematics that was invented to explain things at the "human scale" also applies at very small scales (nuclear) and very large scales (cosmology)? Atiyah's own view is that mathematics *originates* from the physical world but is *organized* and *developed* by the human brain. Moreover, this relationship is complicated by the fact that the brain is itself a part of the physical world and is thereby affected by it and cannot be completely segregated from it. Indeed, an evolutionary point of view is that humans evolved by natural selection so that the human mind is adapted to and reflects physical reality. Mathematical thinking is thus an incidental consequence of evolution. For example, the rules of logic are deduced from experience with cause and effect. This point of view, however, still does not address Wigner's observation.

Current research in neuro-physiology is shedding light on how the brain actually works. Atiyah himself has been collaborating on research into how the brain behaves when one is thinking about mathematics and about different types of mathematics. Neuro-physiology reveals that the rules of logic and grammar (the underpinnings for mathematics and language) appear to be "hard-wired" in the brain. As a consequence of evolution, we are born with the capacity to do mathematics and to learn language. New research has also raised questions about the nature of "conscious decisions". Atiyah speculated that old philosophical questions, including those about the nature of mathematics, will be transformed by future research in neuro-physiology, in much the same way that the ancient

Atiyah, delivering the 2005 Einstein Lecture.

question of "What is life?" was transformed by the discovery of DNA.

Physics and the Nature of Space

Atiyah presented a brief history of physics as it relates to the nature of space. He began with the Earth-centered picture of the second-century astronomer and mathematician Ptolemy. Ptolemy's theory of epicycles, circles rolling on other circles, describes the motion of the sun and the planets. It agrees well with observation and lasted a thousand years. By placing the sun at the center of the solar system, Copernicus achieved a simpler mathematical description that made the same predictions as Ptolemy's theory. The view that *simplicity* ought to be the aim of all physical theory remains prevalent to this day. Kepler wanted to explain the number and positions of the planets in terms of the five Platonic solids and how they can be inscribed in each other. Remarkably, his model accounts for the orbits of the planets known to him within an accuracy of about five percent.

Newton's Law of Universal Gravitation served as a paradigm for all subsequent physical theory—it is both simple and universal, covering, for example, the motion of an apple falling from a tree as well as the motion of the planets, the comets, and the tides. Assisted by the experimental work of Faraday, James Clerk Maxwell found the equations that unite and govern electricity and magnetism via the electromagnetic field. As with the Copernican model of the solar system, the hallmark of Maxwell's theory is its simplicity. Moreover, Maxwell's laws are widely applicable, covering, for example, such down-to-earth phenomena as the behavior of lights, radios, and the telephone. The physicist Richard Feynman believed that, thousands of years in the future, Maxwell's discovery of the laws of electrodynamics will be judged as the most significant event of the 19th century.[2]

It was at this point, in the early twentieth century, that Einstein appeared. Einstein described how mass curves the space-time continuum in general relativity, and he formulated the basic geometric idea in simple mathematical equations. Gravity in general relativity is a modification of Newtonian gravity, differing only negligibly from the latter in our everyday word.

Quantum mechanics was well-developed by the end of the 1920s, and it represented a totally new, mathematically more sophisticated subject. As mentioned above, it relies on the arithmetic of the complex numbers. Whereas the observables of Newtonian mechanics consist of a finite number of position and momentum coordinates, these are replaced in quantum mechanics by position and momentum operators. These operators are self-adjoint, but typically are unbounded and fail to commute. This noncommutativity yields the Heisenberg Uncertainty Principle, which tells us *on theoretical grounds* that the more precisely we know the position of a particle, the less precisely we know its momentum. In spite of the difficulties involved, quantum mechanics is a spectacular success and is the basis of atomic physics.

Einstein tried to find a unified field theory that would include general relativity and electromagnetism. He did not believe quantum mechanics would be an element of such a final theory because he did not accept the uncertainty inherent in quantum mechanics. This view spawned a great philosophical debate, in which Einstein and Niels Bohr were regarded as the main antagonists. The orthodox view among physicists today is that Einstein was wrong, but Atiyah rejected the orthodox view, to some degree, and spent a good deal of time promoting Einstein's viewpoint in this debate.

In the mid-twentieth century, the nuclear forces were studied, geometrically interpreted, and combined with Maxwell's equations. The generality of the results obtained would have pleased Einstein, but quantum mechanics was still used, and general relativity was not. String theory entered the scene in the last quarter of the twentieth century; it aims to combine all of the fundamental forces, including gravity. For this reason, string theory is sometimes called "the theory of everything". String theory is a stunningly complicated theory of the physical world, and some hold the view that it represents a twenty-first century idea that was "accidentally" discovered in the twentieth century.

Here are some important characteristics of string theory:

1. It requires more dimensions, 10 (or 11), than the usual 3 + 1 dimensions of space-time. The

[2] *See* The Feynman Lectures on Physics, *Vol. II.*

additional 6 (or 7) dimensions are hidden from our normal experience of reality.

2. Whereas more classically, the basic objects such as electrons, protons, and quarks, could be thought of as point particles, string theory interprets such objects as being very small "strings". This allows for a "smoothing out" of the singularities that arise in the classical picture when such particles come close together. Even the singularities associated with mixing quantum mechanical and gravitational forces are resolved in this manner.
3. Very sophisticated geometry is used, involving a vast amount of mathematics, both old and new.
4. No unique model or picture has emerged out of string theory, but rather several versions exist. These different theories are now known to be different facets of the same theory. What has happened to the "real world"?
5. Quantum mechanics remains the basic framework.

String theory has had a remarkable and mysterious impact on pure mathematics, leading to many new concepts and results. In some cases, such results have been given proofs in the traditional mathematical sense. In other situations, the "results" merely fit well with known mathematical results or accepted features of string theory. In particular, string theory has had an impact in

1. algebraic geometry, by addressing enumerative questions concerned with counting algebraic curves satisfying certain conditions;
2. knot theory, by construction of new topological invariants of knots that can sometimes distinguish a knot from its mirror image;
3. four-dimensional geometry, by giving new, unexpected, and very deep results that are unique to four dimensions; and
4. various branches of algebra.

A New Paradigm?

If a "theory of everything" emerges from string theory, we will discover a universe built on *fantastically intricate mathematics.* In particular, the Calabi-Yau manifolds that make up the hidden dimensions are extremely complicated. Atiyah suggested that it is not satisfying that the true theory would be so complicated—even writing down the terms of the theory requires a vast amount of background.

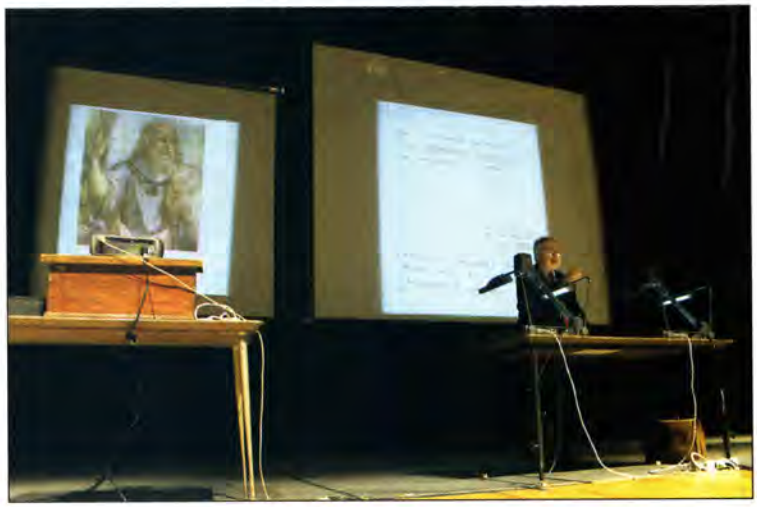
Perhaps, according to Atiyah, a new paradigm is needed; perhaps the complicated mathematics appearing in string theory is merely "in the eye of the beholder". That is, maybe we do not understand the fundamental nature of reality well enough, and this misunderstanding is leading to such exceptionally complicated mathematics. String theory, from this point of view, is only our method of approximating a simple reality. Perhaps, Atiyah suggested, we should follow Einstein and question quantum mechanics.

In order to make progress, we might need to dispense with some piece of accepted dogma. Relativity, quantum mechanics, and string theory have already dispensed with many previously held tenets, and so one might ponder whether there remains any such dogma left to throw away. Atiyah noted that all physical models since Newton, including even quantum mechanics, have assumed one basic premise—that we can *predict the future from full knowledge of the present.* Atiyah suggested an alternative to this paradigm: Perhaps we need full knowledge of the present *and the past* in order to predict the future. That is, maybe the universe has memory. As a simple example, the notion of the velocity of an object is viewed as being a property of the present, but, in reality, to measure velocity one needs to know not only where the object is now but where it was a moment earlier.

Atiyah's hypothesis possibly leads to several interesting consequences:

1. The mathematics used in physical theory would become more difficult, since all previously used mathematics in physics assumes that knowledge of the present suffices. With the new paradigm, for example, retarded (or delay) differential equations would become necessary.
2. Since we do not have complete knowledge of the past, uncertainty would arise. This might shed light on the uncertainty inherent in quantum mechanics.
3. Perhaps the complicated mathematics of string theory arises from our attempt to understand the full implications of the theory of general relativity without incorporating the knowledge of the past.

Atiyah does not promote discarding older, time-tested physical theories. Rather, such a new



paradigm ought to build on the old theories, much as relativity builds on Newtonian mechanics.

Speculations and Questions

There are various attitudes among physicists toward string theory. Some dismiss it as fancy mathematics that is unrelated to the real world, since string theory makes no testable predictions. Others believe the mathematical applications of string theory give confidence in the physical insights and indicate that the theory is on the right track. From this point of view, mathematical applications become a kind of alternative to experimental evidence. A third point of view is that we should continue to push forward with string theory in the hope that the new results and ideas that emerge will serve as a guide for finding a final unified theory.

Atiyah concluded his talk by speculating on the meaning of all this—quantum field theory, string theory, and their mathematical applications. What will the future physical theory look like? The aim is to unify quantum mechanics, the physics of the very small, with general relativity, the physics of the very large. Supersymmetry is a symmetry in which physical laws are unchanged when bosons and fermions are interchanged. Superstring theory, a supersymmetric string theory, is a perturbative approach, one that Atiyah compared with the theory of epicycles developed by Ptolemy. But what is the real theory; that is, what is being perturbed? Is it M-theory, a currently incomplete theory unifying all five versions of string theory? Is the universe really built using all this sophisticated machinery or is this an example of mathematics imposed by us? Perhaps the real physics is simpler and one should adhere to the dictate of Occam's razor—concepts should not be multiplied beyond necessity. Do we need to modify quantum mechanics? Atiyah closed by saying "This is for young people: Go away and explore it. If it works, don't forget I suggested it. If it doesn't, don't hold me responsible."

The second Einstein Public Lecture in Mathematics was delivered on April 29, 2006, in conjunction with the AMS Spring Western Sectional Meeting at San Francisco State University. Benoît Mandelbrot of Yale University spoke on "The nature of roughness in mathematics, science, and art".

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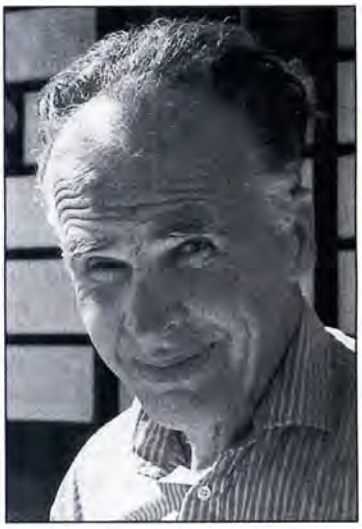
Carleson Receives 2006 Abel Prize



Lennart Carleson

The Norwegian Academy of Science and Letters has decided to award the Abel Prize for 2006, worth 6,000,000 Norwegian kroner (US$920,000) to LENNART CARLESON, professor emeritus at the Royal Institute of Technology, Sweden, and at the University of California, Los Angeles, "for his profound and seminal contributions to harmonic analysis and the theory of smooth dynamical systems."

In 1807 the versatile mathematician, engineer, and Egyptologist Jean Baptiste Joseph Fourier made the revolutionary discovery that many phenomena, ranging from the typical profiles describing the propagation of heat through a metal bar to the vibrations of violin strings, can be viewed as sums of simple wave patterns called sines and cosines. Such summations are now called Fourier series. Harmonic analysis is the branch of mathematics that studies these series and similar objects.

For more than 150 years after Fourier's discovery, no adequate formulation and justification was found of his claim that every function equals the sum of its Fourier series. In hindsight this loose statement should be interpreted as regarding every function for which "it is possible to draw the graph", or more precisely, every continuous function. Despite contributions by several mathematicians, the problem remained open.

In 1913 it was formalized by the Russian mathematician Lusin in the form of what became known as Lusin's conjecture. A famous negative result of Kolmogorov in 1926, together with the lack of any progress, made experts believe that it would only be a matter of time before someone constructed a continuous function for which the sum of its Fourier series failed to give the function value anywhere. In 1966, to the surprise of the mathematical community, Carleson broke the decades-long impasse by proving Lusin's conjecture that every square-integrable function, and thus in particular every continuous function, equals the sum of its Fourier series "almost everywhere".

The proof of this result is so difficult that for over thirty years it stood mostly isolated from the rest of harmonic analysis. It is only within the past decade that mathematicians have understood the general theory of operators into which this theorem fits and have started to use Carleson's powerful ideas in their own work.

Carleson has made many other fundamental contributions to harmonic analysis, complex analysis, quasi-conformal mappings, and dynamical systems. Standing out among them is his solution of the famous corona problem, so called because it examines structures that become apparent "around" a disk when the disk itself is "obscured", poetically analogous to the corona of the sun seen during an eclipse. In this work he introduced what has become known as Carleson measures, now a fundamental tool of both complex and harmonic analysis.

The influence of Carleson's original work in complex and harmonic analysis does not limit

itself to this. For example, the Carleson-Sjölin theorem on Fourier multipliers has become a standard tool in the study of the "Kakeya problem", the prototype of which is the "turning needle problem": how can we turn a needle 180 degrees in a plane, while sweeping as little area as possible? Although the Kakeya problem originated as a toy, the description of the volume swept in the general case turns out to contain important and deep clues about the structure of Euclidean space.

Dynamical systems are mathematical models that seek to describe the behavior in time of large classes of phenomena, such as those observed in meteorology, financial markets, and many biological systems, from fluctuations in fish populations to epidemiology. Even the simplest dynamical systems can be mathematically surprisingly complex. With Benedicks, Carleson studied the Hénon map, a dynamical system first proposed in 1976 by the astronomer Michel Hénon, a simple system exhibiting the intricacies of weather dynamics and turbulence. This system was generally believed to have a so-called strange attractor, drawn in beautiful detail by computer graphics tools, but poorly understood mathematically. In a great tour de force, Benedicks and Carleson provided the first proof of the existence of this strange attractor in 1991; this development opened the way to a systematic study of this class of dynamical systems.

Carleson's work has forever altered our view of analysis. Not only did he prove extremely hard theorems, but the methods he introduced to prove them have turned out to be as important as the theorems themselves. His unique style is characterized by geometric insight combined with amazing control of the branching complexities of the proofs.

Carleson is always far ahead of the crowd. He concentrates on only the most difficult and deep problems. Once these are solved, he lets others invade the kingdom he has discovered, and he moves on to even wilder and more remote domains of science.

The impact of the ideas and actions of Lennart Carleson is not restricted to his mathematical work.

He has played an important role in the popularization of mathematics in Sweden. He wrote the popular book *Matematik för vår tid (Mathematics for Our Time)*, and he has always been interested in mathematical education.

Carleson has had twenty-six Ph.D. students, many of whom became professors at universities in Sweden and elsewhere. As director of the Mittag-Leffler Institute near Stockholm from 1968 to 1984, he realized the original vision of Mittag-Leffler, building the Institute as we now know it, a foremost international research center in mathematics. He also placed special emphasis on the role of the Institute in the mentoring of young mathematicians, a tradition that continues to this day.

As president from 1978 to 1982 of the International Mathematical Union (IMU), Carleson worked hard to have the People's Republic of China represented. He also convinced the IMU to take the contributions of computer science to mathematics into account and was instrumental in the creation of the Nevanlinna Prize, rewarding young theoretical computer scientists. As president of the Scientific Committee of the fourth European Congress in Mathematics, in 2004, he started the initiative of the Science Lectures, where distinguished scientists discuss the most relevant aspects of mathematics to science and technology.

Lennart Carleson is an outstanding scientist with a broad vision of mathematics and its role in the world.

Lennart Carleson was born on March 18, 1928, in Stockholm. He received his Ph.D. from Uppsala University in 1950 and did postdoctoral work at Harvard University, 1950–1951. He has held postions at Uppsala University; the University of Stockholm; the University of California, Los Angeles; and the Royal Institute of Technology in Sweden. In addition to serving as director of the Mittag-Leffler Institute from 1968 to 1984, he has served on the scientific committee for the Institut des Hautes Études Scientifiques since 1983. He is a member of the Royal Swedish Academy of Sciences and a foreign member of several scholarly academies around the world. He received the AMS Steele Prize for a Seminal Contribution to Research (1984), the Wolf Prize (1992), the Lomonosov Gold Medal of the Russian Academy of Sciences (2002), and the Sylvester Medal of the Royal Society, London (2003).

—From a Norwegian Academy of Science and Letters news release

Langlands Receives Nemmers Prize

ROBERT P. LANGLANDS has received the 2006 Frederic Esser Nemmers Prize in Mathematics from Northwestern University. Awarded to scholars who made major contributions to new knowledge or the development of significant new modes of analysis, the Nemmers Prize carries a US$150,000 stipend.

Langlands, Hermann Weyl Professor of Mathematics at the Institute for Advanced Study in Princeton, New Jersey, has been awarded the Nemmers Prize for his "fundamental vision connecting representation theory, automorphic forms, and number theory". In connection with the award, Langlands will deliver public lectures and participate in other scholarly activities at Northwestern during the fall of 2007.

Langlands is best known for the fundamental research program that bears his name. "This program postulates a deep relationship between two different areas of mathematics, number theory, and automorphic forms, via a study of their symmetries," said Kari Vilonen, professor of mathematics at Northwestern. "Since its initiation about forty years ago, the Langlands program has served as a unifying principle in mathematics and has guided research in number theory, automorphic forms, and representation theory," Vilonen said. "Recently, it also has entered mathematical physics. It remains a research program for the future in all these areas."

Langlands has received numerous distinguished awards, including the AMS Steele Prize for a Seminal Contribution to Research (2005), the Grande Medaille d'Or de l'Académie de Sciences de Paris (2000), the Wolf Prize in Mathematics (1995–96), the National Academy of Sciences Award in Mathematics (1988), and the AMS Cole Prize (1982). He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences.

Robert P. Langlands

The Nemmers Prizes are made possible through bequests from the late Erwin E. Nemmers, a former member of the Northwestern University faculty, and his brother the late Frederic E. Nemmers, both of Milwaukee. The prizes are awarded every other year. Previous recipients have been Robert J. Aumann (1998) in economics, and, in mathematics, Yuri I. Manin (1994), Joseph B. Keller (1996), John H. Conway (1998), Edward Witten (2000), Yakov G. Sinai (2002), and Mikhael Gromov (2004).

Erwin Esser Nemmers, who persuaded his brother to join him in making a substantial contribution to Northwestern, served as a member of the faculty of the Kellogg School of Management from 1957 until his retirement in 1986. Along with his brother, Frederic E. Nemmers, he was a principal in a Milwaukee-based, family-owned church music publishing house. Their gifts, totaling US$14 million, were designated for two purposes: the establishment of four endowed professorships in the Kellogg School of Management and the establishment of the Nemmers Prizes.

Lars Hansen, the Homer J. Livingston Distinguished Service Professor at the University of Chicago, was awarded the 2006 Erwin Plein Nemmers Prize in Economics.

—From a Northwestern University news release

Mathematical Sciences in the FY 2007 Budget

Samuel M. Rankin III

Highlights

- Federal support for the mathematical sciences is slated to grow from an estimated US$384.00 million in FY 2006 to an estimated US$396.34 million in FY 2007, an increase of 3.2 percent.
- The National Science Foundation's (NSF) Division of Mathematical Sciences (DMS) would increase by 3.2 percent to US$205.74 million.
- The aggregate funding for the mathematical sciences in the Department of Defense (DOD) agencies (Air Force Office of Scientific Research (AFOSR), Army Research Office (ARO), Defense Advanced Projects Agency (DARPA), National Security Agency (NSA), and Office of Naval Research (ONR)) would increase by 8.5 percent. The majority of this increase comes from two agencies, AFOSR (15.6 percent) and DARPA (9.1 percent).

Introduction

Research in the mathematical sciences is funded through the National Science Foundation, the Department of Defense (including the National Security Agency), the Department of Energy (DOE), and the National Institutes of Health (NIH). As in previous years, the majority of federal support for the mathematical sciences in FY 2007 would come from the NSF, contributing approximately 51.9 percent of the federal total. The DOD accounts for around 20.9 percent of the total, with the NIH supplying 19.8 percent, and the DOE around 7.4 percent. The NSF currently accounts for almost 80.0 percent of the federal support for academic research in the mathematical sciences and is the only agency that supports mathematics research broadly across all fields. The DOD, DOE, and NIH support research in the mathematical sciences that contributes to the missions of these agencies.

The DOD supports mathematical sciences research and related activities in several programs: the Directorate of Mathematics and Information Sciences within the AFOSR; the Mathematical Sciences Division within the ARO; the Mathematical, Computer, and Information Sciences Division within the ONR; the Defense Sciences Program and the Microsystems Technology Office within DARPA; and the Mathematical Sciences Program within the NSA.

The DOE funds mathematics through its Applied Mathematics program within the DOE Mathematical, Information and Computational Sciences program. The National Institutes of Health funds mathematical sciences research primarily through the National Institute of General Medical Sciences (NIGMS) and through the National Institute of Biomedical Imaging and Bioengineering (NIBIB).

Several other agencies have small amounts of funding for mathematics research as it relates to agency missions. These agencies include the National Aeronautics and Space Administration (NASA), the Environmental Protection Agency (EPA), and the National Institute of Standards and Technology (NIST).

Samuel M. Rankin III, is director of the AMS Washington office. His email address is smr@ams.org.

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Trends in Federal Support for the Mathematical Sciences

The FY 2007 estimated aggregate spending for mathematical sciences research and related activities would be US$396.34 million, a potential increase of 3.2 percent over FY 2006 estimated spending. The NSF Division of Mathematical Sciences budget would increase by 3.2 percent in FY 2007, while the DOD agencies would increase by 8.5 percent for FY 2007. AFOSR surprises with a 15.6 percent increase, while DARPA increases by 9.1 percent. The remaining DOD agencies would essentially have no growth in FY 2007. All other agencies would remain level or decrease slightly.

The mathematical sciences are making major contributions to the country's intellectual capacity, and the need for results from the mathematical sciences in scientific discovery and technological innovation is accelerating. Many disciplines depend on discoveries in the mathematical sciences to open up new frontiers. Mathematical sciences research supports new results in the life and social sciences as well as more traditional fields, such as the physical sciences, computer science, geosciences, and engineering.

Yet, even with this increasing need for mathematics, many mathematical scientists who are performing excellent research and who submit grant proposals deemed of very high quality are consistently either not funded or are under-funded. According to the *Science and Engineering Indicators*, 2006 Edition, in FY 2003, only 31.0 percent of full-time mathematical sciences faculty having doctoral degrees received federal research support. This is much lower than most other fields of science.

National Science Foundation (NSF)

The Division of Mathematical Sciences (DMS), `http://www.nsf.gov/div/index.jsp?div=DMS`, is housed in the NSF Directorate of the Mathematical and Physical Sciences (MPS). This directorate also contains the Divisions of Astronomical Sciences, Chemistry, Materials Research, Physics, and Multidisciplinary Activities. The DMS supports advances in the intellectual frontiers of the mathematical sciences, activities contributing to advancing knowledge in other scientific and engineering fields, and research that is critical to national competitiveness.

The mathematical sciences would continue to be an NSF-wide priority area in FY 2007, the last year

Table 1: Federal Funding for the Mathematical Sciences (millions of dollars)[1]

	FY 05 Actual	FY 06 Estimate	FY 07 Request	Change 2006–07 Amount	Change 2006–07 Percent
National Science Foundation					
DMS	200.24	199.30	205.74	6.44	3.2%
Department of Defense					
AFOSR	30.3	32.1	37.1	5.0	15.6
ARO	10.0	10.0	10.0	0.0	0.0
DARPA	19.2	16.5	18.0	1.5	9.1
NSA	3.5	4.0	4.0	0.0	0.0
ONR	13.6	13.6	13.6	0.0	0.0
Total DOD	76.6	76.2	82.7	6.5	8.5
Department of Energy					
Applied Mathematics	29.6	29.4	29.5	0.1	0.3
National Institutes of Health					
NIGMS	35.0	38.0*	38.0*	0.0	0.0
NIBIB	38.2	41.1	40.4	-0.7	-1.7
Total NIH	73.2	79.1	78.4	-0.7	-0.9
Total All Agencies	379.64	384.00	396.34	12.34	3.2

**Estimates based on conversation with program officer.*

[1] *Budget information comes from agency documents and conversations with agency program managers and representatives.*

of this five-year designation. The foundation has budgeted US$78.45 million to carry out the priority area activities in FY 2007, with US$69.26 million of this amount coming from the DMS and the remaining US$9.19 million coming from throughout the foundation. The NSF-wide allocation (US$9.19 million) depends on cooperative funding opportunities with other NSF directorates and requires matching funds from the DMS. The mathematical sciences were first designated an NSF priority area in FY 2003. In 2003 the Mathematical Sciences Priority Area was projected to receive US$109.50 million in the FY 2007 budget. The current budget environment has severely curtailed this priority area.

The DMS is slated to receive a budget of US$205.74 million in FY 2007. This 3.2 percent increase is the first increase in the DMS budget since FY 2004. The DMS budget has increased US$26.95 million since FY 2003, the first year the mathematical sciences was designated a priority area and when the DMS budget was US$178.79 million. The DMS budget increased US$21.56 million or 12.1 percent from FY 2003 to FY 2004 with the last increase of US$5.39 million to come in the FY 2007 budget. The FY 2007 MPS budget is slated for a 6.0 percent increase over FY 2006.

The DMS has essentially two modes of support: research and education grants, and institutes. Grants include individual-investigator awards, awards for multidisciplinary groups of researchers, and educational and training awards aimed at increasing the number of U.S. students choosing careers in the mathematical sciences. The DMS provides core support for five mathematical sciences research institutes as well as major support for three other institutes. These institutes, funded on a competitive basis, serve to develop new ideas and directions in the mathematical sciences, as well as to promote interaction with other disciplines.

For FY 2007, the DMS has the following priorities:

- Maintaining a strong program of research grants, both single investigator and small group research grants;
- Investing in algorithm development and computational tools for large-scale problems of scientific importance;
- Broadening participation in the mathematical sciences;
- Maintaining research training activities in the mathematical sciences;
- Continuing support for the Mathematical Sciences Priority Area, while initiating the mainstreaming of its activities in the DMS portfolio.

Air Force Office of Scientific Research (AFOSR)

The Directorate of Mathematics and Information Sciences provides funds for research in the mathematical sciences in support of the Air Force mission. The AFOSR mathematics program includes specific portfolios in dynamics and control, physical mathematics and applied analysis, computational mathematics, optimization and discrete mathematics, electromagnetics, and signals communication and surveillance. Current areas of interest include cooperative/collaborative control of a team of unmanned aerial vehicles conducting operations; innovative methods and algorithms that improve modeling and simulation capabilities that will enable understanding, prediction, and control of complex physical phenomena crucial to the Air Force; the development of accurate models of physical phenomena that enhance the fidelity of simulation; and the development of resilient algorithms for data representation in fewer bits, image reconstruction/enhancement, and spectral/frequency estimation in the presence of external corrupting factors. See the website `http://www.afosr.af.mil`. The AFOSR budget would increase 15.6 percent over FY 2006.

