Department of Mathematics

The Department of Mathematics seeks to sustain its top ranking in research and education by hiring the best faculty, with special attention to the recruitment of women and members of underrepresented minority groups, and by continuing to serve the varied needs of the department's graduate students, mathematics majors, and the broader MIT community.

Faculty Awards and Honors

A number of major distinctions were given to the department's faculty this year. Professor George Lusztig received the 2014 Shaw Prize in Mathematical Sciences "for his fundamental contributions to algebra, algebraic geometry, and representation theory, and for weaving these subjects together to solve old problems and reveal beautiful new connections." This award provides $1 million for research support. Professors Paul Seidel and Gigliola Staffilani were elected fellows of the American Academy of Arts and Sciences. Professor Larry Guth received the Salem Prize for outstanding contributions in analysis. He was also named a Simons Investigator by the Simons Foundation. Assistant professor Jacob Fox received the 2013 Packard Fellowship in Science and Engineering, the first mathematics faculty member to receive the fellowship while at MIT. He also received the National Science Foundation's Faculty Early Career Development Program (CAREER) award, as did Gonçalo Tabuada. Professors Roman Bezrukavnikov, George Lusztig, and Scott Sheffield were each awarded a Simons Fellowship. Professor Tom Leighton was elected to the Massachusetts Academy of Sciences. Assistant professors Charles Smart and Jared Speck each received a Sloan Foundation Research Fellowship.

MIT Honors

Professor Tobias Colding was selected by the provost for the Cecil and Ida Green distinguished professorship.

Professor Paul Seidel was named the Norman Levinson professor of mathematics.

Professor David Vogan was selected to be the next Norbert Wiener professor of mathematics.

The MIT Research Support Committee selected two of the department's junior faculty members for the following support for FY2014:

> Associate professor Abhinav Kumar: NEC Corporation Fund for Research in Computers and Communications
>
> Associate professor Lie Wang: Solomon Buchsbaum AT&T Research Fund

Distinguished Lectures

Professor Alexei Borodin gave the Minerva Lecture Series at Columbia University in April 2014. Professor Bjorn Poonen gave three distinguished lectures: The Serge Lang Undergraduate Lecture at the University of California, Berkeley, in January 2014, the Maxson Lecture series at Texas A&M University in April 2014, and the Niven Lecture at the University of British Columbia in May 2014.

Instructors and Postdoctorates

Ivan Corwin, an MIT/Microsoft Research New England Schramm Memorial Fellow, received the Rollo Davidson Prize.

Vladislav Voroninski, instructor in applied mathematics, shared the Outstanding Paper Prize of the Society for Industrial and Applied Mathematics with co-authors Emmanuel Candés, Yonina Eldar, and Thomas Strohmer.

Special Department Friend

Dr. James Simons, a long-time friend of the Mathematics Department, was elected to the National Academy of Sciences.

Honorary Conferences

The Department of Mathematics hosted three mathematics conferences in honor of two professors and one Institute Professor Emeritus.

A daylong conference in honor of Institute Professor Emeritus Isadore Singer, "Perspectives in Mathematics and Physics," was held on May 2, 2014. The conference celebrated Singer's 90th birthday and featured five talks by long-time colleagues.

To honor professor David Vogan's 60th birthday, MIT hosted a conference, "Representations of Reductive Groups," from May 19–23. With more than 200 attendees and 23 talks, this international conference highlighted the broad range of areas influenced by Vogan's work. Many colleagues and former students shared inspiring and wonderful stories about David, especially at the Wednesday night banquet at the Royal East restaurant (traditional venue for the Lie groups seminar dinner).

More than 300 mathematicians from around the world gathered at MIT on June 23–27 to honor Professor Richard Stanley at his 70th birthday conference, "Stanley@70." The program included 34 talks (on both historical and cutting-edge topics), with reminiscences by colleagues and former students, a banquet at Walker Memorial (including a new song immortalizing "EC1"), and a Ping-Pong tournament in celebration of Professor Stanley's favorite sport.

New Faculty and Promotions

Jörn Dunkel joined the applied mathematics faculty as assistant professor. He received his PhD in physics from the University of Augsburg and did postdoctoral work at the University of Oxford and the University of Cambridge. His research program includes developing models and mathematical tools for studying physical and biological phenomena.

Ankur Moitra joined the applied mathematics faculty as assistant professor in the area of theoretical computer science. He received his PhD in computer science at MIT under the supervision of Professor Leighton, and held joint postdoctoral appointments at Princeton University and the Institute for Advanced Study. His research concentrates on algorithmic design relevant to several areas, including statistical inference, optimization, and learning theory.

