Department of Mathematics

The Department of Mathematics continues to be the top-ranked mathematics department in the United States. The department is a key part of MIT's educational mission at both the undergraduate and graduate levels and produces top sought-after young researchers. Key to the department's success is recruitment of the very best faculty, postdoctoral fellows, and graduate students in an ever-more competitive environment. The department aims to be diverse at all levels in terms of race, gender, and ethnicity. It continues to serve the varied needs of the department's graduate students, mathematics majors, and the broader MIT community.

Awards and Honors

The faculty received numerous distinctions this year. Professor Emeritus Michael Artin was awarded the National Medal of Science. In 2016, President Barack Obama presented this honor to Artin for his outstanding contributions to mathematics. Two other emeritus professors also received distinctions: Professor Bertram Kostant was selected to receive the 2016 Wigner Medal, in recognition of "outstanding contributions to the understanding of physics through Group Theory." Professor Alar Toomre was elected member of the American Philosophical Society.

Among active faculty, Professor Larry Guth was awarded the New Horizons in Mathematics Prize for "ingenious and surprising solutions to long standing open problems in symplectic geometry, Riemannian geometry, harmonic analysis, and combinatorial geometry." He also received a 2015 Teaching Prize for Graduate Education from the School of Science. Professor Alexei Borodin received the 2015 Henri Poincaré Prize, awarded every three years at the International Mathematical Physics Congress to recognize outstanding contributions in mathematical physics. He also received a 2016 Simons Fellowship in Mathematics. Professor Pavel Etingof was elected as a fellow of the American Academy of Arts and Sciences. Professor Michael Sipser, dean of the School of Science, was selected for the 2016 Margaret MacVicar Faculty Fellowship. He also received a Distinguished Alumni Award from the University of California, Berkeley.

Professor Bonnie Berger was elected to the American Institute for Medical and Biological Engineering College of Fellows. She also received an honorary doctorate from the École Polytechnique Fédérale de Lausanne. The MIT mathematics faculty selected her to be the next Simons Professor of Mathematics, beginning July 2016.

Professor Tobias Colding was a Clay Senior Scholar 2015–2016, and was appointed the David Eisenbud professor at the Mathematical Sciences Research Institute during spring 2016. Professor Michel Goemans received an honorary doctorate from the Université Catholique de Louvain, Belgium. Professor Bjorn Poonen received a 2016 Simons Investigatorship.

At the Institute Awards Convocation, Professors Thomas Leighton and Michael Sipser received the Irwin Sizer Award from the Graduate School Council for most significant improvements to MIT Education. They were honored for their development of the highly successful Course 18C Mathematics with Computer Science major.

Among the department's assistant professors, Professor Jörn Dunkel received the 2016 Complex Systems Scholar Award from the James S. McDonnell Foundation. Professor Emmy Murphy was awarded the Birman Research Prize in Topology and Geometry by the Association for Women in Mathematics. Assistant Professors Vadim Gorin and Ankur Moitra each received a Sloan Research Fellowship.

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.

Lectures

Bonnie Berger delivered keynote addresses at the Association for Computing Machinery 6th Conference on Bioinformatics, Computational Biology, and Health Informatics/ Workshop on Algorithms in Bioinformatics; at the École Polytechnique Fédérale de Lausanne(EPFL) and the EPFL Computer and Information Sciences graduation ceremonies; at the Research in Computational Molecular Biology/International Society for Computational Biology Conference on Regulatory and Systems Biology; at the Howard Hughes Medical Institute/Research in Computational Molecular Biology Conference on Biomedical Education; and at the Gordon Research Conference on Human Single Nucleotide Polymorphisms and Disease. She also presented as part of the Computer Science and Engineering Distinguished Lecture Series at the University of California, San Diego and at the Department of Biomedical Data Science at Stanford University.

Alexei Borodin delivered the Pinsky Lecture Series in Mathematics at Northwestern University in May 2016.