Army Research Office (ARO)

The Mathematics Program, housed in the Mathematical Sciences and Information Sciences Division, `http://www.arl.army.mil/main/main/default.cfm?Action=29&Page=194`, manages the following programs: modeling of complex systems, computational mathematics, discrete mathematics and computer science, probability and statistics and stochastic analysis, and cooperative systems. The Mathematical Sciences Division plays an essential role in the modeling, analysis, and control of complex phenomena and large-scale systems that are of critical interest to the Army. The areas of application include wireless communication networks, image analysis, visualization and synthetic environments, pattern recognition, test and evaluation of new systems, sensor networks, network science, and autonomous systems. The division also works closely with the Computer and Information Sciences Division of ARO to develop mathematical theory for systems control, information processing, information assurance, and data fusion. The FY 2007 budget for the Mathematical Sciences Division remains at the FY 2006 level.

Defense Advanced Research Projects Agency (DARPA)

The Defense Sciences Office (DSO) inside DARPA has a mathematics program encompassing both Applied and Computational Mathematics and Fundamental Mathematics, `http://www.darpa.mil/dso/thrust/math/math.htm`. The thrusts of DSO's programs are structured around focused initiative areas in interdisciplinary and core mathematics. Current program areas include: Discovery and Exploitation of Structure in Algorithms, Femtosecond Adaptive Spectroscopy Techniques for Remote Agent Detection, Geospatial Representation and Analysis, Integrated Sensing and Processing,

Mathematical Time Reversal, Predicting Real Optimized Materials, Protein Design Processes, Quantum Information Science and Technology, Robust Uncertainty Management, Stochastic and Perturbation Methods in PDE Systems, and Waveforms for Active Sensing, as well as Focus Areas in Theoretical Mathematics, Fundamental Laws of Biology, and Topological Data Analysis. The Microsystems Technology Office has several programs where mathematical algorithms play a central role in the optimization, control, and exploitation of microelectronic and optical systems, `http://www.darpa.mil/mto/People/PMs/healy.html`. These include the Analog-to-Information program, the Multiple Optical Non-redundant Aperture Generalized Sensors program, and the Non-Linear Mixed Signal Microsystems program. The DARPA mathematics budget would increase by 9.1 percent over FY 2006.

Department of Energy (DOE)

Mathematics is funded through the Applied Mathematics program of the Mathematical, Information, and Computational Sciences Division (MICS) of DOE, `http://www.science.doe.gov/ascr/mics`. Research is conducted on the underlying mathematical understanding of physical, chemical, and biological systems and advanced numerical algorithms that enable effective description, modeling, and simulation of such systems on high-end computing systems. Research in applied mathematics supported by MICS underpins computational science throughout the DOE. The Applied Mathematics program supports work in a wide variety of areas of mathematics, including: ordinary and partial differential equations, numerical linear algebra, fluid dynamics, optimization, mathematical physics, control theory, accurate treatment of shock waves, mixed elliptic-hyperbolic systems, and dynamical systems. The FY 2007 budget for the Applied Mathematics Program increases the Computational Sciences Fellowship program by US$500,000 to US$4 million. The FY 2007 budget also includes US$8.5 million, the same as for FY 2006, for the Atomic to Macroscopic Mathematics (AMM) effort, which provides the research support in applied mathematics needed for understanding complex physical processes that occur on a wide range of interacting length- and time-scales. The AMM effort supports university researchers, partnerships between universities and national laboratories, and multidisciplinary research teams at national laboratories. The FY 2007 Applied Mathematics budget would increase by 0.3 percent over FY 2006.

National Institutes of Health (NIH)

The NIH funds mathematical sciences research through the National Institute of General Medical Sciences (NIGMS) and the National Institute of Biomedical Imaging and Bioengineering (NIBIB). Mathematical sciences areas of interest are those that support the missions of NIGMS and NIBIB. Currently NIGMS is supporting a biomathematics initiative in cooperation with the National Science Foundation, and NIBIB is participating in a joint initiative with the NSF and other NIH institutes, "Collaborative Research in Computational Neuroscience". The aggregate budget for the mathematical sciences in NIBIB and NIGMS would decline by 0.9 percent in FY 2007.

National Security Agency (NSA)

The Mathematical Sciences Program of the NSA administers a Grants Program that supports fundamental research in the areas of algebra, number theory, discrete mathematics, probability, and statistics. The Grants Program also accepts proposals for conferences and workshops in these research areas. In addition to grants, the Mathematical Sciences Program supports an in-house faculty Sabbatical Program. The program administrators are especially interested in funding initiatives that encourage the participation of underrepresented groups in mathematics (such as women, African-Americans, and other minorities). NSA is the largest employer of mathematicians in the United States. As such, it has a vested interest in maintaining a healthy academic mathematics community in the United States. For more information, see the website `http://www.nsa.gov/msp/index.cfm`. The NSA mathematics budget would remain unchanged for FY 2007.

Office of Naval Research (ONR)

The ONR Mathematical, Computer, and Information Research Division's scientific objective is to establish rigorous mathematical foundations and analytical and computational methods that enhance understanding of complex phenomena, and enable prediction and control for Naval applications in the future. Basic research in the mathematical sciences is focused on analysis and computation for multi-phase, multi-material, multi-physics problems; predictability of models for nonlinear dynamics; electromagnetic and acoustic wave propagation; signal and imaging processing; modeling pathological behaviors of large, dynamic complex networks and exploiting hybrid control to achieve reliability and security; optimization; and formal methods for verifiably correct software construction. For more information see the website, `http://www.onr.navy.mil/sci_tech/31/311/default.asp`. The Mathematical, Computer, and Information Sciences Division's budget would remain unchanged in FY 2007.

Note: Information gathered from agency documents and from agency representatives.

Mathematics People

2006–2007 AMS Centennial Fellowships Awarded

The AMS has awarded two Centennial Fellowships for 2006–2007. The recipients are CHRISTOPHER HACON of the University of Utah and BRYNA KRA of Northwestern University. Each fellowship carries a stipend of US$64,000, an expense allowance of US$3,250, and a complimentary Society membership for one year.

Christopher Hacon

Christopher Hacon received his Ph.D. in 1998 from the University of California at Los Angeles under the direction of Robert Lazarsfeld. He was a Wylie Assistant Professor at the University of Utah from 1998 to 2000, was an assistant professor at the University of California at Riverside from 2000 to 2002, and has been an assistant/associate professor at the University of Utah since 2002. Hacon's research is in the field of algebraic geometry. In particular he is interested in the classification of higher-dimensional complex projective varieties and in questions arising from the minimal model program. He plans to use the fellowship to visit James McKernan at the University of California at Santa Barbara and Sándor Kovács at the University of Washington in Seattle.

Bryna Kra

Bryna Kra works in dynamical systems and ergodic theory, focusing on problems at the intersection of ergodic theory, additive combinatorics, and number theory. She received her Ph.D. from Stanford University in 1995 under the direction of Yitzhak Katznelson and held postdoctoral positions at the Hebrew University of Jerusalem, the University of Michigan, the Institut des Hautes Études Scientifiques, and Ohio State University. She was an assistant professor at Pennsylvania State University from 2000 to 2004 and subsequently has been an associate professor at Northwestern University. Kra plans to use her fellowship at Northwestern University and at the Université de Marne-la-Vallée to continue her collaboration with Bernard Host on multiple ergodic averages.

Christopher Hacon

Bryna Kra

Please note: Information about the competition for the 2007–2008 AMS Centennial Fellowships will be published in the "Mathematics Opportunities" section of an upcoming issue of the *Notices*.

—Allyn Jackson

Barrow Receives Templeton Prize

JOHN D. BARROW, a noted cosmologist whose writings about the relationship between life and the universe, and the nature of human understanding have created new perspectives on questions of ultimate concern to science and religion, has won the 2006 Templeton Prize. The prize is valued at 795,000 pounds sterling, approximately US$1.4 million.

Barrow, 53, who serves as professor of mathematical sciences at the University of Cambridge, has used insights from mathematics, physics, and astronomy to set out wide-ranging views that challenge scientists and theologians to cross the boundaries of their disciplines if they are to fully realize what they may or may not understand about how time, space, and matter began; the behavior of the universe (or, perhaps, "multiverses"); and where it is all headed, if anywhere.

His work—including seventeen books translated into twenty-seven languages and written in accessible, lively

prose; hugely popular lectures; and more than 400 scientific papers—has illuminated understanding of the universe and cast the intrinsic limitations of scientific inquiry into sharp relief. It has also given theologians and philosophers inescapable questions to consider when examining the very essence of belief, the nature of the universe, and humanity's place in it.

At Cambridge Barrow was appointed director of the Millennium Mathematics Project, a many-faceted education initiative aimed at young people, aged five to nineteen, to help them understand and appreciate mathematics and its applications. In February 2006 the program was awarded the Queen's Anniversary Prize for Higher and Further Education in the UK Honors List.

The Templeton Prize for Progress Toward Research or Discoveries about Spiritual Realities was founded in 1972 by philanthropist and global financial pioneer Sir John Templeton. Given annually to a living person to encourage and honor the advancement of knowledge in spiritual matters, it is the world's best-known religion prize and the largest annual monetary prize of any kind given to an individual.

—From a Templeton Prize news release

Hejhal Receives Gårding Prize

Dennis Hejhal of Uppsala University and the University of Minnesota at Minneapolis has been awarded the Eva and Lars Gårding Prize in Mathematics by the Royal Physiographic Society in Lund, Sweden. The prize carries a cash award of approximately US$19,000.

Hejhal was honored for his paper "On a result of Selberg concerning zeros of linear combinations of L-functions", which was published in 2000 in *International Mathematics Research Notices*. The paper considers linear combinations of L-functions, which are number theoretic functions that generalize the Riemann zeta function. He obtains precise estimates of the number and distribution of zeros of generic linear combinations that lie off the critical line in various regions of the complex plane. Hejhal's major research interests are number theory, harmonic analysis, and complex analysis. The Royal Physiographic Society was founded in 1772 and supports research in natural sciences in Sweden.

—From a Royal Physiographic Society announcement

Ferrara, Freedman, and van Nieuwenhuizen Awarded Heineman Prize

Sergio Ferrara of CERN, Daniel Freedman of the Massachusetts Institute of Technology, and Peter van Nieuwenhuizen of Stony Brook University have been awarded the Dannie Heineman Prize for Mathematical Physics "for constructing supergravity, the first supersymmetric extension of Einstein's theory of general relativity, and for their central role in its subsequent development."

The prize carries a cash award of US$7,500 and is presented in recognition of outstanding publications in the field of mathematical physics. The prize was established in 1959 by the Heineman Foundation for Research, Educational, Charitable, and Scientific Purposes, Inc., and is administered jointly by the American Institute of Physics (AIP) and the American Physical Society (APS). The prize is presented annually.

—From an APS announcement

Sheffield Awarded Rollo Davidson Prize

Scott Sheffield of the Courant Institute of Mathematical Sciences, New York University, has been awarded the 2006 Rollo Davidson Prize. Sheffield was honored "for his work on spatial models of probability theory", especially "their relationship to stochastic (Schramm) Loewner evolutions". The Rollo Davidson Trust was founded in 1975 and awards an annual prize to young mathematicians working in the field of probability.

—From a Rollo Davidson Trust announcement

Gelfand Awarded Parzen Prize

Alan E. Gelfand of Duke University has been awarded the 2006 Emanuel and Carol Parzen Prize for Statistical Innovation. He was honored for his significant research on statistical theory and applications, which has transformed Bayesian practice by pioneering statistical inference by Markov Chains Monte Carlo (MCMC) and the Gibbs sampler, and by innovating methods for spatial statistics, hierarchical modeling and model determination, and environment and earth sciences. The Parzen Prize is awarded in even-numbered years by the Department of Statistics at Texas A&M University to North American statisticians who have made outstanding and influential contributions to the development of applicable and innovative statistical methods.

—Department of Statistics, Texas A&M University

Mahlburg Honored with Paper of the Year Prize

The first annual Paper of the Year Prize of the *Proceedings of the National Academy of Sciences* (PNAS) has been awarded to Karl Mahlburg, a doctoral candidate in mathematics at the University of Wisconsin, Madison, for his paper "Partition congruences and the Andrews-

Garvan-Dyson crank". The paper "solves a critical part of a mathematical puzzle in number theory" and was chosen from among 3,000 papers published in the journal in 2005.

The Paper of the Year Prize recognizes outstanding research articles published in PNAS. The winning paper, published in October 2005, is available online at `http://www.pnas.org/cgi/content/abstract/102/43/15373`. An accompanying commentary on the paper is available at `http://www.pnas.org/cgi/content/extract/102/43/15277`.

—From a PNAS announcement

Vatsal Awarded Ribenboim Prize

VINAYAK VATSAL of the University of British Columbia has been awarded the Ribenboim Prize by the Canadian Number Theory Association. The award recognizes his "fundamental contributions to the Iwasawa theory of elliptic curves, introducing profound techniques from ergodic theory into the subject and obtaining startling theorems on the nonvanishing of p-adic L-functions and μ-invariants that had previously been unobtainable by more orthodox analytic methods." His results have "transformed our understanding of the ranks of elliptic curves in towers of number fields." The prize consists of a certificate and a medal and is awarded normally every two years to a mathematician who is Canadian or has connections to Canadian mathematics.

—From an announcement of the Pacific Institute of Mathematical Sciences

Sloan Fellows Announced

The Alfred P. Sloan Foundation has announced the names of the recipients of the 2006 Sloan Research Fellowships. Each year the foundation awards 116 fellowships in the fields of mathematics, chemistry, computational and evolutionary molecular biology, computer science, economics, neuroscience, and physics. Grants of US$45,000 for a two-year period are administered by each fellow's institution. Once chosen, fellows are free to pursue whatever lines of inquiry most interest them, and they are permitted to employ fellowship funds in a wide variety of ways to further their research aims.

Following are the names of the 2006 Sloan Fellows who work in the mathematical sciences: VLADIMIR BARANOVSKY, University of California, Irvine; SIMON BRENDLE, Stanford University; SERGUEI DENISSOV, University of Wisconsin, Madison; FREDERIC G. GIBOU, University of California, Santa Barbara; ANNA C. GILBERT, University of Michigan; SINAN GÜNTÜRK, New York University; SHELLY L. HARVEY, Rice University; MICHAEL V. HITRIK, University of California, Los Angeles; KIRAN SRIDHARA KEDLAYA, Massachusetts Institute of Technology; BENJAMIN J. MORRIS, University of California, Davis; ISABELLA NOVIK, University of Washington; MARTIN OLSSON, University of Texas, Austin; ROBERT POLLACK, Boston University; MIHNEA POPA, University of Chicago; OMRI SARIG, Pennsylvania State University; JOZSEF SOLYMOSI, University of British Columbia; DYLAN P. THURSTON, Columbia University; ANNA-KARIN TORNBERG, New York University; YEN-HSI RICHARD TSAI, University of Texas, Austin; and ALEKSEY ZINGER, Stony Brook University.

The mathematicians on the Sloan fellowship program committee are Ingrid Daubechies of Princeton University, Benedict Gross of Harvard University, and Dusa McDuff of Stony Brook University.

—From a Sloan Foundation announcement

NSF Graduate Research Fellowships Announced

The National Science Foundation (NSF) has awarded its Graduate Research Fellowships for fiscal year 2006. This program supports students pursuing doctoral study in all areas of science and engineering and provides a stipend of US$30,000 per year for a maximum of three years of full-time graduate study. Following are the names of the awardees in the mathematical sciences for 2006, followed by their undergraduate institutions (in parentheses) and the institutions at which they plan to pursue graduate work.

JENNIFER S. BALAKRISHNAN (Harvard University), Princeton University; LAURA S. BARON (University of California, Los Angeles), University of California, Berkeley; ADAM D. CHANDLER (Duke University), New York University; LAUREN M. CHILDS (Duke University), Cornell University; IVAN Z. CORWIN (Harvard University), Princeton University; JACOB FOX (Massachusetts Institute of Technology), Massachusetts Institute of Technology; SHEEL C. GANATRA (Harvard University), Massachusetts Institute of Technology; THOMAS A. GOLDSTEIN (Washington University), Stanford University; JEFFREY L. JAUREGUI (Harvey Mudd College), Duke University; BENJAMIN S. KUNSBERG (Johns Hopkins University), Princeton University; RICKY I. LIU (Harvard University), Princeton University; STEPHANIE M. MOYERMAN (Harvey Mudd College), Princeton University; RONEN E. MUKAMEL (Harvard University), Massachusetts Institute of Technology; EMILY E. RIEHL (Harvard University), University of Chicago; DAVID L. ROE (Massachusetts Institute of Technology), Harvard University; NIKITA ROZENBLYUM (Harvard University), Harvard University; MICHAEL D. SEKORA (Massachusetts Institute of Technology), Princeton University; JOSEF A. SIFUENTES (Rice University), Rice University; STEVEN W. SIVEK (Massachusetts Institute of Technology), Harvard University; BENJAMIN E. SONDAY (University of Michigan, Ann Arbor), Princeton University; MATTHEW J. THIBAULT (Massachusetts Institute of Technology), Massachusetts Institute of Technology; HEM H. WADHAR (University of Pennsylvania), University of California, Los Angeles; PHILLIP D. WHITMAN (University of Texas, Austin), Princeton University; and

TREVOR M. WILSON (California Institute of Technology), University of California, Berkeley.

—From an NSF announcement

Guggenheim Fellowships Awarded

The John Simon Guggenheim Memorial Foundation has announced the names of 187 United States and Canadian artists, scholars, and scientists who were selected as Guggenheim Fellows for 2006. Guggenheim Fellows are appointed on the basis of distinguished achievement in the past and exceptional promise for future accomplishment.

Following are the names of the awardees in the mathematical sciences, together with their affiliations and areas of research interest: L. MAHADEVAN, Harvard University: integrative pathophysiology of sickle-cell disease; JOSEPH MAZUR, Marlboro, Vermont: a mathematical memoir; WILLIAM H. MEEKS III, University of Massachusetts, Amherst: the global structure of complete embedded minimal surfaces in three-manifolds; LAURENT SALOFF-COSTE, Cornell University: diffusions and random walks on groups; and BIN YU, University of California, Berkeley: interpretable models for high-dimensional data.

—From a Guggenheim Foundation news release

Fulbright Awards Announced

The J. William Fulbright Foundation and the United States Department of State, Bureau of Educational and Cultural Affairs, have announced the names of the recipients of the Fulbright Foreign Scholarships for 2005–2006. Following are the U.S. scholars in the mathematical sciences who have been awarded Fulbright scholarships to lecture or conduct research, together with their home institutions and the countries in which they plan to use the awards.

GWYNETH F. HARRISON-SHERMOEN (Wesleyan University), France; JEREMY WEISSMANN (Northwestern University), Netherlands; CARMEL Y. ADRIAN (Vassar College), Germany; STEPHANIE J. JAKUS (Smith College), Hungary; JENNIFER L. LOSAW (Wellesley College), Austria; MICHAEL J. COONS (Baylor University), Hungary; DAVID SUSSILLO (Columbia University), Austria; and CARL S. MCTAGUE (at-large, Ohio), Germany.

—From a Fulbright Awards announcement

Intel Science Talent Search Winners Announced

Three high school students working in mathematics have been awarded Intel Science Talent Search Scholarships for 2006. YI SUN, a seventeen-year-old student at the Harker School, San Jose, California, was awarded second place and a US$75,000 scholarship for a project that involves the winding number of a function. NICHOLAS M. WAGE, a seventeen-year-old student at Appleton East High School in Appleton, Wisconsin, won fourth place and a US$25,000 scholarship for a project on generalized Paley graphs. KIMBERLY M. SCOTT, a seventeen-year-old student at Wellesley High School in Wellesley, Massachusetts, won tenth place and a US$20,000 scholarship for her project analyzing Ehrenfeucht-Fraisse games.

—From an Intel Corporation announcement

Thomas P. Branson (1953–2006)

Thomas P. Branson, who worked in the fields of mathematical physics, differential geometry, geometric analysis, and spectral and representation theory, passed away suddenly on March 11, 2006. Branson received his Ph.D. from the Massachuestts Institute of Technology in 1979. After holding postdoctoral and teaching positions at universities in the United States and in Europe, he had served as a professor at the University of Iowa since 1985. Branson had been an AMS member since 1979. His AMS activities include organizing a number of AMS special sessions on conformal geometry. He is widely known for his "Branson-Paneitz operators" and especially for his pioneering and deep work on conformal invariance and conformal symmetry. In particular, he introduced Q-curvature, and his work on the functional determinant of the conformal Laplacian on four-manifolds is profound.

Tom Branson is survived by siblings, by his wife, and by his two small daughters, who are in the second and third grade. The University of Iowa's mathematics department has set up an education fund for the Branson daughters; contact the department for more information.

—Palle Jorgensen, University of Iowa

Mathematics Opportunities

NSF CAREER Program Guidelines Available

The guidelines for the Faculty Early Career Development (CAREER) Program of the National Science Foundation (NSF) are now available on the Web. The program solicitation number is 05-579. Information is available at `http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf05579`. The deadline for submission of proposals is **July 20, 2006**.

—From an NSF announcement

Computational Science Training for Undergraduates in the Mathematical Sciences

The Computational Science Training for Undergraduates in the Mathematical Sciences (CSUMS) program of the National Science Foundation (NSF) is intended to enhance computational aspects of the education and training of undergraduate students in mathematics and statistics and to better prepare these students to pursue careers and graduate study in fields that require integrated strengths in computation and the mathematical sciences.

The core of the activity is long-term research experiences for cohorts of at least six undergraduates. Projects must focus on research topics that require interplay between computation and mathematics or statistics. Proposals are welcome for projects that create models for education in the mathematical sciences and that influence the direction of academic programs for a broad range of students.

Deadlines for full proposals in 2006 are **June 27, 2006**, and **October 17, 2006**. For further information, see `http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf06559`.

—From an NSF announcement

Call for Nominations for Sloan Fellowships

Nominations for candidates for Sloan Research Fellowships, sponsored by the Alfred P. Sloan Foundation, are due by **September 15, 2006**. A candidate must be a member of the regular faculty at a college or university in the United States or Canada and must have received the Ph.D. or equivalent within the six years previous to the nomination. For information, write to: Sloan Research Fellowships, Alfred P. Sloan Foundation, 630 Fifth Avenue, Suite 2550, New York, NY 10111-0242; or consult the foundation's website: `http://www.sloan.org/programs/fellowship_brochure.shtml`.

—From a Sloan Foundation announcement

Call for Nominations for Aisenstadt Prize

The Centre de Recherches Mathématiques (CRM) solicits nominations for the André Aisenstadt Mathematics Prize. The prize recognizes outstanding research achievement by a young Canadian mathematician in pure or applied mathematics.

Candidates must be Canadian citizens or permanent residents of Canada and must have received the Ph.D. within the preceding seven years. The recipient is invited to deliver a lecture at CRM and to write a brief article on his or her work for publication in the CRM's *Bulletin*.

Nominations must be submitted by at least two sponsors and include the following information: a curriculum vitae, a list of publications, a cover letter explaining the basis of the nomination, up to four reprints, and a maximum of four letters of support. The deadline for nominations is **October 1, 2006.** Nominations must be submitted to the director of the CRM, Université de Montréal, C. P. 6128, Succursale Centre-ville, Montréal, QC H3C 3J7 Canada; fax: 514-343-2254; email: `directeur@crm.umontreal.ca`.

—From a CRM announcement

Call for Nominations for SASTRA Ramanujan Prize

The Shanmugha Arts, Science, Technology Research Academy (SASTRA) invites nominations for the 2006 SASTRA Ramanujan Prize. The prize carries a cash award of US$10,000, and the winner will be invited to give a talk at the SASTRA conference in December 2006. The deadline

for nominations is **July 31, 2006**. For more information, email: sastraprize@math.ufl.edu, or see the website http://www.math.ufl.edu/sastra-prize/.

—Krishnaswami Alladi, University of Florida

Call for Nominations for Heineman Prize

The American Physical Society (APS) and the American Institute of Physics are seeking nominations for the 2007 Dannie Heineman Prize for Mathematical Physics. The prize recognizes outstanding publications in the field of mathematical physics. The prize carries a cash award of US$7,500, an award certificate, and travel expenses to the meeting at which the prize is given. The deadline for nominations is **July 1, 2006**. For more information, see the APS website at http://www.aps.org/praw/heineman/index.cfm.

—From an APS announcement

Call for Nominations for Vasil Popov Prize

The Vasil Popov Prize is awarded every three years for outstanding research contributions in fields related to the work of Vasil Popov, who is best known for his contributions to approximation theory. Candidates must have received the Ph.D. within the previous six years. Nominations should include a brief description of the relevant work and a vita of the candidate. The deadline for nominations is **November 1, 2006**. Nominations should be sent to Pencho Petrushev, Chair, Popov Prize Selection Committee, Department of Mathematics, University of South Carolina, Columbia, SC 29208; email: popov@math.sc.edu. For further information, visit the website http://www.math.vanderbilt.edu/~at07/popov.html.

—Pencho Petrushev, University of South Carolina

Call for Entries for Pirelli INTERNETional Award

The Pirelli INTERNETional Award is an international multimedia competition for the communication of science and diffusion of scientific and technological culture entirely carried out on the Internet. Awards in the 2006 competition will be made for multimedia communications in the areas of mathematics, physics, chemistry, life sciences, and information and communications technology. The prize for the best multimedia work in mathematics is 15,000 euros (approximately US$18,000). The deadline for entries is **December 31, 2006**. For more information, see the website http://www.pirelliaward.com.

—From a Pirelli Award announcement

News from the CRM Montreal

The Centre de Recherches Mathématiques (CRM) in Montreal, Canada, has announced its thematic program for the semester running from June to December 2006. Devoted to combinatorial optimization, it will be organized by David Avis (McGill University), David Bremner (University of New Brunswick), Vašek Chvátal (Concordia University), Bill Cunningham (University of Waterloo), Michel Goemans (MIT), Pierre Hansen (HÉC, Montreal), Odile Marcotte (UQAM, Montreal), and Adrian Vetta (McGill University).

The semester will begin (June 19–30, 2006) with the SMS-NATO Advanced Study Institute 2006 Summer School on Combinatorial Optimization: Methods and Applications, which will be organized by Vašek Chvátal (Concordia University) and Najiba Sbihi (Mohammadia Engineering School, Rabat). It is primarily targeted at senior graduate students, postdocs, and junior faculty members.

The following workshops will be held.

June 12–14, 2006: Approximation Algorithms. Organizers: Joseph Cheriyan (University of Waterloo) and Michel Goemans (MIT).

August 14–16, 2006: Network Design: Optimization and Algorithmic Game Theory. Organizers: Shie Mannor (McGill University) and Adrian Vetta (McGill University).

September 18–22, 2006: Hybrid Methods and Branching Rules in Combinatorial Optimization. Organizer: Vašek Chvátal (Concordia University).

October 10–13, 2006: Data Mining and Mathematical Programming. Organizers: Pierre Hansen (HÉC, Montreal) and Panos Pardalos (University of Florida).

October 17–20, 2006: Polyhedral Computation. Organizers: David Avis (McGill University), David Bremner (University of New Brunswick), and Antoine Deza (McMaster University).

The Aisenstadt Lecturers will be Noga Alon (Tel Aviv University) and Paul Seymour (Princeton University).

Besides the thematic program, a number of activities will take place at the CRM during this period.

A conference on Geometric Group Theory will be held July 3–14, 2006. The organizers are Mladen Bestvina (University of Utah), Steve Boyer (UQAM, Montreal), Tadeusz Januszkiewicz (Ohio State University), Michah Sageev (Technion, Israel), and Daniel Wise (McGill University). During the first week, five minicourses on emerging ideas in geometric group theory will be presented.