Charles Smart is an analyst who joined the pure mathematics faculty as assistant professor. He came to MIT as a CLE Moore instructor in 2011 following the granting of his PhD from the University of California, Berkeley. His research concentrates primarily on nonlinear partial differential equations (PDEs) arising in probabilistic settings, often as a scaling limit of a discrete stochastic process or game.

Assistant professor Lie Wang (statistics) was promoted to associate professor.

Daniel Marinus Kan

Professor emeritus Daniel Kan died peacefully on August 4, 2013, in his home in Newton, MA, at the age of 86. He had served on the department faculty for 34 years.

Professor Kan played a key role in establishing the foundations for the combinatorial reinterpretation of topology, or homotopy theory, that led to the integration of topological methods into many mathematical fields. His insights proved to be so fundamental and natural that they have now become part of the universal language of mathematics. He published two highly influential books with former students and supervised 15 doctoral candidates, all at MIT. He reached many more through his unique seminar in algebraic topology, known to all as the Kan Seminar.

Born in Amsterdam in 1927, Daniel Kan received his BSc and MS from the University of Amsterdam, and his PhD from Hebrew University in 1955. He joined MIT's mathematics faculty in 1959 and retired in 1993. Following retirement, Professor Kan continued an active research program, meeting with colleagues regularly and contributing to abstract homotopy theory. In 1982 he was elected a member of the Royal Netherlands Academy of Arts and Sciences.

Retirements and Departures

Professor Sigurdur Helgason retired from the MIT mathematics faculty, having served 56 years. He first came to MIT as a CLE Moore instructor in 1954, earning his PhD from Princeton University under the direction of Salomon Bochner. He joined the MIT faculty in 1960. Professor Helgason is a geometric analyst who made major contributions to representation theory of group actions on homogeneous spaces, as well as to the theory of generalized radon transforms. Among other accomplishments, his new methods yielded differential equations and a Fourier transform on symmetric spaces. His book, Differential Geometry and Symmetric Spaces, is a classic text in the field. In 1988, he received the Leroy P. Steele Prize for Seminal Contributions by the American Mathematical Society. He was the first recipient of the Institute's graduate student teaching prize in 1975. Among other distinctions, he received the Børge Jessen Diploma Award of the Danish Mathematical Society (1982) and the Major Knights Cross of the Icelandic Falcon (1991). He is a member of the Icelandic Academy of Sciences, a fellow of the American Academy of Arts and Sciences, and a member of the Royal Danish Academy of Sciences and Letters.

Professor Steven Kleiman retired in January from the MIT mathematics faculty after 45 years of service. A graduate of MIT, he received his PhD from Harvard University in 1965, studying under Oscar Zariski. He returned to MIT in 1969 following a faculty appointment at Columbia University. Professor Kleiman concentrates on problems in algebraic geometry and commutative algebra. His early work on a fundamental criterion for ampleness secured a prominent place among mathematicians, and he went on to study a broad range of topics in algebraic geometry and commutative algebra with multiple collaborators. A dedicated teacher, Kleiman mentored more than 25 doctoral students. Seeing a gap in mathematics majors' expository writing, he developed the course 18.096 Principles of Mathematical Exposition, which included the internal production of the *Undergraduate Journal of Mathematics*. The journal set the expository writing standard for future math communications courses. Among other distinctions, Kleiman received an honorary doctorate of science from the University of Copenhagen in 1989. He was elected a foreign member of the Royal Danish Academy of Sciences and Letters in 1992 and a foreign member of the Norwegian Academy of Sciences and Letters in 2002.

Professor James McKernan, an algebraic geometer, will join the faculty at the University of California, San Diego.

Professor Igor Rodnianski will return to the faculty at Princeton University. He is an analyst specializing in general relativity.

Associate Professor Mark Behrens (algebraic topology) will join the faculty at the University of Notre Dame.

Associate Professor Abhinav Kumar (number theory) will work in the finance industry at Renaissance Technologies.

Associate Professor Katrin Wehrheim (geometric analysis) will join the faculty at the University of California, Berkeley.

Assistant professor Charles Smart (analysis) will join the faculty at Cornell University.

Administration

In December 2013, professor Michael Sipser become the interim dean of science, following professor Marc Kastner. Professor Sipser continued as department head until June 30, 2014; he will become dean of science July 1. Professor Tomasz Mrowka will follow Sipser as the interim department head. He will also continue as chair of the pure mathematics committee.