Tobias Colding gave a plenary lecture for the 100th anniversary of the Mittag-Leffler Institute in March 2016.

David Jerison presented an Ordway Distinguished Lecture at the University of Minnesota in March 2016

Gilbert Strang gave the C.C. Lin Memorial Lecture at Tsinghua University in August 2015.

David Vogan delivered an invited address to the eastern sectional meeting of the American Mathematical Society in New Brunswick, Canada, titled "Matrices almost of order two" (November 2015). He also gave a retiring presidential address of the American Mathematical Society to the Joint Mathematics Meetings in Seattle, WA, titled "Conjugacy classes and group representations" (January 2016).

New Faculty and Promotions

Davesh Maulik joined the department faculty as professor from Columbia University. He is a leading algebraic geometer whose interests concern moduli spaces of geometric objects (e.g., algebraic curves or sheaves) and various questions regarding their structure. A former Clay Research Fellow, Professor Maulik received a PhD from Princeton University in 2007, studying under Rahul Pandharipande. He is best known for the resolution of the Tate conjecture, a central conjecture in algebraic cycles formulated by John Tate in 1963.

Andrei Neguț joined the faculty as assistant professor. He concentrates on problems in geometric representation theory, an area that overlaps studies in algebraic geometry and representation theory. His current research focuses on moduli of sheaves, quiver varieties, quantum algebras, and knot invariants. Dr. Neguţ received a PhD from Columbia University in 2015, studying under Andrei Okounkov.

Aaron Pixton also joined the faculty as assistant professor andClay Research Fellow. Dr. Pixton works on various topics in enumerative algebraic geometry, including the tautological ring of the moduli space of algebraic curves, moduli spaces of sheaves on 3-folds, and Gromov-Witten theory. He received a PhD from Princeton University in 2013, studying under Rahul Pandharipande.

Assistant Professor Clark Barwick was promoted to associate professor without tenure.

Associate Professor Laurent Demanet was awarded tenure.

Associate Professor Steven Johnson was promoted to professor.

In Memoriam

Three of the department's professor emeriti passed away in FY2016.

David J. Benney

David J. Benney, professor emeritus of applied mathematics at MIT, died October 9, 2015, after a period of declining health. He was 85.

Professor Benney joined the MIT mathematics faculty in 1960 as assistant professor. He received a PhD in applied mathematics from MIT in 1959, studying under Chia-Chiao Lin, and continued at MIT as instructor in 1959 and 1960. He was promoted to full professor in 1966, and retired from the Institute in 2010.

Professor Benney chaired the Applied Mathematics Committee from 1983 to 1985. He served as department head for two terms in 1989 and 1999, a period of major transition for the department and the Institute. He set the pace for future departmental administrations through major fundraising, building innovation, and furthering the department's cross-disciplinary culture. He expanded the visiting professorship program and oversaw the appointment of many leading scholars to the faculty.

Professor Benney's research was highly original, with many pioneering contributions to applied mathematics. His principal research contributions were in the mathematical analysis of nonlinear waves, hydrodynamic stability, and transitions to turbulence. Beginning with his PhD, Benney and early collaborators showed that nonlinear wave interactions were fundamental to the study of hydrodynamic stability, and could lead to the emergence of turbulent bursts, as were later observed in experiments done at the National Institute of Standards and Technology (previously the National Bureau of Standards). He not only rationalized important physical phenomena, but derived equations to describe them that became relevant in a wide variety of contexts, including aerodynamics, meteorology, oceanography, atmospheric sciences, and optics.

He mentored 18 PhDs, producing 158 academic descendants. David Benney left an extraordinary legacy. He served for 46 years (1968–2013) as managing editor of *Studies in Applied Mathematics*. Under his long tenure, he steered the journal to prominence, making it a leading journal in physical applied mathematics. With Professor Harvey Greenspan, he co-authored the widely used text, *Calculus: An Introduction to Applied Mathematics*, published in 1973 by McGraw-Hill (later republished by Breukelin Press in 1997).