The XXIIIrd International Biometrics Conference will take place at the downtown campus of McGill University, July 16–21, 2006. The president of the conference will be Geert Molenberghs (Limburg University Center, Belgium), and the local organizing committee is chaired by Jim Hanley (McGill University).

The 4th RECOMB Comparative Genomics Satellite Workshop will be held in Montreal, September 24–26, 2006. The local program coordinators are Guillaume Bourque and Nadia El-Mabrouk (University of Montreal).

For more information on the lecturers at various events and on the support available for visitors, graduate students, and postdoctoral fellows, see `http://www.crm.umontreal.ca`.

—CRM announcement

News from the Fields Institute

The Fields Institute for Research in the Mathematical Sciences has announced its thematic program for the 2006–2007 academic year on cryptography and on geometric applications of homotopy theory. The fall program is organized by Hugh Williams (chair), Ian F. Blake, Alfred Menezes, Michele Mosca, Kumar Murty, Renate Scheidler, Douglas Stinson, and Ramarathnam Venkatesan. Activities and dates for the fall program on cryptography follow.

September 18–20, 2006: Algebraic curves in cryptography: The Tenth Workshop on Elliptic Curve Cryptography (ECC 2006).

September 25–27, 2006: Coxeter Lecture Series. Lecturer: Gerhard Frey.

October 2–6, 2006: Workshop on quantum cryptography and computing.

October 30–November 3, 2006: Workshop on computational challenges arising in algorithmic number theory and cryptography.

November 27–December 1, 2006: Workshop on cryptography: Underlying mathematics, provability, and foundations.

The winter semester program on geometric applications of homotopy theory is organized by J. F. Jardine (chair), G. Carlsson, and J. D. Christensen. The dates of the scheduled workshops follow.

January 9–13, 2007: Workshop on higher categories and their applications.

March 26–30, 2007: Workshop on homotopy theory of schemes.

May 14–18, 2007: Workshop on stacks in geometry and topology.

The Fields Distinguished Lecture Series will be presented by Michael Hopkins. The thematic program for fall 2007 will be operator algebras. The principal organizer is George Elliott.

For further information on all Fields Institute activities, see the website `http://www.fields.utoronto.ca`.

—From a Fields Institute announcement

Inside the AMS

Epsilon Awards for 2006

The AMS Epsilon Fund for Young Scholars was established in 1999 to provide financial assistance to summer programs for mathematically talented high school students in the United States. For many years these programs have provided mathematically talented youngsters with their first serious mathematical experiences. The name for the fund was chosen in remembrance of the late Paul Erdős, who was fond of calling children "epsilons".

The AMS has chosen twelve summer mathematics programs to receive Epsilon grants for activities in the summer of 2006. The grants will support program expenses and student scholarships and, in some cases, scholarships only. The programs were chosen on the basis of mathematical excellence and enthusiasm. Award amounts were governed by the varying financial needs of each program and totaled US$80,000.

The programs receiving grants are: All Girls/All Math Summer Camp for High School Girls, University of Nebraska, Lincoln; Canada/USA Mathcamp, University of Puget Sound, Tacoma, Washington; Hampshire College Summer Studies in Mathematics, Amherst, Massachusetts; MathPath, University of California, Santa Cruz; Michigan Math and Science Scholars Summer Program, University of Michigan, Ann Arbor; PROMYS, Boston University; Puerto Rico Opportunities for Talented Students in Mathematics (PROTaSM), University of Puerto Rico, Mayaguez; Ross Mathematics Program, Ohio State University, Columbus; Summer Explorations and Research Collaborations for High School Girls (SEARCH), Mount Holyoke College, South Hadley, Massachusetts; Texas State Honors Summer Math Camp, Texas State University, San Marcos; Texas Tech University Summer Mathematics Academy, Texas Tech University, Lubbock; and University of Chicago Young Scholars Program.

The grants for summer 2006 are paid for by the AMS Epsilon Fund for Young Scholars (supplemented by the AMS Program Development Fund). The AMS is continuing to build the endowment for the Epsilon Fund, with a goal of raising US$2 million through individual donations and grants. Once the Epsilon Fund endowment has reached the targeted amount, the AMS intends to award a total of US$100,000 in Epsilon grants each year.

For further information about the Epsilon Fund for Young Scholars, visit the website `http://www.ams.org/giving-to-ams/`, or contact `development@ams.org`. Information about how to apply for Epsilon grants is available at `http://www.ams.org/outreach/epsilon.html`. A fairly comprehensive listing of summer programs for mathematically talented high school students (including those with and without Epsilon grants) is available at `http://www.ams.org/outreach/mathcamps.html`.

—Elaine Kehoe

AMS Names 2006 Mass Media Fellow

The AMS is pleased to announce that Brie Finegold has been awarded its 2006 Mass Media Fellowship. Brie is a Ph.D. student in mathematics at the University of California at Santa Barbara. She will be working at *Scientific American* for ten weeks over the summer under the sponsorship of the AMS.

The Mass Media Fellowship program is organized by the American Association for the Advancement of Science (AAAS) and is intended to strengthen the connections between science and the media, to improve public understanding of science, and to sharpen the ability of the fellows to communicate complex scientific issues to nonspecialists. The program is available to college or university students (in their senior year, or in any graduate or postgraduate level) who are in the natural, physical, health, engineering, computer, or social sciences or in mathematics and who have outstanding written and oral communication skills and a strong interest in learning about the media. It is a highly competitive program, and the AMS wishes to congratulate Brie Finegold on her accomplishment.

For a list of past AMS Media Fellows, see the webpage `http://www.ams.org/government/massmediafellowaward.html`.

—Anita L. Benjamin, AMS Washington Office

AMS Establishes Eisenbud Prize for Mathematics and Physics

The AMS has established a prize in memory of the mathematical physicist Leonard Eisenbud (1913–2004), funded by his son and daughter-in-law, David (president of the AMS 2003–04) and Monika Eisenbud. Leonard Eisenbud was a student of Eugene Wigner, a friend of Paul Erdős, and one of the founders of the physics department at the State University of New York at Stony Brook, where he taught from 1957 until his retirement in 1983. The prize will honor a work or group of works that brings the two fields of mathematics and physics together. The US$5,000 prize will be awarded every three years for a work published in the preceding six years. It is expected that the first award will be made in January 2008. Nominations will be accepted starting July 1, 2006. For more information see `http://www.ams.org/prizes/eisenbud-prize.html`.

—AMS announcement

AMS Conference on Undergraduate Research

The American Mathematical Society has received funding from the National Security Agency to organize the conference "Promoting Undergraduate Research in Mathematics", to be held September 28–30, 2006, at the Westin O'Hare Hotel in Rosemont, Illinois.

The goal of the conference is to bring together a diverse group of people who are actively involving undergraduates in research, in order that they might share their experiences and explore ways to create more such opportunities. The conference will feature speakers, panels, and small discussion groups. It continues the work of a previous conference on this subject (see `http://www.ams.org/employment/REUproceedings.html`).

The organizing committee creating the program consists of Frank Connolly (University of Notre Dame), Joe Gallian (University of Minnesota, Duluth), Aparna Higgins (University of Dayton), and Ivelisse Rubio (University of Puerto Rico, Humacao).

Space limitations will, unfortunately, restrict the number of participants. Mathematicians who wish to participate should send a letter to `purm-conf@ams.org` discussing their interest in involving undergraduates in research and indicating how they might benefit from or contribute to the conference. Some financial support for participants is available.

—Ellen Maycock, AMS Meetings and Professional Services

Deaths of AMS Members

Emilio R. Alluy, Centro de Estudios Galois, died on December 31, 2005. Born on August 11, 1950, he was a member of the Society for 8 years.

Thomas P. Branson, professor, University of Iowa, died on March 11, 2006. Born on October 10, 1953, he was a member of the Society for 30 years.

Patrick Cassens, professor, Missouri Southern State University, died on July 8, 2005. Born on October 21, 1938, he was a member of the Society for 41 years.

Thyagaraju Chelluri, Rutgers University, Piscataway, died on August 21, 2004. Born on December 18, 1977, he was a member of the Society for 3 years.

Samuil Davidovich Eidelman, professor, International Solomon University, Ukraine, died on June 8, 2005. Born on January 3, 1921, he was a member of the Society for 10 years.

Arnold Grudin, professor emeritus, Denison University, died on March 11, 2006. Born on February 7, 1916, he was a member of the Society for 50 years.

Hans G. Haefeli, professor emeritus, Zentralichweizelisches Tech. Luzern, Switzerland, died in February 2006. Born on June 14, 1917, he was a member of the Society for 56 years.

Ernest Ray Keown, retired, from Wilmore, KY, died on April 11, 2006. Born on March 17, 1921, he was a member of the Society for 57 years.

Jerome P. Levine, professor, Brandeis University, died on April 8, 2006. Born on May 4, 1937, he was a member of the Society for 47 years.

George G. Lorentz, professor emeritus, University of Texas at Austin, died on January 1, 2006. Born on February 25, 1910, he was a member of the Society for 56 years.

George W. Mackey, professor emeritus, Harvard University, died on March 15, 2006. Born in 1916, he was a member of the Society for 65 years.

Alec L. Matheson, professor, Lamar University, died on April 4, 2006. Born on October 26, 1946, he was a member of the Society for 29 years.

Burnett C. Meyer, professor emeritus, University of Colorado, died on March 24, 2006. Born on March 24, 1921, he was a member of the Society for 59 years.

Gloria Olive, retired, University of Otago, New Zealand, died on April 17, 2006. Born on June 8, 1923, she was a member of the Society for 44 years.

Robert D. Stalley, professor emeritus, Oregon State University, Corvallis, died on July 5, 2002. Born on October 25, 1924, he was a member of the Society for 51 years.

John A. Tierney, retired, from St. Augustine, FL, died on January 14, 2006. Born on November 17, 1917, he was a member of the Society for 56 years.

Kathryn B. Toll, retired, from Warminster, PA, died on November 28, 2005. Born on October 18, 1927, she was a member of the Society for 48 years.

William M. Woodruff, from Annandale, VA, died on October 20, 2005. Born on July 26, 1936, he was a member of the Society for 46 years.

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.ou.edu` in the case of the editor and `notices@ams.org` in the case of the managing editor. The fax numbers are 405-325-7484 for the editor and 401-331-3842 for the managing editor. Postal addresses may be found in the masthead.

Information for *Notices* Authors

The *Notices* welcomes unsolicited articles for consideration for publication, as well as proposals for such articles. The following provides general guidelines for writing *Notices* articles and preparing them for submission.

***Notices* readership.** The *Notices* goes to about 30,000 subscribers worldwide, of whom about 20,000 are in North America. Approximately 8,000 of the 20,000 in North America are graduate students who have completed at least one year of graduate school. All readers may be assumed to be interested in mathematics research, but they are not all active researchers.

***Notices* feature articles.** Feature articles may address mathematics, mathematical news and developments, mathematics history, issues affecting the profession, mathematics education at any level, the AMS and its activities, and other such topics of interest to *Notices* readers. Each article is expected to have a large target audience of readers, perhaps 5,000 of the 30,000 subscribers. Authors must therefore write their articles for nonexperts rather than for experts or would-be experts. In particular, the mathematics articles in the *Notices* are expository. The language of the *Notices* is English.

Most feature articles, including those on mathematics, are expected

Where to Find It

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

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

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

Mathematics feature articles in the *Notices* are normally six to nine pages, sometimes a little longer. Shorter articles are more likely to be read fully than are longer articles. The first page is 400 or 500 words, and subsequent pages are about 800 words. From this one should subtract an allowance for figures, photos, and other illustrations, and an appropriate allowance for any displayed equations and any bibliography.

Form of articles. Except with very short articles, authors are encouraged to use section headings and subsection headings to help orient readers. Normally there is no section heading at the beginning of an article. Despite the encouraged use of internal headings, the assigning of numbers to sections and subsections is not permitted in any article.

The bibliography should be kept short. In the case of mathematics articles, bibliographies are normally limited to about ten items and should consist primarily of entries like books in which one may do further reading. To help readers who might want lists of recent literature, an author might include a small number of recent publications with good bibliographies.

Editing process. Most articles that are destined to be accepted undergo an intensive editing process. The purposes of this process are to ensure that the target audience is as large as practicable, that the content of the article is clear and unambiguous, and that the article is relatively easy to read. Usually it is the members of the editorial board who are involved in this process. Sometimes outside referees are consulted.

Preparation of articles for submission. The preferred form for submitted articles is as electronic files. Authors who cannot send articles electronically may send the articles by fax or by postal mail.

Articles with a significant number of mathematical symbols are best prepared in TEX, LATEX, or $\mathcal{A}\mathcal{M}\mathcal{S}$-TEX. There are no special style files for the *Notices*, because TEX code gets converted to something else during the production process. Since the *Notices* is set in narrow columns, keeping displayed formulas relatively short helps to minimize adjustments during the production process; avoiding nonstandard supplementary files and complex sequences of TEX definitions also helps. For the handling of figures and other illustrations, please consult the editor.

Articles without a significant number of mathematical symbols may be prepared as text files or in Microsoft Word. In the case of files prepared in Microsoft Word, it is advisable to send both the file and a fax of a printout.

Instructions for Authors of "WHAT IS...?" Columns

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

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

The writing should be nontechnical and informal. The level should be a little higher than the level of popular articles about mathematical developments one finds in magazines like *Science* that are aimed at a general audience.

There is a strict limit of two *Notices* pages (1,400 words with no picture, or 1,200 words with one picture). A list of "Further Reading" should contain no more than three references.

Inquiries and comments about the "WHAT IS...?" column are welcome and may be sent to `notices-whatis@ams.org`.

Upcoming Deadlines

June 22, 2006: Full proposals for NSF Program in Informal Science Education. See `http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf06520`.

June 27, 2006: Full proposals for Computational Science Training for Undergraduates in the Mathematical Sciences (CSUMS) of the NSF. See "Mathematics Opportunities" in this issue.

July 1, 2006: Nominations for 2007 Dannie Heineman Prize. See "Mathematics Opportunities" in this issue.

July 20, 2006: Proposals for NSF CAREER Program. See "Mathematics Opportunities" in this issue.

July 31, 2006: Nominations for SASTRA Ramanujan Prize. See "Mathematics Opportunities" in this issue.

July 31, 2006: Nominations for the ICTP/IMU Ramanujan Prize. See `http://www.ictp.trieste.it/~sci_info/awards/Ramanujan/Ramanujan.html`.

September 15, 2006: Nominations for Alfred P. Sloan Foundation Fellowships. See "Mathematics Opportunities" in this issue.

October 1, 2006: Nominations for André Aisenstadt Mathematics Prize. See "Mathematics Opportunities" in this issue.

October 1, 2006: Applications for AWM Travel Grants. See `http://www.awm-math.org/travel-grants.html`; telephone 703-934-0163; email: `awm@math.umd.edu`; or contact Association for Women in Mathematics, 11240 Waples Mill Road, Suite 200, Fairfax, VA 22030.

October 17, 2006: Full proposals for Computational Science Training for Undergraduates in the Mathematical Sciences (CSUMS) of the NSF. See "Mathematics Opportunities" in this issue.

November 1, 2006: Nominations for Vasil Popov Prize. See "Mathematics Opportunities" in this issue.

December 31, 2006: Entries for Pirelli INTERNETional Award competition. See "Mathematics Opportunities" in this issue.

New Journals for 2005

Below is a list of mathematical journals appearing for the first time in 2005, as compiled by *Mathematical Reviews*. This list, as well as the listings for new journals for other years, can be found on the Web at `http://www.ams.org/mathweb/mi-newjs.html`.

Journal of Computational Mathematics and Optimization, 0972-9372, SAS International Publications, €120/volume/3 issues/yr.

Book List

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

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

A^3 & His Algebra: How a Boy from Chicago's West Side Became a Force in American Mathematics, by Nancy E. Albert. iUniverse, Inc., January 2005. ISBN 0-595-32817-2. (Reviewed December 2005.)

**Alan Turing's Automatic Computing Engine: The Master Codebreaker's Struggle to Build the Modern Computer*, edited by B. Jack Copeland. Oxford University Press, June 2005. ISBN 0-198-56593-3.

Beyond Coincidence: Amazing Stories of Coincidence and the Mystery and Mathematics behind Them, by Martin Plimmer and Brian King. Thomas Dunne Books, December 2005. ISBN 0-312-34036-2.

The Book of Presidents, by Susan Oakes, Alan Pears, and Adrian Rice. London Mathematical Society, 2005. ISBN 0-950-27341-4.

Chance: A Guide to Gambling, Love, the Stock Market and Just About Everything Else, by Amir D. Aczel. Thunder's Mouth Press, October 2004. ISBN 1-56858-316-8. (Reviewed August 2005.)

Change Is Possible: Stories of Women and Minorities in Mathematics, by Patricia Clark Kenschaft. AMS, September 2005. ISBN 0-8218-3748-6.

Coincidences, Chaos, and All That Math Jazz: Making Light of Weighty Ideas, by Edward B. Burger and Michael Starbird. W. W. Norton, August 2005. ISBN 0-393-05945-6.

The Coxeter Legacy: Reflections and Projections, edited by Chandler Davis and Erich W. Ellers. AMS, March 2006. ISBN 0-8218-3722-2.

The Curious Incident of the Dog in the Night-time, by Mark Haddon. Vintage, May 2004. ISBN 1-400-03271-7. (Reviewed March 2006.)

Dark Hero of the Information Age: In Search of Norbert Wiener, by Flo Conway and Jim Siegelman. Basic Books, December 2004. ISBN 0-738-20368-8. (Reviewed May 2006.)

Decoding the Universe: How the New Science of Information Is Explaining Everything in the Cosmos, from Our Brains to Black Holes, by Charles Seife. Viking Adult, February 2006. ISBN 0-670-03441-X.

**Descartes: A Biography*, by Desmond Clarke. Cambridge University Press, March 2006. ISBN 0-521-82301-3.

Divine Proportions: Rational Trigonometry to Universal Geometry, by N. J. Wildberger. Wild Egg Books, September 2005. ISBN 0-9757492-0-X.

The Equation That Couldn't Be Solved (How Mathematical Genius Discovered the Language of Symmetry), by Mario Livio. Simon and Schuster, September 2005. ISBN 0-743-25820-7.

**The Equations: Icons of Knowledge*, by Sander Bais. Harvard University Press, November 2005. ISBN 0-674-01967-9.

M. C. Escher's Legacy: A Centennial Celebration, edited by Doris Schattschneider and Michele Emmer. Springer, September 2005 (paperback edition). ISBN 3-540-20100-9.

Euler through Time: A New Look at Old Themes, by V. S. Varadarajan. AMS, June 2006. ISBN 0-8218-3722-2.

Experimentation in Mathematics: Computational Paths to Discovery, by Jonathan Borwein, David Bailey, and Roland Girgensohn. A K Peters, March 2004. ISBN 1-56881-136-5. (Reviewed September 2005.)

The Fermat Diary, by C. J. Mozzochi. AMS, August 2000. ISBN 0-8218-2670-0.

The Fermat Proof, by C. J. Mozzochi. Trafford Publishing, Inc., February 2004. ISBN 1-412-02203-7.

God Created the Integers, by Stephen Hawking. Running Press, October 2005. ISBN 0-762-41922-9.

Gödel's Theorem: An Incomplete Guide to Its Use and Abuse, by Torkel Franzén. A K Peters, May 2005. ISBN 1-56881-238-8.

Hiding in the Mirror: The Mysterious Allure of Extra Dimensions, from Plato to String Theory and Beyond, by Lawrence M. Krauss. Viking Adult, October 2005. ISBN 0-670-03395-2.

Incompleteness: The Proof and Paradox of Kurt Gödel, by Rebecca Goldstein. W. W. Norton & Company, February 2005. ISBN 0-393-05169-2. (Reviewed April 2006.)

Infinite Ascent: A Short History of Mathematics, by David Berlinski. Modern Library, September 2005. ISBN 0-679-64234-X.

The Infinite Book: A Short Guide to the Boundless, Timeless and Endless, by John D. Barrow. Pantheon, August 2005. ISBN 0-375-42227-7.

Introducing Game Theory and Its Applications, by Elliott Mendelson. CRC Press, July 2004. ISBN 1-584-88300-6.

**It's About Time: Understanding Einstein's Relativity*, by N. David Mermin. Princeton University Press, September 2005. ISBN 0-691-12201-6.

János Bolyai, Euclid, and the Nature of Space, by Jeremy J. Gray. MIT Press, May 2003. ISBN 0-262-57174-9. (Reviewed October 2005.)

The Knot Book: An Elementary Introduction to the Mathematical

Theory of Knots, Colin C. Adams. AMS, September 2004. ISBN 0-8218-3678-1. (Reviewed September 2005.)

**The Lifebox, the Seashell, and the Soul: What Gnarly Computation Taught Me about Ultimate Reality, the Meaning of Life, and How to be Happy*, by Rudy Rucker. Thunder's Mouth Press, October 2005. ISBN 1-560-25722-9.

Saunders Mac Lane: A Mathematical Autobiography, by Saunders Mac Lane. A K Peters, May 2005. ISBN 1-56881-150-0. (Reviewed December 2005.)

The Man Who Knew Too Much: Alan Turing and the Invention of the Computer, by David Leavitt. Great Discoveries series, W. W. Norton, December 2005. ISBN 0-393-05236-2.

The Math Instinct: Why You're a Mathematical Genius (Along with Lobsters, Birds, Cats, and Dogs), by Keith Devlin. Thunder's Mouth Press, March 2005. ISBN 1-56025-672-9.

Mathematical Adventures for Students and Amateurs, David F. Hayes and Tatiana Shubin, editors. Mathematical Association of America, 2004. ISBN 0-88385-548-8.

Mathematical Musings: A Collection of Quotes, edited by Dan Sonnenschein. Clarium Press, November 2005. ISBN 0-9697688-8-5.

Mathematics by Experiment: Plausible Reasoning in the 21st Century, by Jonathan Borwein and David Bailey. A K Peters, December 2003. ISBN 1-56881-211-6. (Reviewed September 2005.)

Meta Math! The Quest for Omega, by Gregory Chaitin. Pantheon, October 2005. ISBN 0-375-42313-3.

More Mathematical Astronomy Morsels, by Jean Meeus. Willmann-Bell, 2002. ISBN 0-943396-743.

**Mystic, Geometer, and Intuitionist: The Life of L. E. J. Brouwer.* Volume 2: Hope and Disillusion, by Dirk van Dalen. Oxford University Press, October 2005. ISBN 0-198-51620-7.

New Mexico Mathematics Contest Problem Book, by Liong-shin Hahn. University of New Mexico Press, November 2005. ISBN 0-8263-3534-9.

The Newtonian Moment: Isaac Newton and the Making of Modern Culture, by Mordechai Feingold. New York Library and Oxford University Press, December 2004. ISBN 0-195-17735-5.

The Oxford Murders, by Guillermo Martínez. Abacus, January 2005. ISBN 0-349-11721-7. (Reviewed November 2005.)

The Pea and the Sun: A Mathematical Paradox, by Leonard M. Wapner. A K Peters, April 2005. ISBN 1-56881-213-2.

Piero della Francesca: A Mathematician's Art, by J. V. Field. Yale University Press, August 2005. ISBN 0-300-10342-5.

PopCo, by Scarlett Thomas. Harvest Books, October 2005. ISBN 0-156-03137-X. (Reviewed February 2006.)

Probability Theory: The Logic of Science, by E. T. Jaynes. Edited by G. Larry Bretthorst. Cambridge University Press, April 2003. ISBN 0-521-59271-2. (Reviewed January 2006.)

Reality Conditions: Short Mathematical Fiction, by Alex Kasman. Mathematical Association of America, May 2005. ISBN 0-88385-552-6.

Reflections: V. I. Arnold's Reminiscences, by V. I. Arnold. Springer, April 2006. ISBN 3-540-28734-5.

**The Road to Reality: A Complete Guide to the Laws of the Universe*, by Roger Penrose. Knopf, February 2005. ISBN 0-679-45443-8. (Reviewed in this issue.)

Science in the Looking Glass, by E. Brian Davies. Oxford University Press, August 2003. ISBN 0-198-52543-5. (Reviewed December 2005.)

**Shadows of Reality: The Fourth Dimension in Relativity, Cubism, and Modern Thought*, by Tony Robbin. Yale University Press, March 2006. ISBN 0-300-11039-1.

Spaceland, by Rudy Rucker. Tor Books, June 2002. ISBN 0-765-30366-3. (Reviewed August 2005.)

**Symmetry and the Monster: The Story of One of the Greatest Quests of Mathematics*, by Mark Ronan. Oxford University Press, May 2006. ISBN 0-192-80722-6.

The Three Body Problem, by Catherine Shaw. Allison and Busby, March 2005. ISBN 0-749-08347-6.

Using the Mathematics Literature, by Kristine K. Fowler. Marcel Dekker, June 2004. ISBN 0-824-75035-7.

The Visual Mind II, edited by Michele Emmer. MIT Press, May 2005. ISBN 0-262-05076-5.

David P. Robbins Prize 2007

Algebra • Combinatorics • Discrete Mathematics

This prize was established in 2005 in memory of David P. Robbins by members of his family. Robbins, who died in 2003, received his Ph.D. in 1970 from MIT. He was a long-time member of the Institute for Defense Analysis Center for Communications Research and a prolific mathematician whose work (much of it classified) was in discrete mathematics. The prize is for a paper with the following characteristics: it shall report on novel research in algebra, combinatorics or discrete mathematics and shall have a significant experimental component; and it shall be on a topic which is broadly accessible and shall provide a simple statement of the problem and clear exposition of the work. The US$5,000 prize will be awarded every three years. It is expected that the first award will be made in January 2007.

Nominations should be submitted to the AMS Secretary, Robert J. Daverman, American Mathematical Society, 312D Ayres Hall, University of Tennessee, Knoxville, TN 37996-1330. Include a complete bibliographic citation for the work that is the basis of the nomination, supplemented with brief remarks explaining what aspects of the work make it particularly suited for this prize. The nominations will be forwarded by the Secretary to the Prize Selection Committee, which will make the final decision on the award.

Deadline for nominations: August 15, 2006

AMS
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www.ams.org

From the AMS Secretary

Ethical Guidelines for the Society

In January 1994 the AMS Council received the report of its Special Advisory Committee on Professional Ethics. The Committee, which consisted of Murray Gerstenhaber, Frank Gilfeather, Elliott Lieb, and Linda Keen (Chair), presented ethical guidelines for adoption by the Council. Those draft guidelines were published twice in the *Notices* of the AMS, with a request to the membership for responses and suggestions for changes or improvements. These were sent to the Committee, which considered all suggestions. The Committee then redrafted the guidelines and presented the redraft to the January 1995 Council. At that meeting, the Council voted to adopt the guidelines as a resolution of the Council (by a vote that was unanimous save for one abstention), and shortly thereafter the Council adopted them "so as to speak in the name of the Society", a more official designation.

Acting upon recommendations from the AMS Committee on the Profession, in January 2004 the Council approved a general revision to the document, which also incorporated additional statements describing and deploring plagiarism. In January 2005 the Council adopted these guidelines "so as to speak in the name of the Society".

Ethical Guidelines of the American Mathematical Society

To assist in its chartered goal, "...the furtherance of the interests of mathematical scholarship and research ...", and to help in the preservation of that atmosphere of mutual trust and ethical behavior required for science to prosper, the Council of the American Mathematical Society sets forth the following ethical guidelines. These guidelines reflect its expectations of behavior both for AMS members, as well as for all individuals and institutions in the wider mathematical community, including those engaged in the education or employment of mathematicians or in the publication of mathematics. These guidelines are not a complete expression of the principles that underlie them. The guidelines are not meant to be a complete list of all ethical issues. They will be modified and amplified by events and experience. These are guidelines, not a collection of rigid rules.