Until the next department head is selected, the senior faculty chairs will remain as they were in fiscal year 2014:

- Gigliola Staffilani—associate department head
- Michel Goemans—chair of the applied mathematics committee
- Alexei Borodin and William Minicozzi—co-chairs of the graduate committee in pure mathematics
- Peter Shor—chair of the committee in applied mathematics graduate admissions

- Steven Johnson and Ju-Lee Kim—co-chairs of the committee of undergraduate advisors
- Haynes Miller—microteaching workshop leader
- Larry Guth—transfer credit examiner
- Rodolfo Ruben Rosales—chair of the diversity program

Development

The Department of Mathematics had another successful year in reaching out and engaging alumni and friends of the department. We continued to host department events and faculty talks for alumni, parents, and friends, as well as stewardship events for donors. Professor Sipser in his role as department had gave a talk for alumni and friends in New York titled “Beyond Computation: The P versus NP Problem.”

The department has been successful in fundraising efforts for student fellowships, professorship chairs, the renovation of Building 2, and for the Research Science Institute and Summer Program in Undergraduate Research. Next year will see the ninth edition of the department’s annual newsletter, Integral.

Building 2 Renovations

The Building 2 renovations got under way following the relocation of the department to Buildings E17 and E18 in August 2013. The renovation incorporated a major design feature — a fourth-floor addition over the south and east sections of Building 2, scheduled to be completed by January 2016. This will not only solve the space shortage by adding additional offices and meeting rooms, but will also create an exterior change that could be considered a model for other sections of the main building in the future. Ann Beha Architects produced the design. To cover much of the additional cost, the department received very generous support in gifts from many alumni and friends.

Simons Lecture Series

The 2014 Simons Lecture Series featured two world-renowned mathematicians: Daniel Spielman, the Henry Ford II professor of computer science and mathematics at Yale University, and Ben Green, the Waynflete professor of pure mathematics at Oxford University. Professor Spielman is known for his work in analyses of algorithms and heuristics, error-correcting codes, spectral graph theory, and combinatorics. Recipient of the Gödel Prize, the Nevanlinna Prize, and a MacArthur Fellowship, his series was called “Ramanujan Graphs and the Solution of the Kadison-Singer Problem.” Ben Green works in additive combinatorics and number theory; he is well known for the Green-Tao theorem. His distinctions include the Ostrowski Prize, the Shanmugha Arts, Science, Technology and Research Academy Ramanujan Prize, and the Prize of the European Mathematical Society. His series was called “Finding Algebraic Structure in Combinatorial Problems.”

Department Retreat

Mathematics graduate students organized the department's second annual retreat over the weekend of October 4–6, 2013, held at the Purity Spring Resort in Madison, NH. All community members and their families were invited and almost 160 people attended. This event proved a wonderful respite after the hectic summer when the department moved from Building 2. A fall retreat is being planned for the Columbus Day weekend, October 10–12, 2014.

Diversity

Women in Mathematics

This year, the department revamped the D.W. Weeks Lecture Series into a new format and renamed it the Women in Math Luncheon. A female research mathematician is invited to speak and interact at a lunch with women who are mathematicians from around the Institute, primarily graduate students, postdoctoral associates, and faculty. The event takes place monthly and the format will continue next year.

The department maintained its funding support for the Undergraduate Society of Women in Mathematics (USWIM), and resumed support for the Black Women's Alliance, which was reconstituted in September 2013.

USWIM maintained its forums for career development, the Undergraduate Research Opportunities Program (UROP), and "freshwomen" mixers, as well as social events (e.g., math movie night) for women undergraduates. They continued their work with Girls' Angle (a nonprofit math club for girls), organizing for the second year the SUMiT day-long event for 6th- through 10th-grade students during Independent Activities Period (IAP). Described as a "one-day mathematical extravaganza" with emphasis on a community approach to problem solving, SUMiT 2014 hosted 32 students from as far away as Virginia and California. USWIM also assisted in running the Advantage Testing Foundation's Math Prize for Girls, hosted by the department on September 7, 2013. Then-USWIM president Allison Koeneke was the 2013 alumnae speaker at the event.

The Math Prize for Girls is a national mathematics contest for middle- and high-school students. This year, 276 young women from the United States and Canada competed for cash prizes. Danielle Wang, a high-school junior from California, was the first-place winner. The top 49 students were invited to compete in the 2013 Math Prize for Girls Olympiad, also run by the Advantage Testing Foundation. The Olympiad took place on November 14, 2013, and awarded seven gold, five silver, and 11 bronze medals to participants. Next year, the department will host the Math Prize for Girls contest for the fourth consecutive year.