Born in Wellington, New Zealand, on April 8, 1930, Professor Benney received his BSc in mathematics in 1950 (first class honors) from Victoria University, in Wellington, New Zealand, followed by his MSc in 1951. He studied at Cambridge University from 1952 to 1954, and received a BA in mathematics, again with first class honors. He returned to New Zealand as a lecturer at Canterbury University College from 1955 to 1957 before entering the doctoral program at MIT in applied mathematics.

Willem V. R. Malkus

Willem Van Rensselaer Malkus, emeritus professor of applied mathematics at MIT, died in Falmouth, MA, on May 28, 2016, at the age of 92. He was a professor of applied mathematics at MIT from 1969 until his retirement in 1996.

Professor Malkus was a physical applied mathematician who focused on problems in thermal convection, magnetohydrodynamics, and geophysical fluid dynamics. A pioneer in fluid dynamics, he inspired students and colleagues alike to delve deeply into the important problems of his time.

Professor Malkus made fundamental contributions to the theory of thermal convection, turbulence, magnetohydrodynamics, elliptical flows, and their applications in geophysics. He was particularly focused on the magnetic dynamo problem, as concerns the manner in which the motion of an electrically conducting fluid can generate a magnetic field. In 1968, he proposed a novel theory for a precessionally-forced geodynamo, well known to workers in the field. In the early 1960s, he struggled, along with MIT Professor Edward Lorenz, to understand the origins of what is now widely known as "chaos." With MIT colleague Professor Louis Howard, he invented a simple mechanical device, known as the "Malkus-Howard-Lorenz Waterwheel," that realized Lorenz's famous equations, and has been widely used since in the teaching of chaos theory. He delighted in variational principles and was always seeking new applications for them, especially in deducing criteria for hydrodynamic stability. His work continues to inspire applied mathematicians, geophysicists, and the wider scientific community.

Professor Malkus was a founding member of the Geophysical Fluid Dynamics program at the Woods Hole Oceanographic Institution in 1959. This program has been hugely influential in growing an entire community of scholars. In 1959, geophysical fluid dynamics was a new field—but over the years more than 450 student fellows and 1,000 visitors have participated in the program. In 2008, Professor Malkus, with the geophysical fluid dynamics program's other founding members, Louis Howard and Professor George Veronis (from Yale University), received the Excellence in Geophysical Education Award from the American Geophysical Union.

When he arrived at MIT, Professor Malkus founded the Applied Math Laboratory, where he carried out a variety of fluid mechanics experiments, including seminal experiments on thermal convection and elliptical flows. During his time at MIT, he twice served as chair of the Applied Mathematics Committee: from 1977 to 1979 and 1984 to 1987. He was a beloved supervisor of graduate students, many of which now occupy leading academic positions.

Professor Malkus was born in Brooklyn, NY, on November 19, 1923. He studied at the University of Michigan and Cornell University, and was admitted to the PhD program in physics at the University of Chicago to study under Enrico Fermi. Malkus received his PhD in physics in 1950. He was appointed assistant professor at the University of Chicago from 1950 to 1951. He joined the staff at the Woods Hole Oceanographic Institution as a research associate from 1951 to 1956, and was promoted to and worked as a physical oceanographer from 1956 to 1962. From 1958 to 1960, he was a jointly appointed professor of oceanography at MIT. Prior to joining the applied mathematics faculty at MIT, he served on the faculty at the University of California, Los Angeles, as professor of geophysics from 1960 to 1967, and professor of geophysics and mathematics from 1967 to 1969.

Professor Malkus was elected a fellow of the American Academy of Arts and Sciences in 1964. He was also a fellow of the American Physical Society and the American Geophysical Union. He received two Guggenheim Fellowships, in 1972 and 1979. In 1972 he was elected a member of the National Academy of Sciences.

Hartley Rogers, Jr.