The American Mathematical Society, through its Committee on Professional Ethics (COPE), may provide an avenue of redress for individual members injured in their capacity as mathematicians by violations of these ethical principles. In each case, COPE will determine the appropriate ways in which it can be helpful (including making recommendations to the Council of the Society). The AMS cannot enforce these guidelines, however, and it cannot substitute for individual responsibility or for the responsibility of the mathematical community at large.

I. Mathematical Research and Its Presentation

The public reputation for honesty and integrity of the mathematical community and of the Society is its collective treasure and its publication record is its legacy.

The knowing presentation of another person's mathematical discovery as one's own constitutes plagiarism and is a serious violation of professional ethics. Plagiarism may occur for any type of work, whether written or oral and whether published or not.

The correct attribution of mathematical results is essential, both because it encourages creativity, by benefiting the creator whose career may depend on the recognition of the work and because it informs the community of when, where, and sometimes how original ideas entered into the chain of mathematical thought. To that end, mathematicians have certain responsibilities, which include the following:

- To endeavor to be knowledgeable in their field, especially about work related to their research;
- To give appropriate credit, even to unpublished materials and announced results (because the knowledge that something is true or false is valuable,

however it is obtained);

• To publish full details of results that are announced without unreasonable delay, because claiming a result in advance of its having been achieved with reasonable certainty injures the community by restraining those working toward the same goal;

• To use no language that suppresses or improperly detracts from the work of others;

• To correct in a timely way or to withdraw work that is erroneous.

A claim of independence may not be based on ignorance of widely disseminated results. On appropriate occasions, it may be desirable to offer or accept joint authorship when independent researchers find that they have produced identical results. All the authors listed for a paper, however, must have made a significant contribution to its content, and all who have made such a contribution must be offered the opportunity to be listed as an author. Because the free exchange of ideas necessary to promote research is possible only when every individual's contribution is properly recognized, the Society will not knowingly publish anything that violates this principle, and it will seek to expose egregious violations anywhere in the mathematical community.

II. Social Responsibility of Mathematicians

The Society promotes mathematical research together with its unrestricted dissemination, and to that end encourages all to engage in this endeavor. Mathematical ability must be respected wherever it is found, without regard to race, gender, ethnicity, age, sexual orientation, religious belief, political belief, or disability.

The growing importance of mathematics in society at large and of public funding of mathematics may increasingly place members of the mathematical community in conflicts of interest. The appearance of bias in reviewing, refereeing, or in funding decisions must be scrupulously avoided, particularly where decisions may affect one's own research, that of colleagues, or of one's students. When conflicts of interest occur, one should withdraw from the decision-making process.

A recommendation accurately reflecting the writer's views is often given only on the understanding that it be kept confidential; therefore, a request for a recommendation must be assumed to carry an implicit promise of confidentiality, unless there is a statement to the contrary. Similarly, a referee's report is normally provided with the understanding that the name of the writer be withheld from certain interested parties, and the referee must be anonymous unless otherwise indicated in advance. The writer of the recommendation or report must respond fairly and keep confidential any privileged information, personal or mathematical, that the writer receives. If the requesting individual, institution, agency, or company becomes aware that confidentiality or anonymity can not be maintained, that should be immediately communicated.

Where choices must be made and conflicts are unavoidable, as with editors or those who decide on appointments or promotions, it is essential to keep careful records that would demonstrate the process was indeed fair when inspected at a later time.

Freedom to publish must sometimes yield to security concerns, but mathematicians should resist excessive secrecy demands whether by government or private institutions.

When mathematical work may affect the public health, safety, or general welfare, it is the responsibility of mathematicians to disclose the implications of their work to their employers and to the public, if necessary. Should this bring retaliation, the Society will examine the ways in which it may want to help the "whistle-blower", particularly when the disclosure has been made to the Society.

No one should be exploited by the offer of a temporary position at an unreasonably low salary and/or an unreasonably heavy work load.

III. Education and Granting of Degrees

Holding a Ph.D. degree is virtually indispensable to an academic career in mathematics and is becoming increasingly important as a certificate of competence in the wider job market. An institution granting a degree in mathematics is certifying that competence and must take full responsibility for it by insuring the high level and originality of the Ph.D. dissertation work, and sufficient knowledge by the recipient of important branches of mathematics outside the scope of the thesis. When there is evidence of plagiarism it must be carefully investigated, even if it comes to light after granting the degree, and, if proven, the degree should be revoked. Mathematicians and organizations involved in advising graduate students should fully inform them about the employment prospects they may face upon completion of their degrees.

IV. Publications

Editors are responsible for the timely refereeing of articles and must judge articles by the state of knowledge at the time of submission. Editors should accept a paper for publication only if they are reasonably certain the paper is correct.

The contents of submitted manuscript should be regarded by a journal as privileged information. If the contents of a paper become known in advance of publication solely as a result of its submission to or handling by a journal, and if a later paper based on knowledge of the privileged information is received anywhere (by the same or another journal), then any editor aware of the facts must refuse or delay publication of the later paper until after publication of the first—unless the first author agrees to earlier publication of the later paper.

At the time a manuscript is submitted, editors should

notify authors whenever a large backlog of accepted papers may produce inordinate delay in publication. A journal may not delay publication of a paper for reasons of an editor's self interest or of any interest other than the author's. The published article should bear the date on which the manuscript was originally submitted to the journal for publication, together with the dates of any revisions. Editors must be given and accept full scientific responsibility for their journals; when a demand is made by an outside agency for prior review or censorship of articles, that demand must be resisted and, in any event, knowledge of the demand must be made public.

Both editors and referees must respect the confidentiality of materials submitted to them unless these materials have previously been made public, and above all may not appropriate to themselves ideas in work submitted to them or do anything that would impair the rights of authors to the fruits of their labors. Editors must preserve the anonymity of referees unless there is a credible allegation of misuse.

All mathematical publishers, particularly those who draw without charge on the resources of the mathematical community through the use of unpaid editors and referees, must recognize that they have made a compact with the community to disseminate information, and that compact must be weighed in their business decisions.

The Society will not take part in the publishing, printing, or promoting of any research journal where there is some acceptance criterion, stated or unstated, that conflicts with the principles of these guidelines. It will promote the quick refereeing and timely publication of articles accepted to its journals.

—As adopted by the Council of the American Mathematical Society on January 5, 2005, "so as to speak in the name of the Society".

Mathematics Calendar

The most comprehensive and up-to-date Mathematics Calendar information is available on e-MATH at `http://www.ams.org/mathcal/`.

May 2006

29–June 2 **Analytic Function Spaces**, University of Joensuu, Joensuu, Finland. (Apr. 2006, p. 495)

29–June 2 **International School on Partial Differential Equations**, Depto. Matemáticas y Mecánica, IIMAS Universidad Nacional Autónoma de México (UNAM), Mexico City, Mexico. (May 2006, p. 606)

29–June 3 **International Conference on Toric Topology**, Osaka City University, Osaka, Japan. (Dec. 2005, p. 1381)

30–June 2 **DAYS on DIFFRACTION–2006**, St. Petersburg University & St. Petersburg Branch Steklov Math. Inst., St. Petersburg, Russia. (Jan. 2006, p. 68)

30–June 2 **Geometry and Representation Theory: A conference in honor of George Lusztig**, M.I.T., Cambridge, Massachusetts. (Feb. 2006, p. 285)

30–June 3 **2006 USENIX Annual Technical Conference**, Boston, Massachusetts. (Dec. 2005, p. 1381)

30–June 6 **NAFSA 8–8th International Spring School on Nonlinear ANalysis, Function Spaces and Applications**, Czech University of Agriculture, Prague, Czech Republic. (Oct. 2005, p. 1088)

31–June 4 **MASSEE International Congress on Mathematics: MICOM-2006**, Cyprus, Greece. (Mar. 2006, p. 377)

June 2006

1–3 **Carleton Applied Probability Workshop**, Carleton University, Ottawa, Canada. (Apr. 2006, p. 495)

1–July 31 **Algorithmic Biology: Algorithmic Techniques in Computational Biology**, Institute for Mathematical Sciences, National University of Singapore, Singapore. (Dec. 2005, p. 1381)

2–14 **Approximation Algorithms**, Centre de Recherches Mathematiques, Montreal, Canada. (May 2006, p. 607)

4–10 **Workshop on Commutative Rings**, Cortona, Italy. (Feb. 2006, p. 286)

*4–29 **Joint Summer Research Conference**, Snowbird Resort, Snowbird, Utah.
Information: `http://www.ams.org/meetings/src.html`.

5–9 **Poisson 2006: Poisson Geometry in Mathematics and Physics**, National Olympic Memorial Youth Center, Tokyo, Japan. (Jan. 2006, p. 68)

5–9 **Selfsimilar groups and conformal dynamics**, AIM Research Conference Center, Palo Alto, California. (Dec. 2005, p. 1381)

5–9 **Workshop on Fourier Analysis, Geometric Measure Theory and Applications**, Centre de Recerca Matemàtica, Barcelona, Spain. (May 2006, p. 607)

5–12 **Motives and Periods**, University of British Columbia, Vancouver, BC, Canada. (Dec. 2005, p. 1381)

5–15 **Arithmetic and Geometry Around Quantization, European Mathematical Society Summer School**, Galatasaray University, Istanbul, Turkey. (Apr. 2006, p. 495)

*6–8 **Data Mining Training/Workshop**, Australian Graduate School of Management Lecture Theatre, Sydney, Australia.
Objective: The training and workshop are aimed at bringing together researchers and practitioners to learn about data mining technology from practical and theoretical experts. Expect to exchange ideas

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 held in North America 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. Meetings held outside the North American area may carry more detailed information. In any case, 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/`.

and experiences focused on the practice of both data mining and the real world analysis of complex data.
Workshop: Will be similar in format to our Madrid 2005 Workshop, http://www.salforddatamining.com/program-madrid05.htm, and San Diego, CA 2006 Conference, http://www.salforddatamining.com/docs/schedule06.pdf.
Contact: email: abaldwin@salford-systems.com for a registration form. Put Sydney Registration Form Request in the subject line. http://www.salforddatamining.com.

7-10 **Symposium in Complex Analysis**, Kranjska Gora, Slovenia. (Nov. 2005, p. 1264)

8-10 **Lehigh University Geometry/Topology Conference**, Lehigh University, Bethlehem, Pennsylvania. (Apr. 2006, p. 495)

9-11 **Logic and Mathematics 2006**, University of Illinois at Urbana-Champaign, Urbana, Illinois. (May 2006, p. 607)

9-14 **Eight International Conference on Geometry, Integrability and Quantization**, Sts. Constantine and Elena resort (near Varna), Bulgaria. (Oct. 2005, p. 1088)

10-16 **32nd International Conference "Applications of Mathematics in Engineering and Economics" (AMEE'06)**, Town of Sozopol, Bulgaria. (Apr. 2006, p. 495)

10-16 **Discontinuous change in behavior issues in partial differential equations**, Anogia Acdademic Village, Crete, Greece. (May 2006, p. 607)

11-14 **ICMSE 2006- International Conference in Mathematics, Sciences and Science Education**, University of Aveiro, Aveiro, Portugal. (Jan. 2006, p. 68)

*12-14 **Approximation Algorithms**, Centre de recherches mathématiques, Université de Montréal, Montréal, Québec, Canada.
Organizers: Joseph Cheriyan (Waterloo) and Michel Goemans (MIT).
Workshop: Most combinatorial optimization problems are NP-hard, that is, they cannot be solved in polynomial time unless P is equal to NP. As a result, for over three decades, researchers have attempted to derive approximation algorithms that provide in polynomial time suboptimal solutions with a guarantee/proof of their degree of suboptimality. The workshop will include lectures on the latest developments in the field of approximation algorithms, on both the approximability and the inapproximability sides.
Information: http://www.crm.umontreal.ca/Approximation06/index_e.html.

12-15 **2006 International Conference on Applied Mathematics and Interdisciplinary Research-Nankai**, Nankai University, Tianjin, P. R. China. (May 2005, p. 570)

12-15 (REVISED) **Conference on 3-manifold topology in honour of Peter Shalen's 60th birthday**, Centre de Recherches Mathematiques, Montreal, Canada. (Feb. 2006, p. 286; May 2006, p. 608)

12-16 **EMS mathematical weekend in Pays de Loire**, Université de Nantes, Nantes, France. (Feb. 2006, p. 286)

12-16 **Function Theories in Higher Dimensions**, Tampere Univ. of Technology, Tampere, Finland. (Jun/Jul. 2005, p. 674)

12-16 **Permutation Patterns 2006**, Reykjavik University, Reykjavik, Iceland. (May 2006, p. 608)

12-16 **The Twenty-Second Annual Mathematical Problems in Industry Workshop**, Needham, Massachusetts. (Dec. 2005, p. 1381)

12-17 **Boltzmann Equation and Fluidodynamic Limits**, SISSA-ISAS, Trieste, Italy. (May 2006, p. 608)

12-17 **Steklov Mathematical Institute International Workshop on Mathematical Hydrodynamics**, Steklov Mathematical Institute, Moscow, Russia. (Mar. 2006, p. 377)

13-15 **2nd IMT-GT Conference on Mathematics, Statistics and Their Applications**, Gurney Hotel, Penang, Malaysia. (Apr. 2006, p. 495)

13-17 **CBMS Conference on Cluster Algebras and Applications**, Raleigh, North Carolina. (Apr. 2006, p. 495)

13-17 **The Fifteenth International Workshop on Matrices and Statistics**, Uppsala, Sweden. (Jan. 2006, p. 68)

15-22 **Operator Theory, Analysis and Mathematical Physics: OTAMP2006**, Lund Institute of Technology, Lund, Sweden. (Apr. 2006, p. 496)

16-18 **NKS 2006 Wolfram Science Conference**, The Fairmont, Washington, DC. (Mar. 2006, p. 378)

16-20 **CAIMS-MITACS Joint Annual Conference**, York University, Toronto, Ontario, Canada. (Jan. 2006, p. 68)

*19-20 **DIMACS Tutorial on Phylogenetic Trees and Rapidly Evolving Pathogens**, DIMACS Center, CoRE Bldg, Rutgers University, Piscataway, New Jersey.
Organizer: Katherine St. John, The City University of New York, stjohn@lehman.cuny.edu.
Local Arrangements: Workshop Coordinator, DIMACS Center, workshop@dimacs.rutgers.edu, 732-445-5928.
Short Description: Phylogenies, or evolutionary histories, are used throughout biology. In addition to the study of taxonomy, they are used widely to do such things as design drugs, align biomolecular sequences, and to understand rapidly evolving diseases, such as HIV. This tutorial is an introduction to computational phylogenetics and its applications to real-world problems. The topics will include standard phylogenetic reconstruction methods and concepts, as well as advanced topics needed to understand the application of phylogeny to rapidly evolving diseases.
Information: http://dimacs.rutgers.edu/Workshops/PhyloTutorial/.

19-23 **Formal Power Series and Algebraic Combinatorics 2006**, Catamaran Resort Hotel, Pacific Beach, San Diego, California. (Jan. 2006, p. 69)

19-23 **Free Analysis**, AIM Research Conference Center, Palo Alto, California. (Jun/Jul. 2005, p. 674)

19-23 **Harmonic Analysis and Related Problems 2006 (HARP 2006)**, Zaros, Crete, Greece. (Mar. 2006, p. 378)

19-23 **La Pietra Week in Probability, Firenze 2006: Stochastic Processes in Mathematical Physics**, Villa La Pietra, Firenze, Italy. (Apr. 2006, p. 496)

19-23 **Modern stochastics: theory and applications**, Kyiv National Taras Shevchenko University, Kyiv, Ukraine. (Sept. 2005, p. 953)

19-23 **The International Summer School in Several Complex Variables**, Szczyrk, Poland. (Dec. 2005, p. 1382)

19-24 **Hodge Theory**, Venice International University, Venice-Island of San Servolo, Italy. (Feb. 2006, p. 286)

19-July 7 **Computational Number Theory and Applications to Cryptography**, University of Wyoming, Laramie, Wyoming. (Feb. 2006, p. 286)

19-30 **SMS 2006/NATO Advanced Study Institute-Combinatorial Optimization: Methods and Applications**, Université de Montréal, Montréal (QC) Canada. (Jan. 2006, p. 69)

*20-October 26 **Mathematical Finance 2006 (Cycle of Advanced Courses)**, ISEG-Technical University of Lisbon, Lisbon, Portugal.
Program: C1. June 20, 21, 22-Risk Measures (M. Frittelli, U. di Firenze, Italy); C2. June 29, 39, July 1-Math. Tools for Credit Risk (M. Jeanblanc, U. d'Evry, France); C3. September 25, 26, 28, 29-Interest Rate Theory (T. Bjork, Stockholm School of Economics, Sweden); C4. October 23, 24, 25-Portfolio Optimization (W. Runggaldier, U. Degli Studi di Padova, Italy).

Information: Registration is possible for any one of the courses (C1, C2, C3, C4) or any combination. http://pascal.iseg.utl.pt/~matfin/MathFin06-cycle.htm.

20–22 **International Conference on Mathematical, Statistical, and Computer Methods in HIV/AIDS**, Regal Kowloon Hotel, East Kowloon, Hong Kong. (Feb. 2006, p. 286)

*20–24 **Third Advanced Course in Operator Theory and Complex Analysis**, Seville, Spain.
Invited Speakers: Aharon Atzmon, Tel Aviv University; John B. Conway, University of Tennessee; Jean Esterle, Université Bordeaux 1; Stanislav Shkarin, King's College London; Gilles Cassier, Université Lyon 1; Joe Diestel, Kent State University; Jonathan R. Partington, University of Leeds.
Organizers: Manuel Cepedello Boiso, Alfonso Montes Rodriguez, Carmen Romero Moreno.
Topics: Courses and talks will cover topics on Complex Analysis, Operator Theory and related areas of Functional Analysis. Contributed talks related to these topics will also take place: participants who wish to deliver a short talk please submit an abstract to the organizers or any of the collaborators.
Funding: Some funding might be available for undergraduate and Ph.D. students in order to cover registration fee and closure dinner. Remaining fundings will be assigned to cover travel and lodging expenses. Further application info will be available shortly.
Information: http://www.us.es/ceacyto3.

21–23 **ICNPAA-2006: Mathematical Problems in Engineering and Aerospace Sciences**, Budapest, Hungary. (May 2005, p. 570)

21–24 **"Views on ODEs" Conference in Honor of Arrigo Cellina and James A. Yorke on the Occasion of their 65th Birthdays**, Aveiro University, Aveiro, Portugal. (May 2006, p. 608)

*21–24 **Workshop on Algorithms for Modern Massive Data Sets**, Stanford University, Stanford, California.
Organizers: Gene Golub, Michael Mahoney, Petros Drineas, Lek-Heng Lim.
Information: Topics, speakers, registration, and other information: http://mmds.stanford.edu.
Contact: For further information regarding the workshop, please email Lek-Heng Lim at lekheng@cs.stanford.edu.

22–24 **2nd International Workshop on Graph-Theoretic Concepts in Computer Science**, Bergen, Norway. (Dec. 2005, p. 1382)

23–26 **2006 International Conference on Topology and its Applications**, Aegion, Greece. (Jan. 2006, p. 69)

25–28 **SIAM Conference on Discrete Mathematics**, University of Victoria, Victoria, British Columbia, Canada. (Dec. 2005, p. 1382)

25–28 **INFORMS International Hong Kong 2006**, Sheraton Hotel & Towers Hong Kong, Hong Kong, China. (Jun/Jul. 2005, p. 674)

25–28 **The Sixth AIMS Conference on Dynamical Systems, Differential Equations and Applications**, University of Poitiers, Poitiers, France. (Jun/Jul. 2005, p. 674)

26–29 **Special Session on "Coding theory and cryptography"**, Varna, Bulgaria. (May 2006, p. 608)

26–30 **Algebraic Combinatorics: An International Conference in honor of Eiichi Bannai's 60th birthday**, Sendai International Center, Sendai, Japan. (Dec. 2005, p. 1382)

26–30 **Calibrations**, AIM Research Conference Center, Palo Alto, California. (Sept. 2005, p. 954)

*26–30 **Conference on Differential and Difference Equations and Applications 2006**, Rajecke Teplice, (close to Zilina), Slovak Republic.
Organizer: Faculty of Science, University of Zilina.
Topics: Ordinary Differential Equations (ODE), Functional Differential Equations (FDE), Difference Equations (DE), Partial Differential Equations (PDE), Numerical Methods in Differential and Difference Equarions (NM).
Invited Speakers: Igor Bock (Slovak Republic), Alexander Boichuk (Slovak Republic), Theodore A. Burton (USA), Jan Cermak (Czech Republic), Zuzana Dosla (Czech Republic), Ondrej Dosly (Czech Republic), Jozef Dzurina (Slovak Republic), Istvan Gyori (Hungary), Anatolij Ivanov (USA), Jaroslav Jaros (Slovak Republic), Denys Khusainov (Ukraine), Tibor Krisztin (Hungary), Jaroslav Kurzweil (Czech Republic), Takasi Kusano (Japan), Mauro Marini (Italy), Frantisek Neuman (Czech Republic), Mihaly Pituk (Hungary), Irena Rachunkova (Czech Republic), Ewa Schmeidel (Poland), Stefan Schwabik (Czech Republic), Svatoslav Stanek (Czech Republic), Ioannis P. Stavroulakis (Greece), Tomoyuki Tanigawa (Japan), Milan Tvrdy (Czech Republic).
Information: Department of Methematical Analysis and Applied Mathematics, Faculty of Science, University of Zilina, Hurbanova 15, 01026 Zilina, Slovak Republic; email: cddea@fpv.utc.sk; http://www.fpv.utc.sk/cddea/.

26–July 8 **Advanced Course on Limit Cycles of Differential Equations**, Centre de Recerca Matemàtica, Barcelona, Spain. (May 2006, p. 608)

27–July 3 **International Commission on Mathematical Instruction: Challenging Mathematics In and Beyond the Classroom**, Trondheim, Norway. (Apr. 2005, p. 478)

28–30 **Workshop From Lie Algebras to Quantum Groups**, Universidade de Coimbra, Portugal. (May 2006, p. 608)

29–July 4 **21st International Conference on Operator Theory**, West University, Timisoara, Romania. (Feb. 2006, p. 286)

30–July 5 **Computability in Europe 2006 (CiE 2006): Logical Approaches to Computational Barriers**, Swansea, Wales. (Mar. 2006, p. 378)

July 2006

*2–6 **Design Theory of Alex Rosa, a meeting in celebration of Alex Rosa's 70th Birthday**, Bratislava, Slovakia.
Organizers: IAS, University of Washington, Tacoma; Mathematical Institute of the Slovak Academy of Sciences; Department of Applied Informatics and Information Technology; Slovak University of Technology.
Speakers: Charles Colbourn, Jeff Dinitz, Pavol Hell, Curt Lindner, Spyros Magliveras, Eric Mendelsohn, Rudolf Mathon, Jaroslav Nesetril, Vojtech Rodl, Chris Rodger, Gert Sabidussi, Rick Wilson.
Information: Please send an email to horak@u.washington.edu to be included in the mailing list of the conference; http://www.d.umn.edu/~dfroncek/alex/index.htm.

2–7 **ICOTS 7, Working Cooperatively in Statistics Education**, Salvador (Bahia), Brazil. (Mar. 2004, p. 361)

3–7 **Inverse Problems in Applied Sciences—toward break through**, University Conference Hall, Hokkaido University, Sapporo, Japan. (Nov. 2005, p. 1264)

3–7 **Iwasawa 2006 Congress**, Université de Limoges, Limoges, France. (May 2006, p. 608)

*3–8 **Graph Algebras Workshop 2006**, Universidad de Málaga, Spain.
Organizers: Gonzalo Aranda (Universidad Complutense de Madrid); Francesc Perera (Universitat Autònoma de Barcelona); Mercedes Siles (Universidad de Málaga).
Plenary Speakers: Gene Abrams (University of Colorado at Colorado Springs); Pere Ara (Universitat Autònoma de Barcelona, Spain); Enrique Pardo (Universidad de Cádiz, Spain); Iain Raeburn (University of Newcastle, Australia); Mark Tomforde (College of William and Mary, Williamsburg, VA).
Program: A one-week workshop aimed at various aspects of graph C*-algebras and the recently introduced purely algebraic class of

Leavitt path algebras. Experts from the C*-algebra and the pure algebra scenes will deliver a series of lectures (introductory as well as more advanced) in order to foster interaction. Thus the meeting is geared to both graduate students and specialists.
Information/Registration: http://agt.cie.uma.es/~wga06/.

3-22 **Summer School & Conference: Valuation Theory and Integral Closures in Commutative Algebra**, University of Ottawa, Ottawa, Ontario, Canada. (Apr. 2006, p. 496)

5-8 **Numerical Analysis and Approximation Theory, NAAT 2006**, Department of Applied Mathematics of Faculty of Mathematics and Computer Science, Babes-Bolyai University, Cluj-Napoca, Romania. (Mar. 2006, p. 378)

*6-9 **21st Summer Conference on Topology and its Applications**, Georgia Southern University, Statesboro, GA.
Description: The conference will be organized around 7 keynote speakers, 2 workshops, and 6 special sessions. Keynote speakers: S. Dolecki (U. of Bourgogne, France), M. Escardo (U. of Birmingham, UK), N. Hindman (Howard U.), M. Hrusak (UNAM, Mexico), K. Kuperberg (Auburn U.), J. Vaughan (U. of N. Carolina, Greensboro), W. Tholen (York U., Canada). Special Sessions: Topology and Set Theory (O. Pavlov, U. N. Carolina), Topology in Dynamical Systems (R. Devaney, Boston U.), Topological Groups and Semi-groups (M. Megrelishvili (Bar-Ilan U.), Asymmetric Topology (M. Mislove, Tulane U.), Categorical Topology (M. Sioen, Vrije U., Brussels), Fractals and Tilings (K.-S. Lau, Chinese U. of Hong Kong). Workshops: Physics and Domain Theory (K. Martin, Naval Research Lab.), Selection Principles in Topology (M. Scheepers, Boise State U.).
Support: Support from the National Science Foundation will allow about 30 travel grants of up to $450. Students, young researchers, female mathematicians, and members of underrepresented groups are encouraged to apply. Send vita, letter of application (including contact info for one reference) to Frederic Mynard at email: mynard@georgiasouthern.edu.
Information: http://www.cs.georgiasouthern.edu/faculty/mynardf/STC06. htm.