Ethnic Diversity

Although the department has had some success in seeing a steady increase in the number of women mathematicians, this has not held true for members of underrepresented minority groups. The situation for underrepresented minorities in mathematics continues to be challenging. Over the past three years, the department was fortunate to have recruited three African American instructors, but there are no new minority postdoctoral associates joining the department in September 2014.

The department is focusing on developing initiatives to attract more such candidates to the mathematics major. The MIT registrar reports that 24% of undergraduates come from underrepresented minority groups and that 11% are in the mathematics major. Next year, professor Rosales will begin implementing a program to build a stronger pipeline to the mathematics department using the following strategies:

- Identify first-year underrepresented minority students who do A-level work in the fall semester in entry-level core mathematics courses.
- Contact these students to offer encouragement as well as help and counseling with further developing their mathematical talents. In particular:
    - Encourage students to consider the mathematics major, even as a second major, and set up a mentoring environment to support their course choices.
    - For those with a particularly strong inclination toward mathematics, suggest the possibility of continuing as a graduate student in a mathematics program.
    - Assist students in exploring the possibility of further study—in particular MIT's own graduate program.

The department's graduate program has had only modest success in recruiting qualified minority students. This year, one Native American and one Hispanic student joined the department's graduate student body, with one male Hispanic MIT mathematics major. Next year, one female Hispanic student will enter the department's program. Her recruitment, described below, provided a model for attracting minority students from outside MIT. The department's graduate student underrepresented minority group enrollment for AY2015 will be five out of 117 students, or 4.3 percent.

The department faces the following challenges in identifying potential minority graduate students and attracting them to its program: (a) the application pool is very small, and (b) an accurate evaluation of applicants' qualifications is hard, given that few come from undergraduate programs with a high mathematics research profile. This year, these difficulties were eased by the success of one Hispanic woman who participated in the MIT Summer Research Program (MSRP) with faculty advisors John Bush and Ruben Rosales. The student proved to be extremely bright, which led to very strong recommendations from faculty mentors. In the end, she received admission to four strong graduate programs in addition to MIT's; she selected MIT.

Next year, Professor Rosales and former MLK Visiting assistant professor Erika Camacho will work on establishing a network of faculty members and contacts across the US, especially at colleges with large minority enrollments. These faculty members should prove a major resource in identifying potentially strong candidates for MSRP or for graduate study in mathematics. Professor Rosales will arrange to pair each student with an appropriate math faculty mentor, and will continue to serve as a second mentor.

In addition, Professors Dunkel and Kim will mentor one MSRP student each in summer 2014. Professor Rosales will be in touch with these faculty members to monitor the students' progress and assess their potential for graduate study.

Other Initiatives

Mentoring partnerships

The Directed Reading Program (in which a graduate student mentors an undergraduate student in the reading of a math text during IAP) had 22 undergraduates participate this year, including six underrepresented minority group students and two women. The program will be continued next IAP. The Reading Outreach for Undergraduate Talent Exploration, which had been run by associate professor Mark Behrens, was unfortunately discontinued after his departure from the department.

Program for Research in Mathematics, Engineering, and Science

The Program for Research in Mathematics, Engineering, and Science (PRIMES) continued the so-called PRIMES Circle program for a second year. The program is designed to teach a mathematical enrichment curriculum to students from underprivileged backgrounds living in the Boston area. CLE Moore instructor Chelsea Walton continued as the PRIMES Circle coordinator. She recruited 10 promising students, including three African Americans and seven young women, into the program for calendar year 2014. They are studying advanced topics under the guidance of undergraduate student mentors from MIT and Harvard, closely monitored by Walton.

Support for MIT Student Organizations

The department continued its funding support of the Black Women's Alliance and the MIT Black Graduate Student Association. We also provided funds to the Society of Professional Hispanic Engineers.

National Conferences

The department encourages faculty and staff to attend diversity-related events. Staff member Dennis Porche attended the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) conference in fall 2013, and will do so again in October 2014. Chelsea Walton will also participate in the SACNAS 2014 conference as a speaker, mentor, and reviewer of student exhibits.

Education

Curriculum Renovation

With incoming freshmen classes arriving at MIT with stronger mathematical backgrounds, the department decided to review how freshmen place out of the single-variable calculus class 18.01, and how well this process currently serves the department's students. For example, students who score a 4 or 5 on the College Board's Advanced Placement (AP) Calculus BC exam receive credit for 18.01 Calculus. Looking at data that correlates scores on the AP exam with performance in the multivariable calculus class 18.02, we noticed that students who had received a 4 performed markedly worse as a group than those who had scored a 5, or who had received credit for 18.01 through transfer credit or through the International Baccalaureate Program. This observation, together with the fact that 18.01 contains more than the standard curriculum in an AP calculus class, convinced us to submit a proposal, now accepted by the Committee on Curricula, to allow only freshmen who scored a 5 on the AP Calculus BC exam to receive credit for 18.01. This policy will go into effect for students entering MIT in fall 2015.