Hartley Rogers, Jr., professor emeritus of mathematics at MIT, died at the Meadow Green Rehabilitation and Nursing Center in Waltham, MA, on July 17, 2015. He was 89.

Professor Rogers joined the MIT mathematics faculty in 1956 as an assistant professor following a year's visit at the Institute. He was promoted to full professor in 1964, and retired from MIT in 2009.

Professor Rogers's research interests were in mathematical logic, and he is credited as one of the main developers of recursion theory. His 1959 paper "Computing Degrees of Unsolvability" obtained semantical completeness results for higher levels of arithmetical complexity. Professor Rogers authored the 1967 book, *Theory of Recursive Functions and Effective Computability,* which became a central and standard reference in the field and remains in print.

Professor Rogers served as vice president of the Association for Symbolic Logic, senior editor of the *Journal of Symbolic Logic,* senior editor of *Annals of Mathematical Logic,* and associate editor of the *Journal of Computer and System Sciences.* Among his distinctions, he received the Lewis R. Ford Award of the Mathematical Association of America for his expository papers in 1965.

Professor Rogers's career at MIT included significant administrative service during the 1960s and 1970s. From 1962 to 1964, he was a member of the Committee on Curriculum Content Planning, whose report radically modified the general Institute requirements

for undergraduate education. In 1968, he chaired the Panel on November Events and the MIT Community, whose findings further developed the Institute's judicial processes. Professor Rogers served as chair of the MIT faculty from 1971 to 1973, and as associate provost from 1974 to 1980. He chaired the editorial board of the MIT Press from 1974 to 1981 as the Press became an arm of the Institute's educational mission.

At Professor Rogers's suggestion in 1996, the department initiated its Summer Program in Undergraduate Research. For the program, a graduate student mentor is paired with an MIT undergraduate; each team then works intensively on a research problem over a six-week period in the summer, culminating with the undergraduate giving an oral presentation and submitting written materials to a group of mathematics faculty. In 2001, the Rogers family established the Hartley Rogers, Jr. Prize for the top research team(s) selected by the faculty.

From 1993 to 2006, Professor Rogers supervised the MIT mathematics section of the Research Summer Institute program for advanced high school students. From 1995 to 2008, he also helped develop the MIT problem-solving seminar into an important resource for students, especially freshmen, interested in participating in the William Lowell Putnam Mathematical Competition. During this period, MIT's Putnam team placed among the top three teams 10 times, twice in first place.

Professor Rogers was a popular and respected teacher, particularly with his development of course 18.022 Multivariable Calculus with Theory. In 1993, he received the Teaching Prize for Undergraduate Education from the School of Science. He produced 19 doctoral students at MIT, with 557 mathematical descendants in total.

Professor Rogers, was born in Buffalo, NY, on July 6, 1926. He received his BA in English from Yale University in 1946. Following a year at Cambridge University as a Henry Fellow, he returned to Yale to complete his MS in physics in 1950. He continued his studies at Princeton University in mathematics, receiving an MA in 1951 and a PhD in 1952, with Alonzo Church as his thesis advisor. Professor Rogers' first academic appointment was as Benjamin Peirce Lecturer at Harvard University from 1952 to 1955.

Administration

Professor Tomasz Mrowka continued as department head. John Bush followed Gigliola Staffilani as associate department head. For AY2017, Tobias Colding will follow Paul Seidel as chair of the pure mathematics committee. Peter Shor will continue as chair of the applied mathematics committee. Davesh Maulik will follow Alexei Borodin as co-chair of the graduate committee in pure mathematics; William Minicozzi will continue as co-chair. Jonathan Kelner will continue as chair of the committee in applied mathematics. Philippe Rigollet will follow Ju-Lee Kim as co-chair of the committee of undergraduate advisors; Steven Johnson will continue as co-chair for AY2017.

Development

The Department of Mathematics had another successful year in reaching out and engaging alumni and friends of the department. We continued to host events and faculty talks for alumni, parents, and friends, as well as stewardship events for donors.