7-8 **Second International Conference on Nonsmooth/Nonconvex Mechanics with Applications in Engineering**, Faculty of Engineering, Aristotle University, Thessaloniki, Greece. (Apr. 2005, p. 478)

9-15 **DIMACS Reconnect Conference 2006: Reconnecting Teaching Faculty to the Mathematical Sciences Research Enterprise**, Morgan State University, Baltimore, Maryland. (Jan. 2006, p. 69)

9-15 **Which Mathematics for Biology?**, Anogia Academic Village, Crete, Greece. (May 2006, p. 608)

10-12 **SIAM Conference on Analysis of Partial Differential Equations**, Boston Park Plaza Hotel and Towers, Boston, Massachusetts. (Dec. 2005, p. 1382)

10-13 **Markov Processes and Related Topics**, University of Wisconsin-Madison, Madison, Wisconsin. (Apr. 2006, p. 496)

10-14 **International Conference on Analytic Topology**, Lake Plaza Hotel, Rotorua, New Zealand. (Apr. 2005, p. 478)

10-14 **Ninth International Conference on p-adic functional analysis**, University of Concepcion, Concepcion, Chile. (Aug. 2005, p. 787)

10-15 **6th Czech-Slovak International Symposium on Combinatorics, Graph Theory, Algorithms and Applications: Honoring the 60th Birthday of J. Nesetril**, Prague, Czech Republic. (May 2006, p. 608)

10-15 **Conference on Recent Developments in the Arithmetic of Shimura Varieties and Arakelov Geometry (An EMS Marie Curie Conference, supported by the European Commission)**, Centre de Recerca Matemàtica, Bellaterra, Spain. (May 2006, p. 609)

10-15 **Workshop on Stochastic Eigen-Analysis (Random Matrices) and its Applications**, MIT, Cambridge, Massachusetts. (Apr. 2006, p. 496)

11-12 **DIMACS Workshop on Machine Learning Techniques in Bioinformatics**, DIMACS Center, CoRE Bldg, Rutgers University, Piscataway, New Jersey. (May 2006, p. 609)

12-15 **Geometric Analysis and Applications**, University of Illinois, Urbana-Champaign, Illinois. (Apr. 2006, p. 496)

12-16 **Anomalous Transport: Experimental Results and Theoretical Challenges**, Physikzentrum Bad Honnef near Bonn, Germany. (May 2006, p. 609)

13-14 **Conference on Geometric Group Theory**, Centre de Recherches Mathematiques, Montreal, Canada. (May 2006, p. 609)

14-31 **The Ninth International Diffiety School**, Santo Stefano del Sole, Avellino, Italy. (Apr. 2006, p. 496)

16-21 **Recent Advances in Nonlinear Partial Differential Equations: A celebration of Norman Dancer's 60th birthday**, University of New England, Armidale, NSW, Australia. (May 2006, p. 609)

16-22 **Horizon of Combinatorics**, Lake Balaton, Hungary. (May 2006, p. 609)

17-21 **Classification theory for abstract elementary classes**, AIM Research Conference Center, Palo Alto, California. (Feb. 2006, p. 286)

17-21 **Workshop on Singularities in PDE and the Calculus of Variations**, Centre de Recherches Mathématiques, Montreal, Canada. (May 2006, p. 609)

17-August 4 **International Conference and Instructional Workshop on Discrete Groups**, The Morningside Center of Mathematics, Beijing, People's Republic of China. (Dec. 2005, p. 1382)

17-August 11 **Clay Mathematics Institute 2006 Summer School: Arithmetic Geometry**, Mathematisches Institut, Georg-August-Universität, Göttingen, Germany. (Feb. 2006, p. 287)

17-August 11 **Spectral Theory and Partial Differential Equations**, Isaac Newton Institute for Mathematical Sciences, Cambridge, England. (Aug. 2004, p. 835)

18-21 **International Conference on Interdisciplinary Social Sciences**, University of the Aegean, Island of Rhodes, Greece. (Mar. 2006, p. 379)

18-21 **Thirteenth Workshop on Logic, Language, Information and Computation (WoLLIC'2006)**, Stanford, California. (Mar. 2006, p. 379)

23-27 **The Ninth International Conference on Integral Methods in Science and Engineering (IMSE-2006)**, Sheraton Fallsview Hotel and Conference Centre, Niagara Falls, Ontario, Canada. (Aug. 2005, p. 787)

24-28 **2nd SIPTA School on Imprecise Probabilities**, Rey Juan Carlos University, Madrid, Spain. (Feb. 2006, p. 287)

24-28 **Brazilian Operator Algebras Conference**, Florianopolis, Brazil. (Feb. 2006, p. 287)

24-28 **New Trends in Viscosity Solutions and Nonlinear PDE**, Instituto Superior Tecnico, Lisbon, Portugal. (Mar. 2006, p. 379)

24-28 **The Eleventh International Conference on Difference Equations and Applications**, Kyoto University, Kyoto, Japan. (Jan. 2006, p. 69)

24-August 4 **Pan-American Advanced Studies Institute (PASI): Analysis and Probability in Quantum Physics**, San Joaquin campus, Pontificia Catolica de Chile, Santiago, Chile. (Feb. 2006, p. 287)

24-December 22 **Noncommutative Geometry**, Isaac Newton Institute for Mathematical Sciences, Cambridge, England. (Aug. 2004, p. 835)

25-27 **International Conference on Mathematics**, Institute of Mathematics, National University of Mongolia, Ulaanbaatar, Mongolia. (Feb. 2006, p. 287)

27-August 2 **ASL European Summer Meeting (Logic Colloquium '06)**, Nijmegen, Netherlands. (Jun/Jul. 2005, p. 675)

30-August 4 **Institute of Mathematical Statistics (IMS) Annual Meeting and X Brazilian School of Probability (XEBP)**, Instituto Nacional de Matemática Pura e Aplicada (IMPA), Rio de Janeiro, Brazil. (Mar. 2006, p. 379)

*30-August 5 **Harmonic Analysis and Applications and 8th Encuentro Nacional de Analistas Alberto P. Calderon**, Merlo, San Luis, Argentina.
Information: http://mate.dm.uba.ar/~hafg/haa.htm.

30-August 5 **International Conference on Radicals (ICOR-2006)**, Kiev National Taras Shevchenko University, Kiev, Ukraine. (Dec. 2005, p. 1383)

30-August 24 **Bayesian Nonparametric Regression: Theory, Methods and Applications**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom. (Oct. 2004, p. 1097)

31-August 2 **2006 Symposium on Performance Evaluation of Computer and Telecommunication Systems**, Calgary, Canada. (Dec. 2005, p. 1383)

31-August 4 **Numerical invariants of singularities and higher-dimensional algebraic varieties**, AIM Research Conference Center, Palo Alto, California. (Jan. 2006, p. 70)

August 2006

1-5 **Ninth Meeting of New Researchers in Statistics and Probability**, University of Washington, Seattle, Washington. (Mar. 2006, p. 379)

*1-September 30 **Dynamical Chaos and Non-equilibrium Statistical Mechanics: From Rigorous Results to Applications in Nano-systems**, Institute for Mathematical Sciences, National University of Singapore, Singapore.
Organizing Committee: Leonid Bunimovich (Georgia Institute of Technology), Giulio Casati (University Insubria, Italy, and National University of Singapore), Lock Yue Chew (Nanyang Technological University), Baowen Li (National University of Singapore), George Zaslavsky (New York University).
Collaborative Research: During this period, local and overseas researchers will interact and collaborate in research on various topics of the field.
Workshop: The purpose is to bring together researchers worldwide to discuss the most recent developments in anomalous energy (heat) transport in low dimensional systems, synchronization of chaotic systems and applications to communication of information. It also serves as a forum to promote regional as well as international scientific exchange and collaboration.
Information and registration: http://www.ims.nus.edu.sg/Programs/chaos/;email: imssec@nus.edu.sg. For enquiries on scientific aspects of the program, please email Baowen Li at phylibw@nus.edu.sg.

2-4 **31st Sapporo Symposium on Partial Differential Equations**, Department of Mathematics, Hokkaido University, Sapporo, Japan. (Jan. 2006, p. 70)

*2-4 **DIMACS Workshop on Computational Tumor Modeling**, DIMACS Center, CoRE Bldg, Rutgers University, Piscataway, New Jersey.
Organizers: David Axelrod, Rutgers University, Axelrod@nel-exchange.rutgers.edu; Thomas S. Deisboeck, Harvard Medical School, deisboec@helix.mgh.harvard.edu.
Local Arrangements: Workshop Coordinator, DIMACS Center, workshop@dimacs.rutgers.edu, 732-445-5928.
Information: http://dimacs.rutgers.edu/Workshops/TumorModeling/.
Short Description: This workshop will present a variety of relevant computational tumor models and algorithms, covering several scales of interest by starting from the genetic instability and the functional genomics level up to tumor cell invasion and the angiogenesis level. Work on tumor cell signaling and information processing, multicellular pattern formation and scaling laws will be discussed as well. Finally, the workshop will also focus on several key challenges related to cancer modeling, such as biomedical data acquisition, access and quality, as well as the pros and cons of combining different (e.g., discrete and continuous) modeling approaches.

*5-11 **Workshop on Symplectic Field Theory**, Universitaet Leipzig, Germany.
Information: Workshop on Symplectic Field Theory Lecture Series by Y. Eliashberg with contributions by F. Bourgois et al.
Organizers: Y. Eliashberg, K. Cieliebak, M. Schwarz.
Preparatory Precourse: August 5-6; main workshop August 7-11.
Program:http://www.math.uni-leipzig.de/ws/orhttp://math.stanford.edu/~lipshitz/SFT.html.

7-11 **Effective Randomness**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 609)

7-11 **Partial Differential Equations on Noncompact and Singular Manifolds**, University of Potsdam, Potsdam, Germany. (Feb. 2006, p. 287)

9-12 **The Third International Conference on Neural, Parallel & Scientific Computations**, Morehouse College, Atlanta, Georgia. (Mar. 2006, p. 379)

12-15 **Twenty-first Annual IEEE Symposium on Logic in Computer Science (LICS 2006)**, Seattle, Washington. (Mar. 2006, p. 380)

13-19 **Workshop on Triangulated Categories**, University of Leeds, United Kingdom. (Mar. 2006, p. 380)

14-16 **Network Design: Optimization and Algorithmic Game Theory**, Centre de Recherches Mathématiques, Montreal, Canada. (May 2006, p. 609)

14-18 **International Conference on Spectral Theory and Global Analysis**, Carl von Ossietzky University, Oldenburg, Germany. (Feb. 2006, p. 287)

14-18 **Seventh International Conference on Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing (MCQMC 2006)**, Ulm, Germany. (Nov. 2005, p. 1264)

*15-18 **Communicating Mathematics in the Digital Era**, University of Aveiro, Aveiro, Portugal.
Main Topics: The main topics of CMDE2006 include, but are not restricted to: Data Mining, Clustering and Recovery; Digital Libraries and Archiving Networks; E-Mathematics Resources; Electronic Publishing; Free and Open Source Initiatives; Information Representation and Visualization; International Copyrights and Author's Rights; Math-networking and Electronic Communication; Mathematics E-Learning; Metadata Models and Standards; Multimedia Tools; Retrodigitisation; Web Searching.
Information: Can be found in the Webpage of the conference at http://www.cmde2006.org.

16-19 **First announcement: Satellite Conference on Algebraic Geometry**, Segovia, Spain. (Jan. 2006, p. 70)

16-19 **Satellite conference on Algebraic Geometry**, Segovia Campus of the Universidad de Valladolid, Segovia, Spain. (Apr. 2006, p. 497)

16-19 **Trends and Challenges in the Calculus of Variations and its Applications**, Toledo, Spain. (Jan. 2006, p. 70)

16–19 **VII Workshop on Symplectic and Contact Topology, Satellite Conference of the International Congress of Mathematicians (ICM2006)**, Universidad Carlos III (Campus at Getafe), Madrid, Spain. (Apr. 2006, p. 497)

*17–19 **The XIV Conference on Applied and Industrial Mathematics, Satellite Conference of ICM2006**, Chisinau, Moldova.
Organizers: The Romanian Society of Applied and Industrial Mathematics (ROMAI), Mathematical Society of the Republic of Moldova, Moldova State University, Tiraspol State University, Institute of Mathematics and Computer Science of the Academy of Sciences of Moldova and the Center for Education and Research in Mathematics and Computer Science at Moldova State University (CRDF/MRDA).
Description: The Fourteenth Edition of the Conference on Applied and Industrial Mathematics (CAIM XIV) is dedicated to the 60th anniversary of the foundation of the Faculty of Mathematics and Computer Science of Moldova State University. Conference Sections: 1. Algebra, mathematical logic, topology; 2. Ordinary differential equations and finite dimensional dynamical systems; 3. Functional analysis and partial differential equations; 4. Analytical and numerical methods and applications. Industrial mathematics; 5. Theoretical and applied computer sciences; 6. Education.
Deadline for Abstacts: June 15, 2006.
Information: `http://www.usm.md/math/CAIM/`; email: `mathconf@mail.md`.

21–25 **Phase Transitions in Physics, Computer Science, Combinatorics and Probability Theory**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 610)

22–30 **International Congress of Mathematicians**, Madrid, Spain. (Nov. 2005, p. 1264)

*28–September 4 **Large-Scale Random Graph Methods for Modeling Mesoscopic Behavior in Biological and Physical Systems**, Alfred Renyi Institute of Mathematics, Budapest, Hungary.
Workshop Goals: The aim of the workshop is to expose the participants to the newest methods available for the description and analysis of large-scale, complex structures using methods of combinatorics and graph theory, in combination with nonlinear, adaptive systems theory, and statistical physics. The Workshop will cover the following areas: overview of the present state of research on large-scale random graphs in various fields of science; identification the problems in computation theory, brain science and statistical physics that require the development of new random graph methods; detailed discussion of the existing methods and outlining potential new theories to address those problems; application of combinatorial tools to give heuristics and, whenever possible, solve hard problems in various fields; outline avenues of practical application of the novel methods, especially in models of biological and artificial neural networks and brains, physical systems, and also complex networks relevant to communication and information theory.
Information: `http://cnd.memphis.edu/~nsfworkshop06/`.

30–September 1 **Recent Trends in Constructive Approximation Theory. Satellite Conference of ICM06**, Universidad Carlos III de Madrid, Legans, Spain. (May 2006, p. 610)

31–September 2 **Geometry and Topology of Low Dimensional Manifolds**, Burgo de Osma, Spain. (Apr. 2006, p. 497)

31–September 5 **Advanced Course on Combinatorial and Computational Geometry: Trends and topics for the future**, Centre de Recerca Matemàtica, Barcelona, Spain. (May 2006, p. 610)

September 2006

1–4 **Conference on Mathematical Neuroscience**, Sant Julià de Lòira (Andorra), Madrid, Spain. (May 2006, p. 610)

1–4 **Topics in Mathematical Analysis and Graph Theory**, University of Belgrade, Faculty of Electrical Engineering, Department of Applied Mathematics, Serbia and Montenegro. (Dec. 2005, p. 1383)

1–4 **SCRA 2006-FIM XIII, Thirteenth International Conference of Forum for Interdisciplinary Mathematics**, New University of Lisbon–Tomar Polytechnic Institute, Lisbon, Portugal. (Apr. 2006, p. 497)

1–5 **International Summer School and Workshop of Operator Algebras, Operator Theory and its Applications 2006**, Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisbon, Portugal. (Apr. 2006, p. 497)

4–6 **Optimal Discrete Structures and Algorithms (ODSA 2006)**, University of Rostock, Rostock, Germany. (Apr. 2006, p. 497)

4–8 **Barcelona Analysis Conference**, University of Barcelona, Barcelona, Spain. (Jan. 2006, p. 70)

*4–8 **Geometry Conference in Honor of Nigel Hitchin**, Consejo Superior de Investigaciones Cientificas, Madrid, Spain.
Description: This meeting is in honour of Professor Nigel Hitchin (University of Oxford) on the occasion of his 60th birthday. This is a satellite conference of the ICM 2006 to take place in Madrid in August 2006. The meeting is devoted to the many research topics covered by Nigel Hitchin.
Organizing Committee: L. Álvarez-Cónsul (CSIC, Madrid), O. García-Prada (CSIC, Madrid, Chairman), F. Kirwan (University of Oxford), H. Pedersen (University of Southern Denmark, Odense), Y.-S. Poon (University of California at Riverside), S. Salamon (Politecnico di Torino).
Deadline to Register: June 15, 2006.
Information: For a list of speakers and on-line registration, please visit the website `http://www.mat.csic.es/webpages/conf/hitchin2006/`.

*4–8 **International Conference on Arithmetic Algebraic Geometry**, El Escorial, Madrid, Spain.
Topics: This Satellite Conference of ICM2006 is organized by the European Research Network "Arithmetic Algebraic Geometry", and the main topics will be those covered by the network: Arithmetic of varieties over local fields, Arithmetic of varieties over global fields, Automorphic forms and the Langlands Program.
Coordinator of the Organizing Committee: Adolfo Quiros (U. Autonoma de Madrid), email: `aag2006@uam.es`.
Invited Speakers: Laurent Berger (IHES), José Ignacio Burgos-Gil (U. Barcelona), Matthew Emerton (Northwestern U.), Michael Harris (U. Paris VII, tentative), Chandrasekhar Khare (U. Utah, tentative), Philippe Michel (U. Montpellier), Takeshi Saito (Tokyo U.), Emmanuel Ullmo (U. Paris XI), Yakov Varshavsky (Hebrew University of Jerusalem, tentative), Annette Werner (U. Stuttgart).
Information, Registration and Grants: `http://www.uam.es/otros/aag2006/`.

4–8 **International Seminar on Applied Geometry in Andalusia**, University of Granada, Granada, Spain. (May 2006, p. 610)

4–8 **Satellite Conference on Differential Equations and Singularities, in honor of J. M. Aroca's 60th birthday**, Tordesillas(Valladolid, Spain). (Jun/Jul. 2005, p. 675)

4–8 **Stochastic Analysis in Mathematical Physics**, Cl Univ. Lisbon, Lisbon, Portugal. (Mar. 2006, p.380)

4–9 **International Conference on Applied Analysis and Differential Equations**, University "Al.I.Cuza", Faculty of Mathematics, Iasi, Romania. (May 2006, p.610)

4–29 **The Painlevé Equations and Monodromy Problems**, Issac Newton Institute for Mathematical Sciences, Cambridge, England. (Jan. 2006, p. 70)

*7–9 **Modern Mathematical Methods in Science and Technology**, Hotel Agnanti, Island of Paros, Greece.
Information: `http://applied.math.uoa.gr/m3st.html`.

*7–10 **Categorification in Algebra and Topology**, Uppsala University, Uppsala, Sweden.

Invited Speakers: Dror Bar-Natan; Anna Beliakova; Jonathan Brundan; Ian Grojnowski; Bernard Leclerc; Jacob Rasmussen; Raphaël Rouquier; Lev Rozansky (to be confirmed); Vladimir Turaev; Wolfgang Soergel; Catharina Stroppel.
Organizers: Volodymyr Mazorchuk and Oleg Viro.
Information: http://www.math.uu.se/cat2006/.
Inquiries: cat2006@math.uu.se.
Registration Deadline: July 31, 2006.

*8-10 **The Fourth International Conference on Origami in Science, Mathematics, and Education (4OSME)**, California Institute of Technology, Pasadena, California.
Purpose: To gather those interested and showcase new results in mathematical methods, scientific applications, and educational uses of paper folding.
Deadline: For presentation abstracts: April 30, 2006.
Organizers: Robert J. Lang, Thomas C. Hull, Ryda D. Rose.
Speakers: Erik Demaine, MIT.
Information: http://www.langorigami.com/science/4osme/4osme.php4.

*8-10 **International Conference on Modules and Comodules Dedicated to Robert Wisbauer on the Occasion of His 65th Birthday**, University of Porto, Portugal.
Conference: Dedicated to Robert Wisbauer at the occasion of his 65th birthday. It will bring together leading specialists in the theory of rings and modules, corings and comodules as well as in the theory of Quantum groups and its derivates.
Main Speakers: Helena Albuquerque (Coimbra), Tomasz Brzezinski (Swansea), José Gómez Torrecillas (Granada), Pedro Guil Asensio (Murcia), Claudia Menini (Ferrara), Alexandre V. Mikhalev (Moscow), Mike Prest (Manchester), Ivan Shestakov (Sáo Paulo), Patrick Smith (Glasgow).
Information: The deadline for submitting an abstract is the 31st of May 2006. The conference fee for non-students is 75 Euros and 50 Euros for students. Unfortunately we cannot offer any financial support. For more details, including the Conference Program please refer to http://www.fc.up.pt/mp/clomp/ModulesAndComodules/ or send an email to ModulesAndComodules@fc.up.pt.

8-12 **1st Dolomites Workshop on Constructive Approximation and Applications: Dedicated to Walter Gautschi for his 50 years of professional activity**, Alba di Canazei, Trento, Italy. (Apr. 2006, p. 497)

9-12 **SIAM Conference on Nonlinear Waves and Coherent Structures**, University of Washington, Seattle, Washington. (Jan. 2006, p. 70)

11-15 **Complexity of Mappings in CR Geometry**, AIM Research Conference Center, Palo Alto, California. (Apr. 2006, p. 497)

11-15 **Groups of Diffeomorphisms 2006**, University of Tokyo, Tokyo, Japan. (Jan. 2006, p. 70)

11-16 **XV Fall Workshop on Geometry and Physics**, Puerto de la Cruz (Tenerife, Canary Islands), Spain. (May 2006, p. 610)

12-17 **International Conference on Differential Equations, Dedicated to the 100th Anniversary of Ya. B. Lopatynsky**, Ivan Franko National University of Lviv, Lviv, Ukraine. (Mar. 2006, p. 380)

*15-17 **Asymptotic Analysis in Stochastic Processes, Nonparametric Estimation, and Related Problems**, Wayne State University, Detroit, Michigan.
Description: This is one of the IMA Paricipating Institution Conferences. It is devoted to stochastic asymptotic analysis.
Main Speakers: Eugene B. Dynkin, Mark Friedlin, Georgii Golubev, Ildar A. Ibragimov, Rafail Z. Khasminskii, Nicolai Krylov, Harold J. Kushner, Oleg Lepsky, Robert Liptser, Stanislav Molchanov, Michael Nussbaum, George Papanicolaou, Boris Rozovskii, Anatoli Skorokhod.
Local Organizers: Pao-Liu Chow, Boris Mordukhovich, George Yin.
Conference Secretary: Barbara Malicke (email: barb@math.wayne.edu).
Information: http://www.math.wayne.edu/~conf/.

15-19 **International Conference of Numerical Analysis and Applied Mathematics 2006 (ICNAAM 2006)**, Hotel Belvedere Imperial, Hersonnisos, Crete, Greece. (Apr. 2006, p. 497)

18-20 **The 10th Workshop on Elliptic Curve Cryptography (ECC 2006)**, Fields Institute, Toronto, Canada. (May 2006, p. 610)

18-22 **Hybrid Methods and Branching Rules in Combinatorial Optimization**, Centre de Recherches Mathématiques, Montreal, Canada. (May 2006, p. 610)

18-22 **Model Theory of Metric Structures**, AIM Research Conference Center, Palo Alto, CA. (May 2006, p. 610)

*19-23 **New Techniques in Hopf Algebras and Graded Ring Theory**, Vrije Universiteit Brussel, Brussels, Belgium.
Organizing Committee: S. Caenepeel (Brussels), F. Van Oystaeyen (Antwerp).
Invited Speakers: S. Montgomery (Los Angeles), H.-J. Schneider (Munich), Y. Bespalov (Kiev), G. Böhm (Budapest), T. Brzezinski (Swansea at Wales), A. Marcus (Cluj-Napoca), C. Nastasescu (Bucharest), J. Gómez Torrecillas (Granada), A. Stolin (Göteborg), L. Kadison (Göteborg), A. Van Daele (Louvain), V. Turaev (to be confirmed).
Information: Preregistration is possible by sending an email to scaenepe@vub.ac.be; please mention if you plan to present a lecture of 30 minutes. The second announcement, with registration form and information on hotel accomodation will be sent around June 15. More information will appear on http://homepages.vub.ac.be/~scaenepe.

22-29 **Conference on Geometry and Dynamics of Groups and Spaces In Memory of Alexander Reznikov**, Max-Planck-Institut für Mathematik, Bonn, Germany. (May 2006, p. 610)

25-26 **Conference on Mathematics and its Applications**, The University of the West Indies, St. Augustine, Trinidad. (Apr. 2006, p. 498)

*25-29 **50th Annual Meeting of the Australian Mathematical Society**, Macquarie University, Sydney, New South Wales, Australia.
Plenary Speakers: Pascal Auscher (Université de Paris-Sud), Robert Bartnik (Monash University), Michael Batanin (Macquarie University), Steven Evans (University of California, Berkeley), Peter Forrester (University of Melbourne), Andrew Hassell (Australian National University), Frank de Hoog (Commonwealth Scientific and Industrial Organization), Adrian Lewis (Cornell University), Ngaiming Mok (University of Hong Kong), Christopher Skinner (University of Michigan), Terence Tao (University of California, Los Angeles), Katrin Tent (Universität Bielefeld), Claire Voisin (Centre National de la Recherche Scientifique), Xu-Jia Wang (Australian National University).
Special Sessions: Algebraic Geometry, Category Theory, Combinatorics and Geometry, Differential Geometry, Functional Analysis, Future Impact of Applications on Mathematics, Geometry and Topology, Group Theory, Harmonic Analysis, Mathematical Physics, Number Theory, Partial Differential Equations, Probability and Statistics, Representation Theory, Variational Analysis and Optimization.
Information: For further details of the academic program, registration and accommodation, visit http://www.maths.mq.edu.au/austms06/.

*25-29 **The Kadison-Singer Problem**, AIM Research Conference Center, Palo Alto, California.
Organizers: Pete Casazza, Richard Kadison, and David Larson.
Topics: This workshop, sponsored by AIM and the NSF, will be devoted to the Kadison-Singer Problem and its relationship to various areas of research in mathematics and engineering. The

hope is to resolve the problem, or more realistically, to share partial results and to map out paths that could lead to the solution.
Deadline: June 25, 2006.
Description: http://aimath.org/ARCC/workshops/kadisonsinger.html.

29-30 **16th Annual Kansas City Regional Mathematics Technology EXPO**, Rockhurst University, Kansas City, Missouri. (May 2006, p. 611)

*29-October 1 **Mathematical Finance 60th Birthday Conference in Honor of Dilip B. Madan**, University of Maryland at College Park, Maryland.
Information: http://www.norbertwiener.umd.edu/Madan/; email: madan-conference@math.umd.edu.

October 2006

2-6 **Quantum Cryptography and Computing Workshop**, Fields Institute, Toronto, Canada. (May 2006, p. 611)

4-6 **Second Announcement: International Conference on Multifield Problems**, Universität Stuttgart, Stuttgart, Germany. (Apr. 2006, p. 498)

7-10 **PDE Approaches to Image Processing**, Mathematical Institute, University of Cologne, Cologne, Germany. (May 2006, p. 611)

9-13 **Short-term Cardiovascular-Respiratory Control Mechanisms**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 611)

10-13 **Data Mining and Mathematical Programming**, Centre de Recherches Mathématiques, Montreal, Canada. (May 2006, p. 611)

16-20 **Subconvexity Bounds for L-functions**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 611)

17-20 **Polyhedral Computation**, Centre de Recherches Mathématiques, Montreal, Canada. (May 2006, p. 611)

23-27 **Spectra of Families of Matrices Described by Graphs, Digraphs, and Sign Patterns**, AIM Research Conference Center, Palo Alto, California. (Apr. 2006, p. 498)

30-November 3 **Computational Challenges Arising In Algorithmic Number Theory and Cryptography**, Fields, Toronto, Canada. (May 2006, p. 612)

November 2006

1-5 **CCA 2006 Third International Conference on Computability and Complexity in Analysis**, University of Florida, Gainesville, Florida. (May 2006, p. 612)

*4-10 **Second International Conference on Finsler Geometry**, Cairo, Egypt.
Description: The 2006 Conference will focus particular (though not exclusive) attention on Geometries whose metric functions are symmetric polynomials.

In addition to the Scientific proceedings of the 2006 Conference, an extensive cultural program will be provided for participants. Amongst the excursions planned are guided visits to the Pyramid complexes of the Giza Plateau, Dashura, Medum and Saqqara, and the Museum of Egyptian Antiquities in Cairo, which houses incomparably the greatest collection of Egyptian Antiquities in the world. There will also be optional excursions to a number of ancient temples.
Information: email: vgladyshev@mail.ru or email: mpbw1879@yahoo.co.uk or http://hypercomplex.xpsweb.com.

8-10 **Policy and Practice in Mathematics and Science Teaching and Learning in the Elementary Grades**, American University of Beirut, Beirut, Lebanon. (Apr. 2006, p. 498)

8-12 **Policy and Practice in Mathematics and Science Teaching and Learning in the Elementary Grades**, Beirut, Lebanon. (Apr. 2006, p. 498)

27-December 1 **Cryptography: Underlying Mathematics, Provability and Foundations**, Fields Institute, Toronto, Canada. (May 2006, p. 612)

*27-December 22 **Geophysical Fluid Dynamics and Scalar Transport in the Tropics**, Institute for Mathematical Sciences, National University of Singapore, Singapore.
Details: This one-month program is a small effort to address the dearth of knowledge in tropical dynamics. Over two workshops interspersed by two mini-courses, an international gathering of scientists and applied mathematicians would review recent theoretical ideas on geophysical fluid dynamics (GFD) and scalar transport within the tropics, while incubating new ideas. The ideas discussed would help organize and elucidate information in datasets generated by weather or sea-state forecast and pollutant dispersion analysis in Southeast Asia. Thus, the program would also benefit participating applied meteorologists and oceanographers who handle datasets on a day-to-day basis.