During AY2014, the Mathematics Department submitted three proposals to the Alumni Fund, all of which were accepted:

- A proposal by Professor Miller and lecturer Jeremy Orloff to fund the creation of a module on the Laplace Transform to be delivered through the *MITx* platform.
- A proposal by lecturer Jennifer French and professor David Jerison to support translation of a set of problems and applications, suggested by faculty in engineering departments, into the language of calculus.
- A proposal by lecturer Peter Kempthorne, instructor Choongbum Lee, and professor Scott Sheffield to support continuing development of the recently created subject 18.472 Topics in Mathematics with Applications to Finance.

This year, efforts continued on developing a new syllabus for the core subject 18.03 Differential Equations. This effort was begun in AY2013, supported in part by a grant from the d'Arbeloff Fund for Excellence in Education, by a team consisting of Professors Jerison, Haynes Miller, and Gilbert Strang, and Lecturers French and Orloff. Professor Poonen provided a beautiful set of notes that are being used as the backbone of what is expected to be a new version of 18.03—one that could be delivered completely through the MITx platform in the near future.

Finally, David Jerison, Gigliola Staffilani, and Jennifer French have been creating a version of 18.01 Calculus that can be fully delivered through the *MITx* platform, partially supported by the Office of Digital Learning. The department expects to have a preliminary version for use in-house by spring 2015 and to have the class available online by summer 2015 for the exclusive use of incoming freshmen who are taking the 18.01 advanced standing exam.

Graduate Students

There were 117 graduate students in mathematics in 2013–2014, all in the PhD program. A total of 18 students received the doctoral degree.

Most of these graduates will go to postdoctoral positions in mathematics departments or institutes, including Columbia University, New York University, Harvard Medical School, the Institute for Advanced Study, McGill University, Princeton University, the State University of New York at Stony Brook, the University of Utah, and the University of California, Berkeley. A smaller number chose non-academic positions, with one graduate receiving a Mass Media Science and Engineering Fellowship from the American Association for the Advancement of Science to work for WIRED magazine. Another took a position in the financial industry at Renaissance Technologies, and several will work in research and development positions at Amazon, Microsoft, and other firms.

There will be 18 first-year students entering the department's doctoral program in 2014–2015, including five women. The department continues to offer all first-year students fellowship support; as usual, several incoming students come with support from external sources. One new transfer student will join the second-year class of the doctoral program in the fall.

Graduate Student Awards

Michael Donovan and Jennifer Park received the Charles and Holly Housman Award for Excellence in Teaching for their exceptional skill and dedication to undergraduate teaching.

Ailsa Keating and Kestutis Cesnavicius shared the Charles W. and Jennifer C. Johnson Prize for outstanding research papers accepted in a major journal.

Undergraduate Majors

During AY2014, a total of 386 students listed mathematics as their major, meaning that the department remains the largest undergraduate program in the School of Science and the third largest undergraduate program in the Institute. This is the official "fall fifth week" figure, but it increased to more than 440 undergraduates by the spring term. Of these, 101 students graduated with a first degree in mathematics; 45 more finished with a second degree in the department. Responses to the senior survey were only partial (approximately 44% response). Of those responding, 15% of seniors will continue in graduate school in mathematics, 13% in computer science, 7% in physics, and 8% in other disciplines. Other graduates will begin work in a wide array of related areas, with 23% going into software engineering, 15% into the financial sector, and 8% into consulting work. Other students plan to travel, work for volunteer organizations, or pursue other options.

Undergraduate Student Awards

The Jon A. Bucsela Prize in Mathematics, given in recognition of distinguished scholastic achievement, professional promise, and enthusiasm for mathematics, was awarded to senior Dennis Tseng.

Junior Jessie Zhang was an Honorable Mention awardee of the Alice T. Schafer Prize, given by the Associate for Women in Mathematics for excellence in mathematics by an undergraduate woman.

Other noteworthy awards included a Marshall Scholarship for senior Kirin Sinha and Barry Goldwater scholarships for juniors Carl Lian and Daniel Kang.