The department has been successful in fundraising for student fellowships and the renovation of Building 2, now renamed the Simons Building. In addition, the department has increased the number of donors to the Program for Research in Mathematics, Engineering, and Science (PRIMES). We are now looking to raise funds for MathROOTS, the newest addition to the PRIMES outreach program (see more information on PRIMES below). The department will continue to publish its annual newsletter, Integral.

Building 2 Renovations

The renovation of Building 2, now known as the Simons Building, was completed in December 2015. Department members moved back into the building shortly thereafter in a smoothly run multi-phase effort just in time for MIT's centennial celebration of the Main Group in spring 2016. Members of the department were very happy to be back "home," and quite pleased with the newly renovated space. Ann Beha Architects did a wonderful job in modernizing the historic building while staying true to the spirit of the original design, and the department was proud that the renovation project was considered the vanguard for future renovations of the entire original Bosworth Building.

The newly added fourth floor with corner seminar room, expanded common room, multitiered first-year graduate student suite in the ziggurat, and high-tech and modernized Room 2-190 lecture hall are just some examples of the upgrades included in the renovation. The support of the department's many colleagues and friends enabled this project to make the Simons Building a beautiful center for mathematics, and department members look forward to celebrating its dedication in October 2016.

In September, Ann Beha Architects was named one of the top 50 firms of 2015 by *Architect* Magazine. The Building 2 project also received two prestigious awards throughout the year: the 2015–2016 Preservation Award of the Cambridge Historical Commission and the Merit Award for Excellence in Architecture for Building Additions and Adaptive Reuse by the Society for College and University Planning, the American Institute of Architects, and the Committee on Architecture for Education.

Simons Lecture Series

Two world-renowned mathematicians were invited to be the Simons Lecturers in 2016: Michael Brenner, Glover Professor of Applied Mathematics and Applied Physics at Harvard University, and Maryam Mirzakhani, professor at Stanford University. As a physical applied mathematician, Professor Brenner has produced seminal and major results on an exceptional variety of problems, such as bubble sonoluminescence, sedimentation, drop pinching, electrospinning, colloidal physics, and microfluidic studies in materials sciences and biology. He is a fellow of the American Academy of Arts and Sciences and the recipient of the American Physical Society's Stanley Corrsin Award. His Simons lecture series, Adventures in Applied Mathematics, covered topics in artificial living materials, potential singularity mechanics in the Euler equations, and linear algebra and the shape of bird beaks.

Professor Mirzakhani is the first woman Fields Medalist, which she received in 2014 for "outstanding contributions to the dynamics and geometry of Riemann surfaces and their

moduli spaces." Her work integrates methods from algebraic geometry, topology, and probability theory. Professor Mirzakhani also received the Clay Research Award (2014), the Ruth Lyttle Satter Prize in Mathematics (2013) and the Leonard M. and Eleanor B. Blumenthal Award for the Advancement of Research in Pure Mathematics (2009). Her lecture series, which was to concentrate on aspects of hyperbolic surfaces, had to be cancelled due to illness. The department plans to reschedule her Simons Lectures for a later date.

Building Diversity

The Mathematics Department has reconstituted its diversity committee under its new faculty officer, Gigliola Staffilani. This spring, Professor Staffilani assembled a committee—comprised of faculty members and postdoctoral, graduate, and undergraduate students—to review the department's efforts to date and to examine best practices moving forward. (A woman faculty colleague of Professor Staffilani from Tufts University joined as an observer and offered suggestions.)

Women and Minorities in the Department of Mathematics, AY2015–AY2016

	AY2015		AY2016	
	Women	Minorities	Women	Minorities
Faculty	11%	0%	11%	0%
Instructors	13%	6%	11%	3%
Graduate students*	17%	4%	18%	4%
Math majors*	29%	14%	32%	14%

*Registrar figures from the fifth-week of fall term.