Some or all of the listed topics below will be covered. The first two topics underpin the dynamics of numerical prediction of the tropical atmosphere and oceans; the last two topics lie at the fundamentals of chemical transport and dispersion: Hamiltonian and Lagrangian Approach to GFD, Simplified Models of Tropical Atmosphere, Turbulent Scalar Transport, Chaotic Tracer Advection.
Organizing Committee: Peter Haynes (University of Cambridge), Tieh-Yong Koh (Nanyang Technological University), Hock Lim (National University of Singapore), Pavel Tkalich (National University of Singapore).
Information: For further information and registration, please visit http://www.ims.nus.edu.sg/Programs/geophysical/index.htm. email: imssec@nus.edu.sg. For enquiries on scientific aspects of the program, Tieh-Yong Koh email: kohty@ntu.edu.sg.

December 2006

*4-8 **Finding and Keeping Graduate Students in the Mathematical Sciences**, AIM Research Conference Center, Palo Alto, California.
Organizers: Amy Cohen-Corwin, Abbe Herzig, and David Manderscheid.
Description: This workshop, sponsored by AIM and the NSF, will build on recent efforts by groups and individuals within the mathematics community to enhance the recruitment and retention of graduate students in the mathematical sciences, with a particular emphasis on women and underrepresented minorities. The Workshop will bring together leaders in graduate education in the mathematical sciences, giving them the opportunity to develop tangible plans to take these efforts to the next level at their institutions. The Workshop will provide a varied mix of principles for designing successful programs and examples of programs that have demonstrated success in responding to the issues, including models of funding and other logistical considerations. An emphasis will be placed on programs that benefit all students.
Deadline: June 15, 2006.
Details: http://aimath.org/ARCC/workshops/keepinggrads.html.

*12-16 **The Eleventh Asian Technology Conference in Mathematics**, Hong Kong Polytechnic University, Hong Kong, Hong Kong.
Information: "Advancing and Fostering Mathematical Sciences and Education through Technology". The aim of this conference is to provide a forum for educators, researchers, teachers and experts in exchanging information regarding enhancing technology to enrich mathematics learning, teaching and research at all levels. English is the official language of the conference. For more information, please visit http://atcminc.com.
Last Date for Submission Abstracts: May 15, 2006.
Last Date for Submission of Full Papers: July 15, 2006.

13-15 **Workshop on "Geometry of vector distributions, differential equations, and variational problems"**, International School for Advanced Studies (SISSA), Trieste, Italy. (May 2006, p. 612)

15-17 **International Conference on Computer & Information Science (ICCIS'2005)**, Fort Panhala, Kolhapur, India. (Dec. 2004, p. 1379)

*16-18 **The 5th International Conference on Differential Equations and Dynamical Systems**, University of Texas-Pan American, Edinburg, Texas.
Topics: All major research areas in differential equations and dynamical systems with focuses on analysis, modeling, computations and applications to sciences and engineering.
Main Speakers: R. P. Agarwal (Florida Inst. of Technology), G.-Q. Chen (Northwestern U.), L. Debnath (U. of Texas Pan-American), D. L. Russell (Virginia Tech. U.), W. van Saarloos (Inst.-Lorenz, Netherlands), S. Ahmad (U. Texas at San Antonio).
Special Sessions: Proposals are invited. Send to Xinzhi Liu, Dept. of Applied Mathematics, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1, email: `xzliu@uwaterloo.ca`.
Call for Papers: Contributed papers are invited. Abstracts must be submitted to Zhaosheng Feng via email before Sept. 15, 2006: email: `zsfeng@utpa.edu`.
Information: `http://www.watam.org/deds06.htm`.

16-20 **DION 2005: An International Conference on Diophantine Equations: in honour of Professor T. N. Shorey on his 60th Birthday**, Tata Institute of Fundmental Research, Mumbai, India. (Jun/Jul. 2005, p. 675)

17-21 **Integral Closure, Multiplier Ideals and Cores**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 612)

26-January 6, 2006 **CIMPA School on Commutative Algebra**, Institute of Mathematics, Hanoi, Vietnam. (Jun/Jul. 2005, p. 675)

January 2007

*5-8 **Joint Mathematics Meetings**, New Orleans, Louisiana.
Information: `http://www.ams.org/amsmtgs/national.html`

8-June 29 **Analysis on Graphs and its Applications**, Isaac Newton Institute for Mathematical Sciences, Cambridge, UK. (Nov. 2005, p. 1264)

15-July 6 **Highly Oscillatory Problems: Computation, Theory and Application**, Isaac Newton Institute for Mathematical Sciences, Cambridge, UK. (Nov. 2005, p. 1264 (Dec. 2005, p. 1383))

*22-26 **Winter School "Geometric Measure Theory, Random Sets and Digital Stereology"**, Sandbjerg Estate, Sonderborg, Denmark.
Scope: The modern theory of random sets is strongly based on results in geometric measure theory and has important applications in digital stereology. The aim of the winter school is to give an overview of this area that ranges from classical generalizations of differential geometry over stochastic geometry to recent applications in the analysis of digital images.
Addressees: The winter school is addressed to Ph.D.s, PostDocs and other researchers in mathematics and statistics who want to get introduced in the field. Scientists from the natural sciences with an interest in mathematics are also welcome.
Organizers: Eva B. Vedel Jensen and Markus Kiderlen, University of Aarhus.
Teaching Team: Markus Kiderlen, University of Aarhus, Ilya Molchanov, University of Bern, Jan Rataj, Charles University, Praha.
Information: `http://www.thiele.au.dk/winterschool07/`.

March 2007

*3-4 **AMS Southeastern Section Meeting**, Davidson College, Davidson, North Carolina.
Information: `http://www.ams.org/amsmtgs/sectional.html`

*4-8 **Twelfth International Conference on Approximation Theory**, Menger Hotel, San Antonio, Texas.
Invited Speakers: Charles Chui (Univ. Missouri, St. Louis), Frank Deutsch (Penn State Univ.), Ron DeVore (Univ. South Carolina, Ming-Jun Lai (Univ. Georgia), Peter Oswald (International Univ., Bremen), Gabrielle Steidl (Univ. Mannheim), and Joe Ward (Texas A&M).
Organizers: Mike Neamtu and Larry L. Schumaker (Vanderbilt Univ.)
Information: `http://www.math.vanderbilt.edu/~at07/at07.html`,email: `at07math@math.vanderbilt.edu`.

*16-17 **AMS Central Section Meeting**, Miami University, Oxford, Ohio.
Information: `http://www.ams.org/amsmtgs/sectional.html`

*19-23 **Representations of Surface Groups**, AIM Research Conference Center, Palo Alto, California.
Organizers: Steven Bradlow, Oscar Garcia-Prada, William M. Goldman, and Anna Wienhard.
Description: This workshop, sponsored by AIM and the NSF, will bring together researchers studying representations of fundamental groups of Riemann surfaces into real semsimple Lie groups. Such representations form multi-component algebraic sets. Recent progress in understanding these components has come from quite different approaches. The main goal of the workshop is to clarify the relations between these different approaches to initiate further research in this area
Deadline: January 5, 2007.
Details: `http://aimath.org/ARCC/workshops/surfacegroups.html`.

26-30 **Buildings and Combinatorial Representation Theory**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 612)

April 2007

*14-15 **AMS Eastern Section Meeting**, Stevens Institute of Technology, Hoboken, New Jersey.
Information: `http://www.ams.org/amsmtgs/sectional.html`

*21-22 **AMS Western Section Meeting**, University of Arizona, Tucson, Arizona.
Information: `http://www.ams.org/amsmtgs/sectional.html`

23-27 **Problems in Geometric Group Theory**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 612)

May 2007

7-11 **Rational Curves on Algebraic Varieties**, AIM Research Conference Center, Palo Alto, California. (May 2006, p. 612)

14-July 13 **Braids**, Institute for Mathematical Sciences, National University of Singapore, Singapore.

*18-20 **The 2007 Midwest Geometry Conference (MGC 07)**, University of Iowa, Iowa City, Iowa.
MGC 07: To be held in the honor of Thomas P. Branson (1953-2006).
Topics: Functional determinants of conformal operators on 4-manifolds; PDE and geometric measure theory; Geometric and harmonic analysis.
Plenary Speakers: Ivan Avramidi, Alice Chang, Michael Eastwood, Charles Fefferman, Peter B. Gilkey, Rod Gover, Robin Graham, Kengo Hirachi, Gestur Olafsson, Bent Orsted, William Ugalde, Paul C. Yang.
Organizers: Susanne Branson, Oguz Durumeric, Doojin Hong, Palle Jorgensen, Gestur Olafsson, Lawrence Peterson, Vincent Rodgers, Walter Seaman, William Ugalde. Including publication (editors): Michael Eastwood, Rod Gover. `http://www.emis.de/journals/SIGMA/`.

Information: http://www.math.uiowa.edu/MGC2007/ (will be updated periodically).

The following new announcements will not be repeated until the criteria in the next to the last paragraph at the bottom of the first page of this section are met.

June 2007

*4-8 **Arithmetic Harmonic Analysis on Character and Quiver Varieties**, AIM Research Conference Center, Palo Alto, California.
Organizers: Tamas Hausel, Emmanuel Letellier, and Fernando Rodriguez-Villegas.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to bringing together mathematicians working on the following circle of ideas: cohomology of character and quiver varieties, representation theory of finite groups and algebras of Lie type, applications of the Weil conjectures to cohomological calculations, geometric representation theory of various finite and infinite dimensional algebras, and the combinatorics of Macdonald polynomials. Specific questions to be addressed during the workshop are described on the announcement page.
Deadline: February 15, 2007.
Details: http://aimath.org/ARCC/workshops/charvarieties.html.

July 2007

*31-August 3 **First Joint International Meeting between the AMS and the Polish Mathematical Society**, Warsaw, Poland.
Information: http://www.ams.org/amsmtgs/internmtgs.html

October 2007

*8-12 **Dichotomy Amenable/Nonamenable in Combinatorial Group Theory**, AIM Research Conference Center, Palo Alto, California.
Organizers: Mark Sapir and Tatiana Nagnibeda.
Description: This workshop, sponsored by AIM and the NSF, will be devoted to various incarnations of the notion of amenability for a finitely generated group. The main goal of the workshop is to gain better understanding of the meaning of being amenable or nonamenable for a discrete, finitely generated group. Our attention will be concentrated on a certain number of concrete open problems about (non)amenability of groups with origins in very different areas of mathematics, as described on the workshop announcement page.
Deadline: June 20, 2007.
Details:http://aimath.org/ARCC/workshops/nonamenable.html.

*13-14 **AMS Western Section Meeting**, University of New Mexico, Albuquerque, New Mexico.
Information: http://www.ams.org/amsmtgs/sectional.html

November 2007

*3-4 **AMS Southeastern Section Meeting**, Middle Tennessee State University, Murfreesboro, Tennessee.
Information: http://www.ams.org/amsmtgs/sectional.html

December 2007

*12-15 **First Joint International Meeting between the AMS and the New Zealand Mathematical Society (NZMS)**, Wellington, New Zealand.
Information: http://www.ams.org/amsmtgs/internmtgs.html

January 2008

*7-June 27 **Statistical Theory and Methods for Complex, High-Dimensional Data**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom.
Programme Theme: Most of twentieth-century statistical theory was restricted to problems in which the number p of 'unknowns', such as parameters, is much less than n, the number of experimental units. However, the practical environment has changed dramatically over the last twenty years or so, with the spectacular evolution of computing facilities and the emergence of applications in which the number of experimental units is comparatively small but the underlying dimension is massive, leading to the desire to fit complex models for which the effective p is very large. The existence of key applications strongly motivates the programme, but the fundamental aim is to promote core theoretical and methodological research. Both frequentist and Bayesian paradigms will be featured.
Organizers: D. Banks (Duke), P. Bickel (UC Berkeley), P. Hall (Australian National), I. M. Johnstone (Stanford), D. M. Titterington (Glasgow), S. van de Geer (Zurich).
Information: http://www.newton.cam.ac.uk/programmes/SCH/. Isaac Newton Institute for Mathematical Sciences, 20 Clarkson Road, Cambridge, CB3 0EH, U.K. Tel.: +44-1223-335999, Fax.: +44-1223-330508, email: info@newton.cam.ac.uk.

July 2008

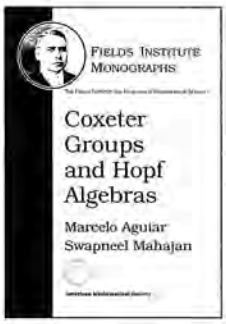
*14-December 19 **Mathematics and Physics of Anderson Localization: 50 Years After**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom.
Programme Theme: In his seminal paper "Absence of diffusion in certain random lattices" (1958) Philip W. Anderson discovered one of the most striking quantum interference phenomena: particle localization due to disorder. In the last 25 years the phenomenon of localization proved to be crucial for the understanding of the Quantum Hall Effect, mesoscopic fluctuations in small conductors as well as some aspects of quantum chaotic behavior. The goal of the program is to bring together the world leaders in spectral theory of random Schrödinger operators and theoretical physicists successfully working on the problem of Anderson localization.
Organizers: Y. V. Fyodorov (Nottingham), I. Goldshied (Queen Mary, London), T. Spencer (Princeton), M. R. Zirnbauer (Cologne).
Information: http://www.newton.cam.ac.uk/programmes/MPA/. Isaac Newton Institute for Mathematical Sciences, 20 Clarkson Road, Cambridge, CB3 0EH, U.K. Tel.: +44-1223-335999, Fax.: +44-1223-330508; email: info@newton.cam.ac.uk.

August 2008

*26-December 19 **The Nature of High Reynolds Number Turbulence**, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom.
Programme Theme: Turbulence is a notoriously difficult subject. The goal of this programme is to bring together leading experts from across the world to debate the fundamental questions. The discussion will be wide ranging, from the initiation of turbulence through to its asymptotic state at high Reynolds number, including the effects of rotation and stratification, and the addition of different phases, such as bubbles, particles and polymers.
Organisers: P. Bartello (McGill), P. A. Davidson (Cambridge), D. Dritschel (St. Andrews), Y. Kaneda (Nagoya), R. Kerswell (Bristol).
Information: http://www.newton.cam.ac.uk/programmes/HRT/. Isaac Newton Institute for Mathematical Sciences, 20 Clarkson Road, Cambridge, CB3 0EH, U.K. Tel.: +44-1223-335999, Fax.: +44-1223-330508, email: info@newton.cam.ac.uk .

New Publications Offered by the AMS

Algebra and Algebraic Geometry



Coxeter Groups and Hopf Algebras

Marcelo Aguiar, *Texas A&M University, College Station, TX*, and **Swapneel Mahajan**, *Indian Institute of Technology, Powai, Mumbai, India*

An important idea in the work of G.-C. Rota is that certain combinatorial objects give rise to Hopf algebras that reflect the manner in which these objects compose and decompose. Recent work has seen the emergence of several interesting Hopf algebras of this kind, which connect diverse subjects such as combinatorics, algebra, geometry, and theoretical physics. This monograph presents a novel geometric approach using Coxeter complexes and the projection maps of Tits for constructing and studying many of these objects as well as new ones. The first three chapters introduce the necessary background ideas making this work accessible to advanced graduate students. The later chapters culminate in a unified and conceptual construction of several Hopf algebras based on combinatorial objects which emerge naturally from the geometric viewpoint. This work lays a foundation and provides new insights for further development of the subject.

To read more about Coxeter groups see *The Coxeter Legacy: Reflections and Projections.*

This item will also be of interest to those working in discrete mathematics and combinatorics.

Titles in this series are copublished with The Fields Institute for Research in Mathematical Sciences (Toronto, Ontario, Canada).

Contents: Coxeter groups; Left regular bands; Hopf algebras; A brief overview; The descent theory for Coxeter groups; The construction of Hopf algebras; The Hopf algebra of pairs of permutations; The Hopf algebra of pointed faces; Bibliography; Author index; Notation index; Subject index.

Fields Institute Monographs, Volume 23

July 2006, 181 pages, Hardcover, ISBN 0-8218-3907-1, LC 2006044456, 2000 *Mathematics Subject Classification*: 05E05, 06A07, 06A11, 16W30, 20F55, 51E24, **All AMS members US$47**, List US$59, Order code FIM/23

Ischia Group Theory 2004

Proceedings of a Conference in Honor of Marcel Herzog

Zvi Arad, *Bar-Ilan University, Ramat-Gan, Israel*, **Mariagrazia Bianchi**, *Università degli Studi di Milano, Italy*, **Wolfgang Herfort**, *University of Technology, Vienna, Austria*, **Patrizia Longobardi** and **Mercede Maj**, *Università di Salerno, Fisciano, (SA), Italy*, and **Carlo Scoppola**, Editors

Experts in the theory of finite groups and in representation theory provide insight into various aspects of group theory, such as the classification of finite simple groups, character theory, groups with special properties, table algebras, etc.

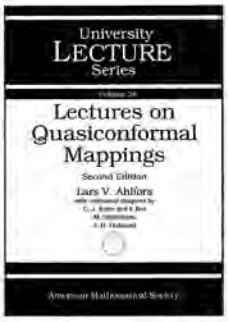
This book is copublished with Bar-Ilan University (Ramat-Gan, Israel).

Contents: Z. Arad and **W. Herfort**, The history of the classification of finite groups with a CC-subgroup; **Y. Berkovich** and **Z. Janko**, Structure of finite p-groups with given subgroups; **E. A. Bertram**, Lower bounds for the number of conjugacy classes in finite groups; **M. Bianchi**, **A. Gillio**, and **L. Verardi**, Monounary simple algebras; **D. Chillag**, Algebras with positive bases, commutators and covering numbers; **C. Delizia** and **C. Nicotera**, On certain group theoretical properties generalizing commutativity; **E. Detomi** and **A. Lucchini**, Probabilistic non-generators in profinite groups; **M. Giudici**, **C. H. Li**, **C. E. Praeger**, **A. Seress**, and **V. Trofimov**, Limits of vertex-transitive graphs; **R. Göbel** and **O. H. Kegel**, Group rings with simple augmentation ideals; **M. Herzog**, **P. Longobardi**, and **M. Maj**, On the number of commutators in groups; **Z. Janko**, New results in the theory of finite 2-groups; **G. Kaplan**, The existence of normal and characteristic subgroups in finite groups; **A. Lev**, On the covering numbers of finite groups: Some old and new results; **M. Mainardis**, Normal subgroups in the subgroup lattices of finite p-groups; **A. Mann**, On characters-classes duality and orders of centralizers; **A. Regev**, Bijections for identities of multisets of hook numbers; **D. O. Revin** and **E. P. Vdovin**, Hall subgroups of finite groups.

Contemporary Mathematics, Volume 402

June 2006, 263 pages, Softcover, ISBN 0-8218-3711-7, LC 2006040728, 2000 *Mathematics Subject Classification*: 20C15, 20D15, 20D20, **All AMS members US$63**, List US$79, Order code CONM/402

Analysis



Lectures on Quasiconformal Mappings

Second edition

Lars V. Ahlfors

with additional chapters by C. J. Earle and I. Kra, M. Shishikura, J. H. Hubbard

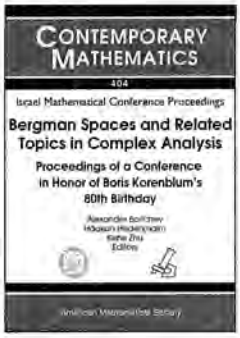
Lars Ahlfors's *Lectures on Quasiconformal Mappings*, based on a course he gave at Harvard University in the spring term of 1964, was first published in 1966 and was soon recognized as the classic it was shortly destined to become. These lectures develop the theory of quasiconformal mappings from scratch, give a self-contained treatment of the Beltrami equation, and cover the basic properties of Teichmüller spaces, including the Bers embedding and the Teichmüller curve. It is remarkable how Ahlfors goes straight to the heart of the matter, presenting major results with a minimum set of prerequisites. Many graduate students and other mathematicians have learned the foundations of the theories of quasiconformal mappings and Teichmüller spaces from these lecture notes.

This edition includes three new chapters. The first, written by Earle and Kra, describes further developments in the theory of Teichmüller spaces and provides many references to the vast literature on Teichmüller spaces and quasiconformal mappings. The second, by Shishikura, describes how quasiconformal mappings have revitalized the subject of complex dynamics. The third, by Hubbard, illustrates the role of these mappings in Thurston's theory of hyperbolic structures on 3-manifolds. Together, these three new chapters exhibit the continuing vitality and importance of the theory of quasiconformal mappings.

Contents: *Part 1*: Differentiable quasiconformal mappings; The general definition; Extremal geometric properties; Boundary correspondence; The mapping theorem; Teichmüller spaces; Editors' notes; *Part 2*: A supplement to Ahlfors's lectures; Complex dynamics and quasiconformal mappings; Hyperbolic structures on three-manifolds that fiber over the circle.

University Lecture Series, Volume 38

August 2006, approximately 156 pages, Softcover, ISBN 0-8218-3644-7, LC 2006040650, 2000 *Mathematics Subject Classification*: 30C62, 30Cxx, **All AMS members US$28**, List US$35, Order code ULECT/38



Bergman Spaces and Related Topics in Complex Analysis

Proceedings of a Conference in Honor of Boris Korenblum's 80th Birthday

Alexander Borichev, *Université Bordeaux I, Talence, Cedex, France*, **Håkan Hedenmalm**, *Royal Institute of Technology, Stockholm, Sweden*, and **Kehe Zhu**, *State University of New York at Albany, NY*, Editors

This volume grew out of a conference in honor of Boris Korenblum on the occasion of his 80th birthday, held in Barcelona, Spain, November 20–22, 2003. The book is of interest to researchers and graduate students working in the theory of spaces of analytic function, and, in particular, in the theory of Bergman spaces.

This book is copublished with Bar-Ilan University (Ramat-Gan, Israel).

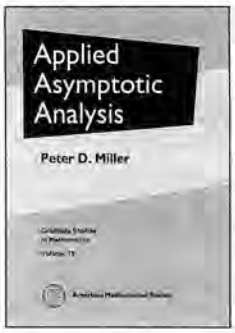
Contents: A. Aleman, **S. Richter**, and **C. Sundberg**, Invariant subspaces for the backward shift on Hilbert spaces of analytic functions with regular norm; **A. Atzmon** and **B. Brive**, Surjectivity and invariant subspaces of differential operators on weighted Bergman spaces of entire functions; **K. F. Barth** and **P. J. Rippon**, Exceptional values and the MacLane class $\mathcal{A}$; **O. Blasco**, Operators on weighted Bergman spaces; **A. Dahlner**, A Wiener Tauberian theorem for weighted convolution algebras of zonal functions on the automorphism group of the unit disc; **W. K. Hayman**, Domination on sets and in norm; **C. Horowitz** and **B. Pinchuk**, Extensions of the asymptotic maximum principle; **S. Jakobsson**, Singularity resolution of weighted Bergman kernels; **B. Korenblum**, Blaschke sets for Bergman spaces; **X. Massaneda** and **P. J. Thomas**, Phragmén-Lindelöf-type problems for $A^{-\alpha}$; **A. Olofsson**, A representation formula for reproducing subharmonic functions in the unit disc; **F. Pérez-González** and **J. C. Ramos**, On dominating sets for Bergman spaces; **S. Shimorin**, Trigonometric obstacle problem and weak factorization; **K. Zhu**, A sharp norm estimate of the Bergman projection on L^p spaces.

Contemporary Mathematics, Volume 404

July 2006, 205 pages, Softcover, ISBN 0-8218-3712-5, LC 2006040697, 2000 *Mathematics Subject Classification*: 30–06, 46E15, 32A36; 30D50, 30D55, **All AMS members US$55**, List US$69, Order code CONM/404

COURSE ADOPTION

Differential Equations



Applied Asymptotic Analysis

Peter D. Miller, *University of Michigan, Ann Arbor, MI*

This book is a survey of asymptotic methods set in the current applied research context of wave propagation. It stresses rigorous analysis in addition to formal manipulations. Asymptotic expansions developed in the text are justified rigorously, and students are shown how to obtain solid error estimates for asymptotic formulae. The book relates examples and exercises to subjects of current research interest, such as the problem of locating the zeros of Taylor polynomials of entire nonvanishing functions and the problem of counting integer lattice points in subsets of the plane with various geometrical properties of the boundary.

The book is intended for a beginning graduate course on asymptotic analysis in applied mathematics and is aimed at students of pure and applied mathematics as well as science and engineering. The basic prerequisite is a background in differential equations, linear algebra, advanced calculus, and complex variables at the level of introductory undergraduate courses on these subjects.

The book is ideally suited to the needs of a graduate student who, on the one hand, wants to learn basic applied mathematics, and on the other, wants to understand what is needed to make the various arguments rigorous. Down here in the Village, this is known as the Courant point of view!!

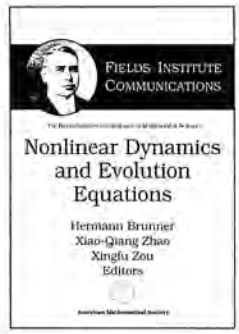
—Percy Deift, Courant Institute, New York

Peter D. Miller is an associate professor of mathematics at the University of Michigan at Ann Arbor. He earned a Ph.D. in Applied Mathematics from the University of Arizona and has held positions at the Australian National University (Canberra) and Monash University (Melbourne). His current research interests lie in singular limits for integrable systems.

Contents: *Fundamentals:* Themes of asymptotic analysis; The nature of asymptotic approximations; *Asymptotic analysis of exponential integrals:* Fundamental techniques for integrals; Laplace's method for asymptotic expansions of integrals; The method of steepest descents for asymptotic expansions of integrals; The method of stationary phase for asymptotic analysis of oscillatory integrals; *Asymptotic analysis of differential equations:* Asymptotic behavior of solutions of linear second-order differential equations in the complex plane; Introduction to asymptotics of solutions of ordinary differential equations with respect to parameters; Asymptotics of linear boundary-value problems; Asymptotics of oscillatory phenomena; Weakly nonlinear waves; Appendix: Fundamental inequalities; Bibliography; Index of names; Subject index.

Graduate Studies in Mathematics, Volume 75

July 2006, approximately 475 pages, Hardcover, ISBN 0-8218-4078-9, LC 2006040794, 2000 *Mathematics Subject Classification*: 34E05, 34E10, 34E13, 34E15, 34E20, 41A60, 74J30, 33-01, 81Q20, **All AMS members US$55**, List US$69, Order code GSM/75



Nonlinear Dynamics and Evolution Equations

Hermann Brunner and **Xiao-Qiang Zhao**, *Memorial University of Newfoundland, St. John's, NL, Canada*, and **Xingfu Zou**, *University of Western Ontario, London, ON, Canada*, Editors

The papers in this volume reflect a broad spectrum of current research activities on the theory and applications of nonlinear dynamics and evolution equations. They are based on lectures given during the International Conference on Nonlinear Dynamics and Evolution Equations at Memorial University of Newfoundland, St. John's, NL, Canada, July 6–10, 2004. This volume contains thirteen invited and refereed papers. Nine of these are survey papers, introducing the reader to, and describing the current state of the art in major areas of dynamical systems, ordinary, functional and partial differential equations, and applications of such equations in the mathematical modelling of various biological and physical phenomena. These papers are complemented by four research papers that examine particular problems in the theory and applications of dynamical systems.

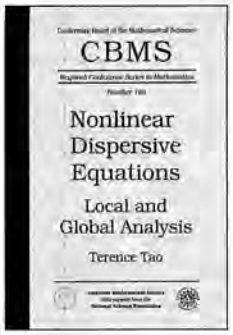
This item will also be of interest to those working in applications and geometry and topology.