The MIT team placed first in the William Lowell Putnam Mathematical Competition. The team consisted of sophomore Mitchell Lee and juniors Benjamin Gunby and Zipei Nie. Overall, MIT students once again dominated the competition. Four MIT participants ranked in the top five test-takers, calledPutnam Fellows: junior Zipei Nie, sophomore Mitchell Lee, and freshmen Bobby Shen and David Yang. In addition, MIT students accounted for 15 of the top 25 competitors, and for a record 35 out of the 81 who received honorable mention or above (a full 43% of all such recipients). Students benefited from excellent coaching by professors Richard Stanley, Abhinav Kumar, and Henry Cohn.

Undergraduate and High School Summer Research Programs

In summer 2013, the department hosted its 17th Summer Program in Undergraduate Research, a six-week intensive mathematical research experience for MIT undergraduates in which each undergraduate pursues an individual project with a graduate student mentor. Eleven MIT undergraduates participated, supervised by five graduate students. The program culminated in oral presentations and final research papers, which were posted online. A jury of faculty members selected winners for the Hartley Rogers Jr. Family Prize, awarded jointly to a student–mentor team. The 2013 Rogers Prize was shared between junior Fan Zheng and his mentor Chenjie Fan, and the team of sophomore Zipei Nie and junior Anthony Wang and their mentor Ben Yang.

Summer 2013 was the 21st year of the Mathematics Department's participation in the Research Science Institute (RSI) program for gifted high-school students. Eleven students carried out mathematics projects in RSI, supervised by seven graduate students. The program concluded with oral presentations and final research papers, which were posted online. Five RSI students achieved success with their projects at various national and international science competitions (11 awards total). Two students reached the final stage: Jessica Shi, mentored by Francisco Unda, became a finalist in the Intel Science Talent Search 2014; and Rumen Dangovski, mentored by Nathan Harman, won second prize at the Intel International Science and Engineering Fair 2014.

Program for Research in Mathematics, Engineering, and Science

In calendar year 2014, the department participated in the fourth year of PRIMES. This year, 19 gifted high-school students from greater Boston worked on research projects or participated in reading groups in the mathematical section of PRIMES, mentored by 10 graduate students and postdoctoral associates. Additionally, the department is participating in the significantly expanded PRIMES-USA mathematics section; this is a section of PRIMES that is open to high-school juniors (or home-schooled students of the same age) from across the US. Thirteen exceptional out-of-state students are doing research projects, supervised by 10 graduate students and postdoctoral associates via telecommunication channels.

On May 17 and18, PRIMES held its fourth annual conference at MIT. The well-attended event demonstrated the success of the program. Several projects will likely lead to publications in professional journals and will be strong contenders at national science competitions for high-school students. Several PRIMES students will enter MIT as undergraduates in fall 2014 and are likely to continue their research under the UROP program.

In fall 2013, PRIMES and PRIMES-USA students successfully completed 17 individual and group mathematics research projects during calendar year 2013, garnering the following distinctions:

- Fourteen students were invited to present at the undergraduate poster session at the 2014 Joint Mathematics Meeting; four of them received an Outstanding Presentation Award.
- 2013 Siemens Competition in Math, Science & Technology: Kavish Gandhi and Noah Golowich, mentored by Laszlo Lovasz, each won second prize (a $50,000 scholarship); there were also three regional finalist and seven semifinalist awardees.
- 2014 Intel Science Talent Search: William Kuszmaul, supervised by Darij Grinberg, took third prize ($50,000); there were also two national finalist and 11 national semifinalist awardees.
- Ravi Jagadeesan, mentored by Akhil Mathew, was selected to be a Davidson Fellow Laureate ($50,000).
- Ritesh Ragavender, supervised by Alex Ellis, took first prize at 2014 Intel International Science and Engineering Fair, and became a Davidson Fellow ($25,000).

Research Highlights

Professors Colding and Minicozzi are major collaborators in the study of differential geometry and PDEs. Over the past year, they jointly resolved a long-standing major conjecture about singularities of mean curvature flow (submitted in December 2013 to *Annals of Mathematics*).

In essence, once one knows that singularities occur, one naturally wonders what they are like. For minimal varieties the first answer, already known to H. Federer and W.H. Fleming in 1959, is that they weakly resemble cones. For mean curvature flow, by the combined work of G. Huisken, T. Ilmanen, and B. White, singularities weakly resemble shrinkers. Unfortunately, the simple proofs leave open the possibility that a minimal variety or a mean curvature flow, looked at under a microscope, will resemble one blowup, while under higher magnification, it might (as far as anyone knows) resemble a completely different blowup. Whether this ever happens is perhaps the most fundamental question about singularities. It is this long-standing open problem that Colding and Minicozzi settled for mean curvature flow at all generic singularities, and for mean convex mean curvature flow at all singularities.