Unfortunately Professor Alice Guionnet will return to France in AY2017. This will reduce our percentage of women faculty to 8% in current projections for AY2017. (During the year, the pure mathematics committee reviewed a potential senior woman candidate and made an offer to a junior member, but neither case worked out.) Our postdoctoral instructorship program will have 8% women and 5% underrepresented minority participation in AY2017. For faculty and postdoctoral appointments, the department works to attract the top women and underrepresented minority candidates from the application pool, as well as considering leading faculty who may wish to transfer to MIT.

The department is modestly pleased to see slight increases in its women math majors and graduate students over the past two years, but this is still an overall decline from AY2010 (when we had 39% female math majors and 23% female graduate students). Overall, the underrepresented minority percentages, low as they are, have seen a gradual increase over the past 10 years.

The department continued to focus on building a pipeline for future students by reaching out to high school students. All indicators point to the critical role of mentoring (one-on-one when possible), ideally beginning in the early years, in order to build the confidence and know-how for academic performance and the ambition for an intellectual life in mathematics.

The Mathematics Major

A large number of female and underrepresented minority students take core mathematics courses their first year, with a substantial number performing well. To initiate their interest in considering the mathematics major (which can also accommodate any other STEM [science, technology, engineering, and math] field as a second major), the diversity committee organized a "Meet-the-Mathematician" event, held in the spring term when first-year students are considering their major(s). The event featured upperclass women and underrepresented minority math majors, postdoctoral students, and faculty members sharing their experiences of having chosen a mathematics major in college. One of the goals of this event is to provide a sense of the MIT mathematics community to first-year women and underrepresented minority undergraduates—a community whose members are available for one-on-one mentoring on academic and career development. The Meet-the-Mathematician event was a major success, and the diversity committee plans to continue it in the first week following spring break.

The Graduate Program

In 2014, the department began building a network of outside math faculty at colleges and universities with higher underrepresented minority enrollments in order to identify potential undergraduates who, with additional training, might be eligible to apply to leading math graduate programs. The department would invite these candidates to its Summer Research Program at MIT to offer them early exposure to the Institute. For students who succeed and demonstrate strong capability, department faculty could recommend them to leading programs of the students' choice (including MIT). For those admitted to MIT, accommodations could be made to offer courses to fill in any potential gaps in the first year. In the summer of 2016, faculty members will mentor two MIT Summer Research Program students.

We decided, however, that we needed to provide more than the MIT Summer Research Program pipeline for our graduate program, as faculty are often away during the summer months. One option we are considering is the design of a full-year exchange program, modeled in part on the Vanderbilt-Fisk cross-registered master's program in physics and Smith College's junior exchange program for female undergraduates. The MIT math exchange program would be offered in the junior year, so that students would have their senior year to apply for graduate admission. Students would be carefully selected by our faculty, working with the department's network of outside faculty. Depending on funding, the department would seek to offer the program to a set number of students who would essentially take classes as a group with MIT undergraduates, and would meet afterward with an overseeing postdoctoral researcher or faculty mentor for follow-up discussions.

Other ideas under consideration include videotaping lectures for distribution primarily to learning institutions with high underrepresented minority enrollment. The department will be further exploring these options in AY2017 with the Office of the Dean for Graduate Education and the Office of Minority Education.

Martin Luther King Program

The Dr. Martin Luther King Jr. Visiting Professors Program has been central to our efforts to build a network of outside faculty at institutions with high underrepresented minority enrollment. For 2016–2017, Assistant Professor Ryan Hynd will join our faculty as an MLK visiting faculty member. He is an ambitious researcher in analysis at the University of Pennsylvania, whose program includes studies in both pure and applied mathematics. He also comes highly recommended as a teacher and mentor, and has shared with us his proposal to the National Science Foundation for the University of Pennsylvania, which includes developing a master's program similar to one MIT is considering. Professor Ryan has agreed to join our diversity committee, where his perspective and experience at Penn should prove highly valuable.