Titles in this series are copublished with the Fields Institute for Research in Mathematical Sciences (Toronto, Ontario, Canada).

Contents: **J. Arino** and **P. van den Driessche**, Disease spread in metapopulations; **P. W. Bates**, On some nonlocal evolution equations arising in materials science; **W. Craig**, Invariant tori for Hamiltonian PDE; **N. Dancer**, Stable and not too unstable solutions on R^n for small diffusion; **Y. Du** and **J. Shi**, Some recent results on diffusive predator-prey models in spatially heterogeneous environment; **S. A. Gourley** and **J. Wu**, Delayed non-local diffusive systems in biological invasion and disease spread; **J. Jiang**, Asymptotic behavior for systems comparable to quasimonotone systems; **T. Krisztin**, C^1-smoothness of center manifolds for differential equations with state-dependent delay; **C. Rousseau**, Normal forms for germs of analytic families of planar vector fields unfolding a generic saddle-node or resonant saddle; **R. Saghin** and **Z. Xia**, Generic properties of symplectic diffeomorphisms; **B. D. Sleeman**, Mathematical aspects of modelling tumour angiogenesis; **G. S. K. Wolkowicz**, Interpretation of the generalized asymmetric May-Leonard model of three species competition as a food web in a chemostat; **Y. Yi** and **X. Zhang**, On exact Poisson structures.

Fields Institute Communications, Volume 48

June 2006, 311 pages, Hardcover, ISBN 0-8218-3721-4, LC 2006042831, 2000 *Mathematics Subject Classification*: 34C20, 34K05, 35B40, 35J55, 37C05, 37C65, 37K55, 53D17, 92D25, 92D30, **All AMS members US$87**, List US$109, Order code FIC/48



Nonlinear Dispersive Equations

Local and Global Analysis

Terence Tao, *University of California, Los Angeles, CA*

Among nonlinear PDEs, dispersive and wave equations form an important class of equations. These include the nonlinear Schrödinger equation, the nonlinear wave equation, the Korteweg de Vries equation, and the wave maps equation. This book is an introduction to the methods and results used in the modern analysis (both locally and globally in time) of the Cauchy problem for such equations.

Starting only with a basic knowledge of graduate real analysis and Fourier analysis, the text first presents basic nonlinear tools such as the bootstrap method and perturbation theory in the simpler context of nonlinear ODE, then introduces the harmonic analysis and geometric tools used to control linear dispersive PDE. These methods are then combined to study four model nonlinear dispersive equations. Through extensive exercises, diagrams, and informal discussion, the book gives a rigorous theoretical treatment of the material, the real-world intuition and heuristics that underlie the subject, as well as mentioning connections with other areas of PDE, harmonic analysis, and dynamical systems.

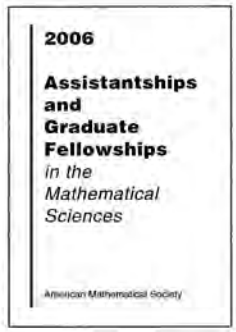
As the subject is vast, the book does not attempt to give a comprehensive survey of the field, but instead concentrates on a representative sample of results for a selected set of equations, ranging from the fundamental local and global existence theorems to very recent results, particularly focusing on the recent progress in understanding the evolution of energy-critical dispersive equations from large data. The book is suitable for a graduate course on nonlinear PDE.

Contents: Ordinary differential equations; Constant coefficient linear dispersive equations; Semilinear dispersive equations; The Korteweg de Vries equation; Energy-critical semilinear dispersive equations; Wave maps; Tools from harmonic analysis; Construction of ground states; Bibliography.

CBMS Regional Conference Series in Mathematics, Number 106

July 2006, 373 pages, Softcover, ISBN 0-8218-4143-2, LC 2006042820, 2000 *Mathematics Subject Classification*: 35Q53, 35Q55, 35L15, **All Individuals US$44**, List US$55, Order code CBMS/106

General and Interdisciplinary



Assistantships and Graduate Fellowships in the Mathematical Sciences 2006

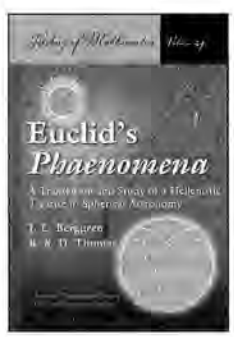
From a review of a previous edition:

This directory is a tool for undergraduate mathematics majors seeking information about graduate programs in mathematics. Although most of the information can be gleaned from the Internet, the usefulness of this directory for the prospective graduate student is the consistent format for comparing different mathematics graduate programs without the hype. Published annually, the information is up-to-date, which is more than can be said of some Websites. Support for graduate students in mathematics is a high priority of the American Mathematical Society, which also provides information for fellowships and grants they offer as well as support from other societies and foundations. The book is highly recommended for academic and public libraries.

—American Reference Books Annual

This valuable reference source brings together a wealth of information about resources available for graduate study in mathematical sciences departments in the U.S. and Canada.

November 2006, approximately 112 pages, Softcover, ISBN 0-8218-4152-1, **Individual member US$18**, List US$23, Order code ASST/2006



Euclid's *Phaenomena*

A Translation and Study of a Hellenistic Treatise in Spherical Astronomy

J. L. Berggren, *Simon Fraser University, Burnaby, BC, Canada*, and **R. S. D. Thomas**, *University of Manitoba, Winnipeg, Manitoba, Canada*

The book contains a translation and study of Euclid's *Phaenomena*, a work which once formed part of the mathematical training of astronomers from Central Asia to Western Europe. Included is an introduction that sets Euclid's geometry of the celestial sphere, and its application to the astronomy of his day, into its historical context for readers not already familiar with it. So no knowledge of astronomy or advanced mathematics is necessary for an understanding of the work. The book shows mathematical astronomy shortly before the invention of trigonometry, which allowed the calculation of exact results and the subsequent composition of Ptolemy's *Almagest*.

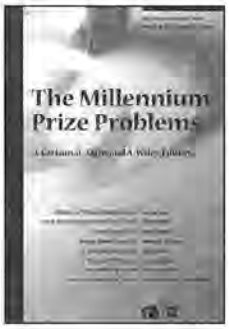
The *Phaenomena* itself begins with an introduction (possibly not by Euclid) followed by eighteen propositions set out in geometrical style about how arcs of the zodiacal circle move across the sky. The astronomical application is to the small arc of that circle occupied by the Sun, but the Sun is not mentioned. This work and the (roughly) contemporaneous treatises of Autolycus and Aristarchos form a corpus of the oldest extant works on mathematical astronomy. Together with Euclid's *Optics* one has the beginnings of the history of science as an application of mathematics.

Copublished with the London Mathematical Society beginning with Volume 4. Members of the LMS may order directly from the AMS at the AMS member price. The LMS is registered with the Charity Commissioners.

Contents: Introduction; Euclid's presuppositions; Notes on the translation; Sigla; *Euclid's* Phaenomena *translated with commentary:* Euclid's *Phaenomena*; English glossary of selected technical terms and phrases; Greek glossary of selected technical terms and phrases; Bibliography; Index of names; Index of subjects; Index of subjects (Greek).

History of Mathematics, Volume 29

June 2006, 132 pages, Softcover, ISBN 0-8218-4072-X, 2000 *Mathematics Subject Classification*: 01A20; 01A75, **All AMS members US$23**, List US$29, Order code HMATH/29



The Millennium Prize Problems

James Carlson, *Clay Mathematics Institute, Cambridge, MA*, **Arthur Jaffe**, *Harvard University, Cambridge, MA*, and **Andrew Wiles**, *Institute for Advanced Study, Princeton, NJ*, Editors

Guided by the premise that solving some of the world's most important mathematical problems will advance the field, this book offers a fascinating look at the seven unsolved Millennium Prize problems. This work takes the unprecedented approach of describing these important and difficult problems at the professional level.

In announcing the seven problems and a US$7 million prize fund in 2000, the Clay Mathematics Institute emphasized that mathematics still constitutes an open frontier with important unsolved problems. The descriptions in this book serve the Institute's mission to "further the beauty, power and universality of mathematical thinking."

Separate chapters are devoted to each of the seven problems: the Birch and Swinnerton-Dyer Conjecture, the Hodge Conjecture, the Navier-Stokes Equation, the **P** versus **NP** Problem, the Poincaré Conjecture, the Riemann Hypothesis, and Quantum Yang-Mills Theory.

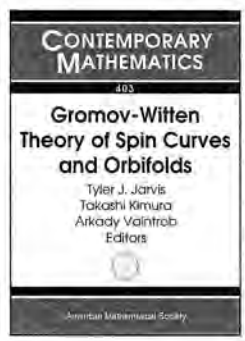
An essay by Jeremy Gray, a well-known expert in the history of mathematics, outlines the history of prize problems in mathematics and shows how some of mathematics' most important discoveries were first revealed in papers submitted for prizes. Numerous photographs of mathematicians who shaped mathematics as it is known today give the text a broad historical appeal. Anyone interested in mathematicians' continued efforts to solve important problems will be fascinated with this text, which places into context the historical dimension of important achievements.

A co-publication of the AMS and the Clay Mathematics Institute (Cambridge, MA).

Contents: J. Gray, A history of prizes in mathematics; **A. Wiles**, The Birch and Swinnerton-Dyer conjecture; **P. Deligne**, The Hodge conjecture; **C. L. Fefferman**, Existence and smoothness of the Navier-Stokes equation; **J. Milnor**, The Poincaré conjecture; **S. Cook**, The **P** versus **NP** problem; **E. Bombieri**, The Riemann hypothesis; **A. Jaffe** and **E. Witten**, Quantum Yang-Mills theory; Rules for the Millennium Prizes; Authors' biographies.

June 2006, 165 pages, Hardcover, ISBN 0-8218-3679-X, LC 2006044570, 2000 *Mathematics Subject Classification*: 00Bxx; 01Axx, 11G05, 14C30, 35Q30, 57R60, 03D15, 11M26, 81T13, **All AMS members US$23**, List US$29, Order code MPRIZE

Geometry and Topology



Gromov-Witten Theory of Spin Curves and Orbifolds

Tyler J. Jarvis, *Brigham Young University, Provo, UT*, **Takashi Kimura**, *Boston University, MA*, and **Arkady Vaintrob**, *University of Oregon, Eugene, OR*, Editors

This volume is a collection of articles on orbifolds, algebraic curves with higher spin structures, and related invariants of Gromov-Witten type. Orbifold Gromov-Witten theory generalizes quantum cohomology for orbifolds, whereas spin cohomological field theory is based on the moduli spaces of higher spin curves and is related by Witten's conjecture to the Gelfand-Dickey integrable hierarchies.

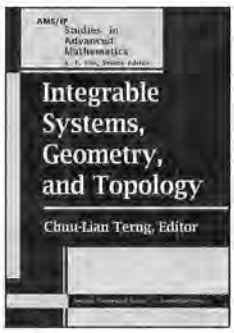
A common feature of these two very different looking theories is the central role played by orbicurves in both of them. Insights in one theory can often yield insights into the other. This book brings together for the first time papers related to both sides of this interaction. The articles in the collection cover diverse topics, such as geometry and topology of orbifolds, cohomological field theories, orbifold Gromov-Witten theory, G-Frobenius algebra and singularities, Frobenius manifolds and Givental's quantization formalism, moduli of higher spin curves and spin cohomological field theory.

Contents: A. Polishchuk, Moduli spaces of curves with effective r-spin structures; **A. Chiodo**, A construction of Witten's top Chern class in K-theory; **Y.-P. Lee**, Witten's conjecture and the Virasoro conjecture for genus up to two; **X. Liu**, Idempotents on the big phase space; **R. M. Kaufmann**, Singularities with symmetries, orbifold Frobenius algebras and mirror symmetry; **Y. Ruan**, The cohomology ring of crepant

resolutions of orbifolds; **E. Lupercio** and **B. Uribe**, Differential characters on orbifolds and string connections I: Global quotients; **J. Morava**, HKR characters and higher twisted sectors; **S. V. Shadrin**, Combinatorics of binomial decompositions of the simplest Hodge integrals; **J. Spencer**, The orbifold cohomology of the moduli of genus-two curves; List of participants and abstracts.

Contemporary Mathematics, Volume 403

July 2006, 189 pages, Softcover, ISBN 0-8218-3534-3, LC 2005057126, 2000 *Mathematics Subject Classification*: 14N35, 53D45, **All AMS members US$47**, List US$59, Order code CONM/403



Integrable Systems, Geometry, and Topology

Chuu-Lian Terng, Editor

The articles in this volume are based on lectures from a program on integrable systems and differential geometry held at Taiwan's National Center for Theoretical Sciences. As is well-known, for many soliton equations, the solutions have interpretations as differential geometric objects, and thereby techniques of soliton equations have been successfully applied to the study of geometric problems.

The article by Burstall gives a beautiful exposition on isothermic surfaces and their relations to integrable systems, and the two articles by Guest give an introduction to quantum cohomology, carry out explicit computations of the quantum cohomology of flag manifolds and Hirzebruch surfaces, and give a survey of Givental's quantum differential equations. The article by Heintze, Liu, and Olmos is on the theory of isoparametric submanifolds in an arbitrary Riemannian manifold, which is related to the n-wave equation when the ambient manifold is Euclidean. Mukai-Hidano and Ohnita present a survey on the moduli space of Yang-Mills-Higgs equations on Riemann surfaces. The article by Terng and Uhlenbeck explains the gauge equivalence of the matrix non-linear Schrödinger equation, the Schrödinger flow on Grassmanian, and the Heisenberg Feromagnetic model.

The book provides an introduction to integrable systems and their relation to differential geometry. It is suitable for advanced graduate students and research mathematicians.

Titles in this series are copublished with International Press, Cambridge, MA.

This item will also be of interest to those working in discrete mathematics and combinatorics.

Contents: F. E. Burstall, Isothermic surfaces: Conformal geometry, Clifford algebras and integrable systems; **M. A. Guest**, Introduction to homological geometry: part I; **M. A. Guest**, Introduction to homological geometry: part II; **E. Heintze**, **X. Liu**, and **C. Olmos**, Isoparametric submanifolds and a Chevalley-type restriction theorem; **M. Mukai-Hidano** and **Y. Ohnita**, Gauge-Theoretic approach to harmonic maps and subspaces in moduli spaces; **C.-L. Terng** and **K. Uhlenbeck**, Schrödinger flows on Grassmannians.

AMS/IP Studies in Advanced Mathematics, Volume 36

May 2006, 256 pages, Softcover, ISBN 0-8218-4048-7, LC 2006040699, 2000 *Mathematics Subject Classification*: 14N35, 35Q58, 37K05, 37K25, 37K35, 53A05, 53C40, 53C43, 53D45, 58E20, **All AMS members US$47**, List US$59, Order code AMSIP/36

New AMS-Distributed Publications

Geometry and Topology

Feuilletages et actions de groupes sur les espaces projectifs

Julie Déserti and **Dominique Cerveau**, *Université de Rennes I, France*

A holomorphic foliation $\mathcal{F}$ on a compact complex manifold M is said to be an $\mathcal{L}$-foliation if there exists an action of a complex Lie group G such that the generic leaf of $\mathcal{F}$ coincides with the generic orbit of G. The book studies $\mathcal{L}$-foliations of codimension one, in particular in projective space, in the spirit of classical invariant theory, but here the invariants are sometimes transcendental ones. The book gives a list of examples and general properties. Some classification results are obtained in low dimensions.

A publication of the Société Mathématique de France, Marseilles (SMF), distributed by the AMS in the U.S., Canada, and Mexico. Orders from other countries should be sent to the SMF. Members of the SMF receive a 30% discount from list.

Contents: Introduction; L-feuilletages; Exemples de L-feuilletages; L-feuilletages de petits degrés sur $\mathbf{CP}(n)$ et compléments; L-feuilletages en dimension 3; L-feuilletages quadratiques; L-feuilletages de degré 3 en dimension 4; Bibliographie.

Mémoires de la Société Mathématique de France, Number 103

February 2006, 124 pages, Softcover, ISBN 2-85629-182-1, 2000 *Mathematics Subject Classification*: 37F75, 32M05, 32M17, 32M25, 32S65, **Individual member US$34**, List US$38, Order code SMFMEM/103

La théorie de l'homotopie de Grothendieck

Georges Maltsiniotis, *Université Paris 7 Denis Diderot, France*

The aim of this book is to explain the very beautiful homotopy theory developed by Grothendieck in "Pursuing Stacks". The question is to characterize categories of presheaves that modelize homotopy types, thus generalizing the theory of simplicial sets. The criteria discovered by Grothendieck show that there are pretty many such categories, called *elementary modelizers*. The book describes a categorical construction of left homotopy Kan extensions, generalizing a construction of homotopy colimits by Thomason. The book studies two remarkable classes of functors, *proper and smooth* functors, these two notions being mutually dual. These functors are characterized by cohomological properties inspired by the proper or smooth base change theorem in algebraic geometry.

A publication of the Société Mathématique de France, Marseilles (SMF), distributed by the AMS in the U.S., Canada, and Mexico. Orders from other countries should be sent to the SMF. Members of the SMF receive a 30% discount from list.

Contents: Preface; Introduction; La théorie des catégories test; Les localisateurs fondamentaux; Théorie homotopique élémentaire des catégories; Bibliographie; Index des notations; Index terminologique.

Astérisque, Number 301

February 2006, 140 pages, Softcover, ISBN 2-85629-181-3, 2000 *Mathematics Subject Classification*: 14F20, 14F35, 18B25, 18F20, 18G10, 18G30, 18G50, 18G55, 55P10, 55P15, 55P60, 55Q05, 55U10, 55U35, 55U40, **Individual member US$34**, List US$38, Order code AST/301

Classified Advertisements

Positions available, items for sale, services available, and more

CALIFORNIA

Mathematical Sciences Research Institute
Director

(CORRECTED)

Applications are invited for the position of Director at the Mathematical Sciences Research Institute (MSRI), an independent research organization located on the campus of the University of California in Berkeley. The appointment will be for a five-year term starting July 2007. For more information, see `http://www.msri.org/about/jobs/director`. Applications will be considered starting March 1, 2006.

MSRI is an Equal Opportunity Employer.

000236

CYPRUS

UNIVERSITY OF CYPRUS
Department of Mathematics and Statistics

The department invites applications for one position in analysis, algebra and geometry at the rank of lecturer or assistant professor. The official languages of the university are Greek and/or Turkish. For the above position knowledge of Greek is necessary. The deadline for applications is July 7, 2006. For more information, see `http://www.mas.ucy.ac.cy`.

000238

ITALY

SCUOLA NORMALE SUPERIORE, PISA
Class of Science

The Scuola Normale Superiore of Pisa (Italy) announces a competition for 13 fellowships for graduate studies reserved to citizens of nations which are not part of the European Union in the following subject areas: Science: mathematics, mathematics for technology and finance, physics, condensed matter physics, chemistry, neurobiology, molecular biology; Humanities: classical philology and linguistics, modern philology and linguistics, history, art history, philosophy. The first deadline for applications is June 30, 2006. If one or more grants remain unassigned, a second deadline will be set to October 31, 2006. Citizens of non-European Union nations who possess a 2nd-level university degree or equivalent and are no more than thirty-two years of age by the application deadline can compete for positions in the graduate program. Of the 13 grants, at least 4 will be assigned to citizens of Far Eastern countries. The graduate program lasts three years. The starting date is October 1, 2006, for candidates admitted with the first selection, and January 1, 2007, for candidates admitted with the second selection. Under motivated circumstances, the starting date can be postponed to a later date prior to October 2007. At the conclusion of their graduate studies, students must submit a dissertation, which will be subject to international refereeing, and pass a final exam for their Ph.D. diploma. The complete announcement, including the application form, is available at the Web address `http://www.sns.it/en/scuola/ammissione/corsodiperfezionamento/bandounico/`. For additional information, please contact:

Prof. Fulvio Ricci
Scuola Normale Superiore
56126 Pisa, Italy
`fricci@sns.it`

000237

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 2006 rate is $100 per inch or fraction thereof on a single column (one-inch minimum), calculated from top of headline. Any fractional text of 1/2 inch or more will be charged at the next inch rate. No discounts for multiple ads or the same ad in consecutive issues. For an additional $10 charge, announcements can be placed anonymously. Correspondence will be forwarded.

Advertisements in the "Positions Available" classified section will be set with a minimum one-line headline, consisting of the institution name above body copy, unless additional headline copy is specified by the advertiser. Headlines will be centered in boldface at no extra charge. Ads will appear in the language in which they are submitted.

There are no member discounts for classified ads. Dictation over the telephone will not be accepted for classified ads.

Upcoming deadlines for classified advertising are as follows: August 2006 issue–May 26, 2006; September 2006 issue–June 27, 2006, October 2006 issue–July 31, 2006; November 2006 issue–August 28, 2006; December 2006 issue–September 28, 2006; January 2007 issue–October 27, 2006.

U.S. laws prohibit discrimination in employment on the basis of color, age, sex, race, religion, or national origin. "Positions Available" advertisements from institutions outside the U.S. cannot be published unless they are accompanied by a statement that the institution does not discriminate on these grounds whether or not it is subject to U.S. laws. Details and specific wording may be found on page 1373 (vol. 44).

Situations wanted advertisements from involuntarily unemployed mathematicians are accepted under certain conditions for free publication. Call toll-free 800-321-4AMS (321-4267) in the U.S. and Canada or 401-455-4084 worldwide for further information.

Submission: Promotions Department, AMS, P.O. Box 6248, Providence, Rhode Island 02940; or via fax: 401-331-3842; or send email to `classads@ams.org`. AMS location for express delivery packages is 201 Charles Street, Providence, Rhode Island 20904. Advertisers will be billed upon publication.

Meetings & Conferences of the AMS

IMPORTANT INFORMATION REGARDING MEETINGS PROGRAMS: AMS Sectional Meeting programs do not appear in the print version of the *Notices*. However, comprehensive and continually updated meeting and program information with links to the abstract for each talk can be found on the AMS website. See `http://www.ams.org/meetings/`. Final programs for Sectional Meetings will be archived on the AMS website accessible from the stated URL and in an electronic issue of the *Notices* as noted below for each meeting.

Salt Lake City, Utah

University of Utah

October 7–8, 2006

Saturday – Sunday

Meeting #1019

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: August 2006
Program first available on AMS website: August 24, 2006
Program issue of electronic *Notices*: October 2006
Issue of *Abstracts*: Volume 27, Issue 3

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: June 20, 2006
For abstracts: August 15, 2006

Invited Addresses

William Arveson, University of California Berkeley, *Title to be announced.*

Alexei Borodin, California Institute of Technology, *Title to be announced.*

Izabella Joanna Laba, University of British Columbia, *Title to be announced.*

Darren Long, University of California Santa Barbara, *Title to be announced.*

Special Sessions

Commutative Algebra (Code: SS 3A), **Paul Roberts**, **Anurag K. Singh**, and **Oana Veliche**, University of Utah.

Complex Geometry, Kaehler Groups, and Related Topics (Code: SS 9A), **Terrence Napier**, Lehigh University, **Mohan Ramachandran**, State University of New York at Buffalo, and **Domingo Toledo**, University of Utah.

Floer Methods in Low-dimensional Topology (Code: SS 8A), **Alexander Felshtyn** and **Uwe Kaiser**, Boise State University.

Harmonic Analysis: Trends and Perspectives (Code: SS 1A), **Alex Iosevich**, University of Missouri, and **Michael T. Lacey**, Georgia Institute of Technology.

Interface of Stochastic Partial Differential Equations and Gaussian Analysis (Code: SS 7A), **Davar Khoshnevisan**, University of Utah, and **Eulalia Nualart**, University of Paris XIII.

Low Dimensional Topology and Geometry (Code: SS 4A), **Mladen Bestvina** and **Kenneth W. Bromberg**, University of Utah.

Mathematics Motivated by Physics (Code: SS 5A), **Aaron J. Bertram**, **Yuan-Pin Lee**, and **Eric R. Sharpe**, University of Utah.

Multi-variable Operator Theory (Code: SS 13A), **William B. Arveson**, University of California Berkeley, **Scott A. McCullough**, University of Florida, and **Geoffrey L. Price**, U.S. Naval Academy.

Noncommutative Dynamical Systems (Code: SS 12A), **William B. Arveson**, University of California Berkeley,

Scott A. McCullough, University of Florida, and **Geoffrey L. Price**, U.S. Naval Academy.

Nonconvex Variational Problems: Recent Advances and Applications (Code: SS 10A), **Marian Bocea**, North Dakota State University and University of Utah, and **Andrej Cherkaev**, University of Utah.

Nonlinear Differential Equations: Methods and Applications (Code: SS 2A), **David G. Costa**, University of Nevada, and **Zhi-Qiang Wang**, Utah State University.

Number Theory (Code: SS 14A), **Jasbir Singh Chahal**, Brigham Young University, and **Machiel van Frankenhuijsen**, Utah Valley State College.

Random Motion in Random Media (Code: SS 11A), **Firas Rassoul-Agha**, University of Utah, and **Tom Schmitz**, Swiss Federal Institute of Technology (ETH), Zurich.

Theory and Applications of Infinite Dimensional Dynamical Systems (Code: SS 6A), **Peter W. Bates**, Michigan State University, and **Kening Lu**, Brigham Young University.

Cincinnati, Ohio

University of Cincinnati

October 21–22, 2006

Saturday – Sunday

Meeting #1020

Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: August 2006
Program first available on AMS website: September 7, 2006
Program issue of electronic *Notices*: October 2006
Issue of *Abstracts*: Volume 27, Issue 3

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: July 5, 2006
For abstracts: August 29, 2006

Invited Addresses

Suncica Canic, University of Houston, *Title to be announced.*

Bryna R. Kra, Northwestern University, *Title to be announced.*

Ezra N. Miller, University of Minnesota, *Title to be announced.*

Jon G. Wolfson, Michigan State University, *Title to be announced.*

Special Sessions

Algebraic Coding Theory—Honoring the Retirement of Vera Pless (Code: SS 8A), **William Cary Huffman**, Loyola University, and **Jon-Lark Kim**, University of Louisville.

Analysis and Potential Theory on Metric Spaces (Code: SS 4A), **Thomas Bieske**, University of South Florida, and **Zair Ibragimov** and **Nageswari Shanmugalingam**, University of Cincinnati.

Applied Algebraic Geometry and Cryptography (Code: SS 3A), **Jintai Ding**, **Jason Eric Gower**, and **Timothy J. Hodges**, University of Cincinnati, **Lei Hu**, Chinese Academy of Sciences, and **Dieter S. Schmidt**, University of Cincinnati.

Birational Geometry (Code: SS 2A), **Mirel Constantin Caibar** and **Gary P. Kennedy**, Ohio State University.

Boundary Value Problems for Differential Equations with Applications (Code: SS 11A), **Xiaojie Hou**, **Philip L. Korman**, and **Bingyu Zhang**, University of Cincinnati.

Ergodic Theory (Code: SS 1A), **Nikos Frantzikinakis**, Pennsylvania State University, **Bryna R. Kra**, Northwestern University, and **Mate Wierdl**, University of Memphis.

Financial and Actuarial Mathematics (Code: SS 12A), **Srdjan D. Stojanovic** and **Ning Zhong**, University of Cincinnati.

Geometric Combinatorics (Code: SS 6A), **Ezra N. Miller**, University of Minnesota, and **Igor Pak**, Massachusetts Institute of Technology.

Limit Theorems of Probability Theory (Code: SS 9A), **Wlodzimierz Bryc** and **Magda Peligrad**, University of Cincinnati.

Mathematical Modeling of Biological Systems (Code: SS 15A), **Edward W. Swim**, Air Force Institute of Technology, and **Richard Schugart**, Ohio State University.

Nonlinear Functional Analysis and Applications (Code: SS 5A), **S. P. Singh** and **Bruce Watson**, Memorial University of Newfoundland.

Nonlinear Partial Differential and Its Applications (Code: SS 7A), **Changyou Wang**, University of Kentucky, and **Guan Bo**, Ohio State University.