In another major work completed this past year, Colding and Minicozzi, with Tom Ilmanen from ETH Zürich, demonstrated that singularities of mean curvature flow are rigid in a very strong sense. To their knowledge, this is the first general rigidity theorem for singularities of a nonlinear geometric flow. They expect that the techniques and ideas developed in this paper will have applications to other flows. Their results hold in all dimensions and do not require a priori smoothness.

Professor Alice Guionnet works in probability theory and random matrices. The study of random matrices involves the analyses of arrays of data, to understand noise correlation, and the study of randomly chosen operators. She cites as her most significant work the study of how random matrices apply in combinatorics and to operator algebra. Some of her recent results in this area include the following:

- Construction of towers of subfactors (with V. Jones and D. Shlyakhtenko),
- Construction of a transport map and new isomorphisms results of some C* algebras (with D. Shlyakhtenko),
- Study of the spectral properties of heavy tails matrices, an important class of random matrices which are still quite mysterious (with C. Bordenave, F. Benaych-Georges, and C. Male)
- Study of the universality properties of the spectrum of random matrices by applying optimal transport ideas (with F. Bekerman and A. Figalli)

Guionnet also developed, together with G. Borot and K. Kozlowski, a theoretical approach to analyzing the large dimension expansions of mean field interacting particles with Coulomb interaction, and to obtaining topological expansion in a much wider framework than random matrices.

Professor Guth studies metric geometry and harmonic analysis. In harmonic analysis, he did joint work with Jean Bourgain, making a small improvement in the estimates for the Stein restriction problem. This is actually a major problem in Fourier analysis, with the most recent improvements made around 2001–2002 by Tom Wolff and Terence Tao.

Guth also wrote a paper in geometry about the connection between the k-dilation of a map and the homotopy class of the map. The k-dilation of a map measures how much the map stretches or contracts *k*-dimensional areas. The paper connects geometric properties of a map with subtle homotopy information encoded with Steenrod squares. Steenrod squares are usually thought about in a pretty algebraic way in algebraic topology, and so it is challenging to connect them with geometry. The paper includes some examples of maps with surprising behavior and some theorems that other behaviors are impossible.

Professor Jerison works in PDEs and Fourier analysis. His recent work (with A. Figalli) concerns the stability of the Brunn-Minkowksi inequality, a fundamental inequality of convex geometry. This stability question has strong connections to additive number theory. They also have an entirely unrelated theorem characterizing convex sets using their marginals (recognizing convexity using an X-ray- or CAT-scan-type transform).

Jerison has also been working recently on internal diffusion limited aggregation, a model, proposed by Institute Professor John Deutch and chemist Paul Meakin in 1986, intended to describe corrosion or electropolishing processes. With Lionel Levine and Scott Sheffield, he has resolved a 20-year-old conjecture about fluctuations of this model.

Jerison identifies his most long-standing and significant research program to be on free boundary problems. These are partial differential equations that model physical problems in which there is an unknown interface, such as between oil and water, between water and air, and between the wake of a boat and the vorticity-free region of the water surface. The free boundary can also describe the decision boundary between buying or selling a stock, or between stopping or continuing a medical trial. His most recent work (with Ovidiu Savin) concerns smoothness of stable free boundaries; it has deep parallels with fundamental work by James Simons on stable minimal surfaces. His recent work (with his former student Nikola Kamburov) on singularities of unstable free boundaries is intimately tied to prize-winning work by Tobias Colding and William Minicozzi on unstable minimal surfaces.

Professor Miller, a MacVicar Faculty Fellow, has led an effort to understand the structure of topological objects exhibiting operations of addition and multiplication. The issue of commutativity is particularly interesting; in topology, commutativity turns out to be not a property but a structure, and it comes in a variety of different strengths. The work of his graduate students Vigleik Angeltveit, Ricardo Andrade, and Geoffroy Horel show how these structures can be measured. It turns out that there is a duality between certain algebraic commutativity structures and parallelizable manifolds, a seemingly unrelated family of geometric structures. Another student working under Miller's direction, Rune Haugseng, has in effect constructed a channel through which these and many other connections between algebra and geometry can be made more efficiently.