MathROOTS

From June 19, 2016, to July 3, 2016 the department hosted its second MathROOTS summer camp program designed specifically for underrepresented minority students. Twenty nationally selected African American and Latino high school students participated in a program filled with math games, guest lectures, recitations, team contests, and group trips. Six graduate and undergraduate mentors taught a rigorous academic curriculum focused on number theory, algebra, combinatorics, and geometry. The goal was to expose enthusiastic young mathematics students from underrepresented backgrounds to beautiful-yet-accessible mathematics, to immerse them in the MIT academic culture, and to create a friendly social environment of like-minded peers and mentors.

The first MathROOTS camp held in summer 2015 proved to be an effective pipeline of underrepresented minority students for MIT undergraduate admissions. MathROOTS 2015 participants commented: "Thanks to MathROOTS, I met 19 other students who had the same level of interest in mathematics as me! … I believe that these bonds will last for a lifetime." And, "This program opened some windows for me. I realized if I work hard, I could be here [at MIT]."

Among the 20 MathROOTS 2015 participants, 17 were seniors, 11 were admitted to MIT, and eight chose to attend. Thus, 40% of MathROOTS 2015 participants are now MIT students.

PRIMES Circle for High School Students

For the fourth year, the Program for Research in Mathematics, Engineering, and Science (PRIMES) successfully ran its PRIMES Circle section, which teaches a mathematical enrichment curriculum to students with underprivileged backgrounds from the Boston area. A total of 14 students from urban public high schools, including three African American, one Latino, and 10 female students, participated in the 2016 program. They studied advanced topics in probability, number theory, combinatorics, and knot theory; prepared expository papers; and delivered presentations at a mini-conference at MIT in May 2016.

PRIMES Circle section has been very successful. In a 2015 survey of PRIMES Circle students, 67% rated their study as "very interesting," 58% rated their mentor as "excellent,"

and 42% rated their mentor as "good." Participants commented: "This program helped me a lot in understanding math and also made me love math even more." And, "The program definitely helped me decide on my major in college—applied mathematics."

Directed Reading Program

Begun in January 2011 with funding from a National Science Foundation Research Training Group grant, the Directed Reading Program has been regularly offered as part of the mathematics Independent Activities Period program in January. Modeled on a program at the University of Chicago and other venues, an undergraduate is paired with a graduate mentor to work through one or more mathematics texts. Underrepresented minority students are especially encouraged to apply, and the number of participants have been steadily increasing, from 22 participants in 2014 to 35 in 2015 to 38 in 2016. Funding for this program has now run out, but given its success, the department hopes to continue supporting the program for the foreseeable future.

Ongoing Initiatives

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

The department encourages faculty and staff to attend diversity-related events. Staff member Dennis Porche attended the SACNAS conference in fall 2015 in Washington, DC, and will participate in the SACNAS 2016 conference in Long Beach, CA. (SACNAS is dedicated to fostering the success of Chicano/Hispanic and Native American scientists).

Women in Mathematics

For the fifth consecutive year, the department hosted the annual Advantage Testing Foundation Math Prize for Girls, a national mathematics contest for middle and high school students (held September 20, 2015). As in the 2014 competition, young women from the United States and Canada competed for cash prizes, resulting in 14 top-ranked students, followed by 27 highly ranked participants, from a field of 271 contestants. Hosting the Math Prize competition at MIT exposes these young women to the Institute and its math department early on in their academic careers. The department will continue to support hosting the Math Prize for Girls for the foreseeable future.

Girls' Angle

Women mathematics majors, graduate students, and academic staff continue to participate as mentors in Girls' Angle—a nonprofit math club in Cambridge for young women in middle school years that was started by one of our doctoral alumni.

Building Community for Women

Through special dinners and other events, the department fosters a sense of community for its female faculty, postdoctoral researchers, and students. Gigliola Staffilani hosts a very popular women-in-math dinner at her home each year for math department women as well as female mathematicians in the Greater Boston area. The department supports

the monthly Women in Math Luncheon, in which a senior female mathematician is invited to talk about her career and her research. In addition, the department maintains funding support for the Undergraduate Society of Women in Mathematics—which helps welcome new women mathematics majors—and brings in speakers to describe how mathematics is related to their work, both in academics and industry.