Optimal Controls and Stochastic Differential Games (Code: SS 14A), **Michael J. McAsey** and **Libin Mou**, Bradley University.

Physical Knotting and Linking (Code: SS 13A), **Eric J. Rawdon**, University of St. Thomas, **Kenneth C. Millett**, University of California Santa Barbara, and **Jonathan Simon**, University of Iowa.

Recent Results on Operator Algebras (Code: SS 10A), **Herbert Halpern**, **Gary Weiss**, **Costel Peligrad**, **Shuang Zhang**, and **Victor G. Kaftal**, University of Cincinnati.

Storrs, Connecticut

University of Connecticut

October 28–29, 2006

Saturday – Sunday

Meeting #1021

Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: August 2006

Program first available on AMS website: September 14, 2006
Program issue of electronic *Notices*: October 2006
Issue of *Abstracts*: Volume 27, Issue 4

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: July 11, 2006
For abstracts: September 6, 2006

Invited Addresses

Changfeng Gui, University of Connecticut, Storrs, *Title to be announced.*

Niranjan Ramachandran, University of Maryland, College Park, *Title to be announced.*

Kannan Soundararajan, University of Michigan, *Title to be announced.*

Katrin Wehrheim, Institute for Advanced Study, *Title to be announced.*

Special Sessions

Algebraic Geometry and Moduli Spaces (Code: SS 12A), **Dan Abramovich**, Brown University, and **Ralph M. Kaufmann**, University of Connecticut, Storrs.

Algebraic and Analytic Combinatorics (Code: SS 11A), **Richard Ehrenborg** and **Margaret A. Readdy**, University of Kentucky and MIT.

Analysis and Probability on Fractals (Code: SS 3A), **Robert S. Strichartz**, Cornell University, and **Alexander Teplyaev**, University of Connecticut, Storrs.

Combinatorial Methods in Equivariant Topology (Code: SS 1A), **Tara Holm**, University of Connecticut, Storrs, and **Tom C. Braden**, University of Massachusetts, Amherst.

Computability Theory in Honor of Manuel Lerman's Retirement (Code: SS 4A), **Joseph S. Miller** and **David Reed Solomon**, University of Connecticut, Storrs.

Geometric Analysis (Code: SS 9A), **Jesse Ratzkin**, University of Connecticut, and **Rob Kusner**, University of Massachusetts.

Geometric Structures Related to Quantum Field Theory (Code: SS 14A), **Roman Fedorov** and **Ivan Mirkovic**, University of Massachusetts, Amherst.

Harmonic Analysis and Integral Geometry (Code: SS 7A), **William O. Bray**, University of Maine, and **Wolodymyr R. Madych**, University of Connecticut, Storrs.

Homotopy Theory of Compactified Moduli Spaces (Code: SS 15A), **Thomas J. Lada**, North Carolina State University, and **Jim Stasheff**, University of North Carolina, Chapel Hill.

Nonlinear Elliptic and Parabolic Equations (Code: SS 5A), **Yung-Sze Choi**, **Changfeng Gui**, and **Joseph McKenna**, University of Connecticut, Storrs.

Nonlinear Geometric PDEs (Code: SS 10A), **Wenxiong Chen**, Yeshiva University, and **Zheng-Chao Han**, Rutgers University.

Number Theory (Code: SS 2A), **Keith Conrad**, University of Connecticut, Storrs, **David Pollack**, Wesleyan University, and **Thomas A. Weston**, University of Massachusetts, Amherst.

Teichmuller Theory and Hyperbolic Geometry (Code: SS 13A), **Martin Bridgeman**, Boston College, **Jeffrey F. Brock**, Brown University, **Linda Keen**, Lehman College, CUNY, and **Kasra Rafi**, University of Connecticut, Storrs.

Topology and Computing (Code: SS 6A), **Thomas J. Peters**, University of Connecticut, Storrs.

Undergraduate Mathematics Education (Code: SS 8A), **Tom Roby**, University of Connecticut, Storrs.

Fayetteville, Arkansas

University of Arkansas

November 3–4, 2006

Friday – Saturday

Meeting #1022

Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: September 2006
Program first available on AMS website: September 21, 2006
Program issue of electronic *Notices*: November 2006
Issue of *Abstracts*: Volume 27, Issue 4

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: July 18, 2006
For abstracts: September 12, 2006

Invited Addresses

R. P. Anstee, University of British Columbia, Vancouver, Canada, *Forbidden configurations, a survey.*

Arun Ram, University of Wisconsin, *Space walks: Combinatorics, representations, spherical functions, and p-compact groups.*

Donald G. Saari, University of California Irvine, *Mathematics of voting.*

Andras Vasy, Massachusetts Institute of Technology, *Scattering theory on symmetric spaces and N-body scattering.*

Special Sessions

Algebraic Combinatorics (Code: SS 6A), **Marcelo Aguiar**, University of Texas A&M, and **Claudia Malvenuto**, University of Rome "La Sapienza".

Analytic Number Theory and Modular Forms (Code: SS 2A), **Matthew Boylan** and **Gang Yu**, University of South Carolina.

Boundary Operators in Real and Complex Domains (Code: SS 3A), **Loredana Lanzani**, University of Arkansas, Fayetteville, and **David E. Barrett**, University of Michigan, Ann Arbor.

Combinatorial Representation Theory (Code: SS 5A), **Arun Ram**, University of Wisconsin-Madison, and **Frank Sottile**, University of Texas A&M.

Dirac Operators in Analysis and Geometry (Code: SS 1A), **John Ryan**, University of Arkansas, **Marius Mitrea**, University of Missouri, and **Mircea Martin**, Baker University.

Evolution Equations in Physics and Mechanics (Code: SS 4A), **John P. Albert**, University of Oklahoma, **Jerry L. Bona**, University of Illinois at Chicago, and **Jiahong Wu**, Oklahoma State University.

Extremal and Probabilistic Combinatorics (Code: SS 9A), **Jerrold R. Griggs**, University of South Carolina, and **Peter Keevash**, California Institute of Technology.

Progress on Problems in Mathematical Fluid Dynamics (Code: SS 8A), **Ning Ju** and **Jiahong Wu**, Oklahoma State University.

Scattering Theory and Wave Propagation (Code: SS 7A), **Tanya J. Christiansen**, University of Missouri, Columbia, and **Andras Vasy**, Stanford University.

Subelliptic PDEs and Sub-Reimannian Geometry (Code: SS 10A), **Luca Capogna**, University of Arkansas, **Scott Pauls**, Dartmouth College, and **Jeremy T. Tyson**, University of Illinois, Urbana-Champaign.

New Orleans, Louisiana

New Orleans Marriott and Sheraton New Orleans Hotel

January 5–8, 2007

Friday – Monday

Meeting #1023

Joint Mathematics Meetings, including the 113th Annual Meeting of the AMS, 90th Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: October 2006
Program first available on AMS website: November 1, 2006
Program issue of electronic *Notices*: January 2007
Issue of *Abstracts*: Volume 28, Issue 1

Deadlines

For organizers: Expired
For consideration of contributed papers in Special Sessions: August 1, 2006
For abstracts: September 26, 2006

AMS-MAA Invited Addresses

Bryna R. Kra, Northwestern University, *Title to be announced.*

AMS Invited Addresses

Peter D. Lax, New York University-Courant Institute, *Title to be announced* (AMS Josiah Willard Gibbs Lecture).

Andrei Okounkov, Princeton University, *Title to be announced* (AMS Colloquium Lectures).

Bjorn Poonen, University of California Berkeley, *Title to be announced.*

Victor S. Reiner, University of Minnesota, Minneapolis, *Title to be announced.*

Andras Vasy, Stanford University, *Title to be announced.*

Margaret H. Wright, New York University-Courant Institute, *Title to be announced.*

AMS Special Sessions

Some sessions are cosponsored with other organizations. These are noted within the parentheses at the end of each listing, where applicable.

Arithmetic Geometry (Code: SS 38A), **Matthew H. Baker**, Georgia Institute of Technology, and **Bjorn Poonen**, University of California Berkeley.

Arithmetic of Function Fields (Code: SS 33A), **Allison M. Pacelli**, Williams College, and **Michael J. Rosen**, Brown University.

Arrangements and Related Topics (Code: SS 1A), **Daniel C. Cohen**, Louisiana State University, and **Anne V. Shepler**, University of North Texas.

Calculus of Variations and Nonlinear PDEs: Theory and Applications (Code: SS 2A), **Marian Bocea** and **Cristina M. Popovici**, North Dakota State University.

Coding Theory and Its Applications (Code: SS 3A), **Roxana N. Smarandache**, University of Notre Dame and San Diego State University, and **Pascal O. Vontobel**, Massachusetts Institute of Technology.

Cohomology and Representation Theory (Code: SS 4A), **Jon F. Carlson** and **Daniel K. Nakano**, University of Georgia, and **Julia Pevtsova**, University of Washington.

Commutative Algebra and Algebraic Geometry (Code: SS 5A), **Paul C. Roberts**, **Anurag K. Singh**, and **Oana Veliche**, University of Utah.

Continuous and Discrete Integrable Systems and Their Applications (Code: SS 6A), **Wen-Xiu Ma**, University of South Florida, **Taixi Xu**, Southern Polytechnic State University, and **Bao-Feng Feng** and **Zhijun Qiao**, University of Texas-Pan American.

Dynamic Programming (Code: SS 7A), **Gerald C. Kobylski** and **Randal Hickman**, United States Military Academy.

Experimental Mathematics in Action (Code: SS 8A), **Victor H. Moll** and **Tewodros Amdeberhan**, Tulane University.

Financial Mathematics (Code: SS 9A), **Jean-Pierre Fouque**, University of California Santa Barbara, **Craig A. Nolder**, Florida State University, **Knut Solna**, University of California Irvine, and **Thaleia Zariphopoulou**, University of Texas Austin.

Fixed Point Theory, Dynamics, and Group Theory (Code: SS 10A), **Michael R. Kelly**, Loyola University, and **Peter N. Wong**, Bates College.

Frames and Wavelets in Harmonic Analysis, Geometry, and Applications (Code: SS 11A), **Palle E. T. Jorgensen**, University of Iowa, **David R. Larson**, Texas A&M University, **Peter R. Massopust**, Institute of Biomathematics and Biometry, Neuherberg, and Technical University of Munich, and **Gestur Olafsson**, Louisiana State University.

Free Discontinuity Problems: From Image Processing to Materials Science (Code: SS 12A), **Blaise Bourdin**, Louisiana State University, and **Christopher J. Larsen**, Worcester Polytechnic Institute.

Geometric Group Theory (Code: SS 13A), **Ruth M. Charney**, Brandeis University, and **Karen Vogtmann**, Cornell University (AMS-AWM).

Group Representations, Ergodic Theory, and Mathematical Physics: Honoring the Memory of George W. Mackey (Code: SS 14A), **Robert S. Doran**, Texas Christian University, **Calvin C. Moore**, University of California Berkeley, and **Robert J. Zimmer**, Brown University.

History of Mathematics (Code: SS 15A), **Joseph W. Dauben**, Lehman College, **Patti Hunter**, Westmont College, **Victor J. Katz**, University of the District of Columbia, and **Karen H. Parshall**, University of Virginia (AMS-MAA).

Infinite Dimensional Analysis, Honoring H.-H. Kuo (Code: SS 16A), **Ambar N. Sengupta** and **P. Sundar**, Louisiana State University.

Initial- and Boundary-Value Problems, Solvability, and Stability for some Nonlinear PDEs: Theorem, Computation, and Application (Code: SS 17A), **Jerry L. Bona**, University of Illinois at Chicago, and **Laihan Luo**, Stockton College of New Jersey.

Invariant Theory (Code: SS 18A), **Mara D. Neusel**, Texas Tech University, and **Frank D. Grosshans**, West Chester University.

Knots, 3-manifolds, and Their Invariants (Code: SS 19A), **Oliver T. Dasbach**, Louisiana State University, and **Xiao-Song Lin**, University of California Riverside.

Logical Methods in Computational Mathematics (Code: SS 20A), **Saugata Basu**, Georgia Institute of Technology, and **Charles N. Delzell**, Louisiana State University (AMS-ASL).

Mapping Class Groups and Handlebodies (Code: SS 21A), **Tara E. Brendle**, Louisiana State University, and **William R. Vautaw**, Southeastern Louisiana University.

Math Circles and Similar Programs for Students and Teachers (Code: SS 22A), **Morris Kalka**, Tulane University, **Hugo Rossi**, Mathematical Sciences Research Institute, **Tatiana Shubin**, San Jose State University, **Zvezdelina E. Stankova**, Mills College, **Daniel H. Ullman**, George Washington University, and **Paul A. Zeitz**, University of San Francisco.

Mathematical Techniques in Musical Analysis (Code: SS 23A), **Robert W. Peck**, Louisiana State University, **Julian Hook**, Indiana University-Bloomington, and **Rachel W. Hall**, Saint Joseph's University.

Mathematics and Education Reform (Code: SS 37A), **William H. Barker**, Bowdoin College, **Dale R. Oliver**, Humboldt State University, **Bonnie S. Saunders**, University of Illinois at Chicago, and **Michael Starbird**, University of Texas, Austin (AMS-MAA-MER).

Microlocal Analysis and Singular Spaces (Code: SS 36A), **Paul A. Loya**, Binghamton University, and **Andras Vasy**, Massachusetts Institute of Technology.

Nonlinear Variational Inclusion Problems and Optimization Theory (Code: SS 24A), **Ram U. Verma**, University of Toledo, and International Publications.

Nonsmooth Analysis in Inverse and Variational Problems (Code: SS 25A), **M. Zuhair Nashed**, University of Central Florida, and **Otmar Scherzer**, University of Innsbruck.

Numerical Relativity (Code: SS 26A), **Alexander M. Alekseenko**, California State University Northridge, and **Arup Mukherjee**, Montclair State University.

Radon Transforms, Convex Geometry, and Geometric Analysis (Code: SS 27A), **Eric L. Grinberg**, University of New Hampshire, **Peter Kuchment**, Texas A&M University, **Gestur Olafsson**, Louisiana State University, **Eric Todd Quinto**, Tufts University, and **Boris S. Rubin**, Louisiana State University.

Recent Advances in Mathematical Biology, Ecology, and Epidemiology (Code: SS 28A), **Lih-Ing Roeger** and **Linda J. Allen**, Texas Tech University, and **Sophia Jang**, University of Louisiana at Lafayette.

Recent Developments in Analysis and Numerics of Geophysical Fluid Dynamics Problems (Code: SS 29A), **Jie Shen**, Purdue University, and **Shouhong Wang**, Indiana University.

Recent Developments in Floer Homology (Code: SS 30A), **Scott J. Baldridge**, Louisiana State University, **Ronald A. Fintushel**, Michigan State University, **Thomas E. Mark**, Southeastern Louisiana University, and **Brendan E. Owens**, Louisiana State University.

Representation Theory and the Theta Correspondence (Code: SS 31A), **Wee Teck Gan**, University of California San Diego, **Hongyu He**, Louisiana State University, and **Annegret Paul**, Western Michigan University.

Structure Theory for Matroids and Graphs (Code: SS 32A), **Joseph P. Kung**, University of North Texas, and **Bogdan S. Oporowski** and **James G. Oxley**, Louisiana State University.

Time Scales: Dynamic Equations with Applications (Code: SS 34A), **Martin J. Bohner**, University of Missouri-Rolla, and **Allan C. Peterson**, University of Nebraska-Lincoln.

Universal Algebra and Order (Code: SS 35A), **John W. Snow**, Sam Houston State University, and **Japheth Wood**, Chatham College.

Davidson, North Carolina

Davidson College

March 3–4, 2007
Saturday - Sunday

Meeting #1024
Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines
For organizers: August 3, 2006
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Chaim Goodman-Strauss, University of Montreal, *Title to be announced.*

Andrew J. Granville, University of Arkansas at Fayetteville, *Title to be announced (Erdős Memorial Lecture).*

Alex Iosevich, University of Missouri-Columbia, *Analysis, combinatorics, and arithmetic of incidence theory.*

Shrawan Kumar, University of North Carolina, *Eigenvalue problem for Hermitian matrices and its generalization to arbitrary reductive groups.*

Special Sessions

Between Harmonic Analysis, Number Theory, and Combinatorics (Code: SS 1A), **Alex Iosevich**, University of Missouri-Columbia, **Michael T. Lacey**, Georgia Institute of Technology, and **Konstantin Oskolkov**, University of South Carolina.

Computational Group Theory (Code: SS 3A), **Luise Charlotte Kappe**, Binghamton University, **Arturo Magidin**, University of Louisiana at Lafayette, and **Robert F. Morse**, University of Evansville.

Eigenvalue Problem for Hermitian Matrices and Its Generalization to Arbitrary Reductive Groups (Code: SS 2A), **Shrawan Kumar**, University of North Carolina.

Oxford, Ohio

Miami University

March 16–17, 2007
Friday - Saturday

Meeting #1025
Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines
For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Sergey Fomin, University of Michigan, *Title to be announced.*

Naichung Conan Leung, University of Minnesota, *Title to be announced.*

Emil J. Straube, Texas A&M University, *Title to be announced.*

Shouhong Wang, Indiana University, *Title to be announced.*

Special Sessions

Finite Geometry and Combinatorics (Code: SS 3A), **Mark A. Miller**, Marietta College.

Geometric Topology (Code: SS 2A), **Jean-Francois LaFont**, SUNY Binghamton and Ohio State University, and **Ivonne J. Ortiz**, Miami University.

Large Cardinals in Set Theory (Code: SS 1A), **Paul B. Larson**, Miami University, **Justin Tatch Moore**, Boise State University, and **Ernest Schimmerling**, Carnegie Mellon University.

Hoboken, New Jersey

Stevens Institute of Technology

April 14–15, 2007
Saturday - Sunday

Meeting #1026
Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: September 14, 2006
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Neal Koblitz, University of Washington, *Title to be announced.*

Florian Luca, Universidad Nacional Autónoma de México, *Title to be announced.*

Natasa Pavlovic, Princeton University, *Title to be announced.*

Elisabeth Werner, Case Western Reserve University, *Title to be announced.*

Special Sessions

Affine Invariants, Randomness and Approximation in Convex Geometry (Code: SS 2A), **Elisabeth Werner**, Case Western Reserve University, and **Artem Zvavitch**, Kent State University.

Convex Sets (Code: SS 1A), **David Larman**, University College London, and **Valeriu Soltan**, George Mason University.

Tucson, Arizona

University of Arizona

April 21–22, 2007

Saturday – Sunday

Meeting #1027

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: September 21, 2006
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Liliana Borcea, Rice University, *Title to be announced.*

James Cushing, University of Arizona, Tucson, *Title to be announced.*

Hans Lindblad, University of California, San Diego, *Title to be announced.*

Vinayak Vatsal, University of British Columbia, Vancouver, *Title to be announced.*

Special Sessions

Representations of Algebras (Code: SS 1A), **Frauke Maria Bleher**, University of Iowa, **Birge K. Huisgen-Zimmermann**, University of California Santa Barbara, and **Dan Zacharia**, Syracuse University.

Warsaw, Poland

University of Warsaw

July 31 – August 3, 2007

Tuesday – Friday

Meeting #1028

First Joint International Meeting between the AMS and the Polish Mathematical Society
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Henryk Iwaniec, Rutgers University, *Title to be announced.*

Tomasz J. Luczak, Adam Mickiewicz University, *Title to be announced.*

Tomasz Mrowka, Massachusetts Institute of Technology, *Title to be announced.*

Ludomir Newelski, University of Wroclaw, *Title to be announced.*

Madhu Sudan, Massachusetts Institute of Technology, *Title to be announced.*

Anna Zdunik, Warsaw University, *Title to be announced.*

New Brunswick, New Jersey

Rutgers University-New Brunswick, Busch Campus

October 6–7, 2007

Saturday – Sunday
Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: March 6, 2007
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Albuquerque, New Mexico

University of New Mexico

October 13–14, 2007

Saturday – Sunday
Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Murfreesboro, Tennessee

Middle Tennessee State University

November 3–4, 2007

Saturday – Sunday
Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 4, 2007
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Invited Addresses

Daniel K. Nakano, University of Georgia, *Title to be announced.*

Carla D. Savage, North Carolina State University, *Title to be announced.*

Sergei Tabachnikov, Pennsylvania State University, *Title to be announced.*

Wellington, New Zealand

To be announced

December 12–15, 2007

Wednesday – Saturday
First Joint International Meeting between the AMS and the New Zealand Mathematical Society (NZMS).
Associate secretary: Matthew Miller
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

San Diego, California

San Diego Convention Center

January 6–9, 2008

Sunday – Wednesday
Joint Mathematics Meetings, including the 114th Annual Meeting of the AMS, 91st Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: October 2007
Program first available on AMS website: November 1, 2007
Program issue of electronic *Notices*: January 2008
Issue of *Abstracts*: Volume 29, Issue 1

Deadlines

For organizers: April 1, 2007
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

New York, New York

Courant Institute of New York University

March 22–23, 2008

Saturday – Sunday
Eastern Section
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: August 22, 2007
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Baton Rouge, Louisiana

Louisiana State University, Baton Rouge

March 28–30, 2008

Friday – Sunday
Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: August 28, 2007
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Bloomington, Indiana

Indiana University

April 4–6, 2008

Friday – Sunday
Central Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: September 4, 2007
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Claremont, California

Claremont McKenna College

May 3–4, 2008

Saturday – Sunday
Southeastern Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: October 4, 2007
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Rio de Janeiro, Brazil

Instituto Nacional de Matemática Pura e Aplicada (IMPA)

June 4–7, 2008

Wednesday – Saturday
First Joint International Meeting between the AMS and the Sociedade Brasileira de Matemática.
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program first available on AMS website: Not applicable
Program issue of electronic *Notices*: Not applicable
Issue of *Abstracts*: Not applicable

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Vancouver, Canada

University of British Columbia and the Pacific Institute of Mathematical Sciences (PIMS)

October 4–5, 2008

Saturday – Sunday
Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: March 9, 2008
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Huntsville, Alabama

University of Alabama, Huntsville

October 24–26, 2008

Friday – Sunday
Southeastern Section
Associate secretary: Matthew Miller
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: March 24, 2008
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Shanghai, People's Republic of China

Fudan University

December 17–21, 2008

Wednesday – Sunday
First Joint International Meeting Between the AMS and the Shanghai Mathematical Society
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program first available on AMS website: Not applicable
Program issue of electronic *Notices*: Not applicable
Issue of *Abstracts*: Not applicable

Deadlines

For organizers: To be announced
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Washington, District of Columbia

Marriott Wardman Park Hotel and Omni Shoreham Hotel

January 7–10, 2009

Wednesday – Saturday
Joint Mathematics Meetings, including the 115th Annual Meeting of the AMS, 92nd Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).
Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: October 2008
Program first available on AMS website: November 1, 2008
Program issue of electronic *Notices*: January 2009
Issue of *Abstracts*: Volume 30, Issue 1

Deadlines

For organizers: April 1, 2008
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Urbana, Illinois

University of Illinois at Urbana-Champaign

March 27–29, 2009

Friday – Sunday
Southeastern Section
Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: August 29, 2008
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

San Francisco, California

Moscone Center West and the San Francisco Marriott

January 6–9, 2010

Wednesday – Saturday

Joint Mathematics Meetings, including the 116th Annual Meeting of the AMS, 93rd Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society of Industrial and Applied Mathematics (SIAM).

Associate secretary: Matthew Miller
Announcement issue of *Notices*: October 2009
Program first available on AMS website: November 1, 2009
Program issue of electronic *Notices*: January 2010
Issue of *Abstracts*: Volume 31, Issue 1

Deadlines

For organizers: April 1, 2009
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

New Orleans, Louisiana

New Orleans Marriott and Sheraton New Orleans Hotel

January 5–8, 2011

Wednesday – Saturday

Joint Mathematics Meetings, including the 117th Annual Meeting of the AMS, 94th Annual Meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Susan J. Friedlander
Announcement issue of *Notices*: October 2010
Program first available on AMS website: November 1, 2010
Program issue of electronic *Notices*: January 2011
Issue of *Abstracts*: Volume 32, Issue 1

Deadlines

For organizers: April 1, 2010
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Boston, Massachusetts

John B. Hynes Veterans Memorial Convention Center, Boston Marriott Hotel, and Boston Sheraton Hotel

January 4–7, 2012

Wednesday – Saturday

Joint Mathematics Meetings, including the 118th Annual Meeting of the AMS, 95th Annual Meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: October 2011
Program first available on AMS website: November 1, 2011
Program issue of electronic *Notices*: January 2012
Issue of *Abstracts*: Volume 33, Issue 1

Deadlines

For organizers: April 1, 2011
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

San Diego, California

San Diego Convention Center and San Diego Marriott Hotel and Marina

January 9–12, 2013

Wednesday – Saturday

Joint Mathematics Meetings, including the 119th Annual Meeting of the AMS, 96th Annual meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association for Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Lesley M. Sibner
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced
Program issue of electronic *Notices*: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 1, 2012
For consideration of contributed papers in Special Sessions: To be announced
For abstracts: To be announced

Meetings and Conferences of the AMS

Associate Secretaries of the AMS

Western Section: Michel L. Lapidus, Department of Mathematics, University of California, Sproul Hall, Riverside, CA 92521-0135; e-mail: lapidus@math.ucr.edu; telephone: 951-827-5910.

Central Section: Susan J. Friedlander, Department of Mathematics, University of Illinois at Chicago, 851 S. Morgan (M/C 249), Chicago, IL 60607-7045; e-mail: susan@math.nwu.edu; telephone: 312-996-3041.

Eastern Section: Lesley M. Sibner, Department of Mathematics, Polytechnic University, Brooklyn, NY 11201-2990; e-mail: lsibner@duke.poly.edu; telephone: 718-260-3505.

Southeastern Section: Matthew Miller, Department of Mathematics, University of South Carolina, Columbia, SC 29208-0001, e-mail: miller@math.sc.edu; telephone: 803-777-3690.

The Meetings and Conferences section of the *Notices* gives information on all AMS meetings and conferences approved by press time for this issue. Please refer to the page numbers cited in the table of contents on this page for more detailed information on each event. Invited Speakers and Special Sessions are listed as soon as they are approved by the cognizant program committee; the codes listed are needed for electronic abstract submission. For some meetings the list may be incomplete. **Information in this issue may be dated. Up-to-date meeting and conference information can be found at** www.ams.org/meetings/.

Meetings:

Important Information Regarding AMS Meetings

Potential organizers, speakers, and hosts should refer to page 296 in the February 2006 issue of the *Notices* for general information regarding participation in AMS meetings and conferences.

Abstracts

Speakers should submit abstracts on the easy-to-use interactive Web form. No knowledge of LaTeX is necessary to submit an electronic form, although those who use LaTeX may submit abstracts with such coding, and all math displays and similarily coded material (such as accent marks in text) must be typeset in LaTeX. Visit http://www.ams.org/cgi-bin/abstracts/abstract.pl. Questions about abstracts may be sent to abs-info@ams.org. Close attention should be paid to specified deadlines in this issue. Unfortunately, late abstracts cannot be accommodated.

Conferences: (see http://www.ams.org/meetings/ for the most up-to-date information on these conferences.)

June 4–June 29, 2006: Joint Summer Research Conferences, Snowbird, Utah (see November 2005 *Notices*, page 1296).

Co-sponsored conferences: *22nd Annual Workshop on Mathematical Problems in Industry*, June 12-16, 2006, Olin College, Needham, MA. For details see http://projects.olin.edu/mpi2006/.

Recent advances in nonlinear partial differential equations and applications: A conference in honor of Peter D. Lax and Louis Nirenberg, June 7-10, 2006, Toledo, Spain. For more details see http://www.mat.ucm.es/~ln06/.

Poisson 2006: Poisson Geometry in Mathematics and Physics, June 5-9, 2006, Tokyo, Japan. For more details see http://www.ams.org/mathcal/info/2006_jun5-9_tokyo.html.