Professor Moitra is a theoretical computer scientist whose program concentrates on machine learning. Over the past six months, his research has focused on developing provable algorithms for dictionary learning. Sparse recovery is one of the most well-known and well-studied problems in signal processing and statistics; but in many applications ranging from edge detection, image de-noising, compression, and super resolution to deep learning, the linear transformation (the "dictionary") that serves as a basis for the observed samples is unknown. The basic problem is to compute a dictionary so that all of the samples can be sparsely represented, and until Moitra's recent work with Sanjeev Arora and Rong Ge, no provable algorithm was known for the so-called overcomplete case, which is by far the most interesting in applications. (Spielman, Wang and Wright had previously given an algorithm for the full-rank case, for which they received the Conference on Learning Theory Best Paper Award in 2012.) Their algorithm was based on a novel reinterpretation of the problem through overlapping clustering. In subsequent work, with Arora, Ge, and Tengyu Ma, Moitra proved that a variant of a well-known heuristic called alternating minimization in fact yields a nearly optimal algorithm for this problem. This not only lends new insights into how these approaches work in practice, but also has biological implications; one of the original motivations for studying this problem came from questions about how the mammalian visual cortex is organized. His work has caught the attention of theorists and statisticians and led to a flurry of recent activity in this area, including invited talks across a broad range of venues covering signal processing, statistics, and information theory.

Professor Poonen's recent research concerns the general problem of deciding whether a system of polynomial equations has a solution in rational numbers. Research conducted by Manin, Colliot-Thélène, Sansuc, Harari, and Skorobogatov from 1970 to 2009 carried out a "grand unification" of the existing methods for proving nonexistence of rational solutions. But Poonen discovered a new method to prove nonexistence of solutions, and also produced examples for which he could prove that his method succeeded while the earlier ones did not.

In a joint article with Michael Stoll, Poonen proved that for most polynomials f of odd degree ≥7, the equation $y^2 = f(x)$ has no rational solutions. This is the first time that Gerd Faltings's 1983 result (which was awarded the Fields Medal) has been made effective for a large fraction of curves in a family. A referee called the Poonen-Stoll result "the most profound result in the arithmetic of curves since Faltings' Theorem."

In a joint article with Jeffrey Lagarias and Margaret Wright, Poonen proved that the restricted Nelder-Mead algorithm converges for reasonable two-variable functions. This optimization procedure has been widely used in the sciences since 1965, and this is the first proof of its convergence in a nontrivial situation.

Professor Shor works in quantum computation and information. He has been studying a particular core problem on entanglement with his former student Ramis Movassagh and is readying the work for publication.

Consider that quantum mechanics allows particles to be dependent, i.e., "feel" each other, without any signal sent between them. "Entanglement" refers to this highly nonclassical phenomenon, in which two particles can be interlocked in a state even though they are possibly very distant from each other, where there is no classical communication between them, such as a signal or a force field. Entanglement serves as a key resource for quantum computation and information processing.

It is largely believed that quantum many-body systems that have a gap in their spectrum (difference of the first and second smallest energies of the Hamiltonian) obey an area law. Entropy, like energy, is an extensive quantity, which means that it scales linearly with the size of the system (volume). However, because of the locality of interaction in quantum systems, in many cases entanglement entropy obeys an area law, which means it scales with the surface area, not with the volume. Until now, people largely believed that in critical systems, the area law would be violated by at most a factor of log(n) (where n is the number of quantum particles). Shor has shown for the first time that in physically reasonable quantum spin chain models, the entanglement entropy scales as a square root of n, which is much larger than the log(n) violation of a constant, expected for one-dimensional chains. This shows that simple quantum systems can possess a large amount of entanglement, which in principle might be utilized for quantum computation.

Professor Tabuada is an algebraic topologist. He works on the development of a theory of noncommutative motives as envisioned by Maxim Kontsevich. His recent results include:

- The computation of the noncommutative motives of Azumaya algebras
- The computation of the Chow groups of intersections of quadrics (this solved a conjecture of Paranjape-Srinivas)
- The computation of the cyclic homology of toric and twisted projective varieties (this was an open problem)
- The development of a theory of Jacobians of noncommutative motives
- The extension of the Weil restriction functor to the noncommutative setting
- The construction of a precise bridge between Voevodsky's triangulated category of mixed motives and Kontsevich's triangulated category of noncommutative mixed motives.

Professor Vogan works in group representations and Lie theory. Since 2002, he has been working with the research group, Atlas of Lie Groups and Representations, led by Jeff Adams at the University of Maryland. The group is building software to make calculations in infinite-dimensional representation theory of semisimple Lie groups. Partly as a consequence of the ways of thinking forced by software development, four mathematicians from the group have found an algorithm to classify the irreducible unitary representations of a semisimple Lie group. This is the most important problem in the field, solved in the simplest special cases by Valentine Bargmann and Israel Gelfand in the 1940s and studied by many people since then. There are certainly fundamental applications to pure mathematics, and possibly also to mathematical physics—mathematical physics, because the problem solved can be formulated as, "What are the possible quantum mechanical systems on which a specified symmetry group can act?"

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