Education

Curriculum Updates

During AY2016, the Department of Mathematics reduced its faculty teaching requirements from three to two courses per year in order to remain competitive with peer institutions. Doing so was greatly facilitated by efforts to restructure and streamline the department's curriculum, led last year by Professor Staffilani. One outcome of these efforts was a more consistent numbering of mathematics subjects that better reflects the level and content of classes. Furthermore, a number of dormant subjects were removed, and some sporadically offered classes were consolidated under "Special Subject in Mathematics" umbrellas.

The department has also added a new version of 18.100 Real Analysis, an important introductory course in pure mathematics. Previously, there were three versions, 18.100A, 18.100B, and 18.100C, where 18.100A was a less demanding version of 18.100B, while 18.100C was a version of 18.100B that allowed students to satisfy the Institute's communication requirement in mathematics (CI-M). Owing to the attraction of the CI-M credit, many students who should have taken 18.100A took 18.100C, and found themselves out of their depth academically. In order to avert this problem, the department created CI-M versions of both 18.100A and 18.100B, respectively, and 18.100P and 18.100Q (the re-numbered 18.100C).

The ongoing reform of the core 18.0N courses is being done with a view to raising the level of mathematical literacy across the Institute among students in science and engineering. Some four years ago, Lecturer Jerry Orloff, Professor Haynes Miller, and CLE Moore Instructor Jon Bloom, with the support of the Davis Educational Foundation, revised 18.05 Introduction to Probability and Statistics with a view to making it more effective and relevant. The subject is now taught in the "flipped" style, using MIT's special Technology-Enhanced Active Learning classrooms.

Three years ago, Professors David Jerison, Haynes Miller, and Gilbert Strang, with the help of digital learning scientist, Dr. Jennifer French and Jerry Orloff, revisited the content of 18.03 Differential Equations with a view to include more linear algebra, thereby conforming to changes in the undergraduate programs in several engineering departments. Concurrently, Haynes Miller and Jerry Orloff developed 18.031 System Functions and the Laplace Transform, a three-unit class given over Independent Activities Period that covers material removed from 18.03 by recent curriculum reforms. This subject is one of the department's few ventures into the realm of modularization, a matter of considerable current interest around the Institute.

The democratization of education through OpenCourseWare, MITx, and edX programs presents exciting opportunities for MIT on the international stage. AY2016 saw the completion of all three 18.01x Calculus 1 modules, now available on the edX platform, an effort supported in part by MIT's Office of Digital Learning and the Class of 1960 Fund. 18.01.1x Calculus 1A: Differentiation was released in the summer of 2015, with a total enrollment of 35,000 students (about 2,000 active). 18.01.2x Calculus 1B: Integration was released in November 2015, featuring a total enrollment of more than 21,000 students (about 2,000 active). 18.01.3x Calculus 1C: Coordinate Systems & Infinite Series was released in March 2016, and saw a total enrollment of 15,000 students (about 1,200 active). The online material generated is also being used for 18.01 Calculus in the spring term at MIT (a small class of less than 10 students, many of whom failed 18.01 the previous fall term). Consequently, the course can now be managed by a graduate student rather than a faculty member.

The development of 18.01x represents the first step toward online versions of many of the department's core undergraduate offerings. The next course to be released onto edX is 18.03 Differential Equations, a course for which the online platform has already been developed for MITx by David Jerison, Haynes Miller, Gilbert Strang, Bjorn Poonen, Jennifer French, and Jerry Orloff, with original funding from a d'Arbeloff Grant in AY2013 and current funding from the MITx Grant Program. In the past three years, the department has used the 18.03 notes on MITx as the textbook for its regular 18.03 class. 18.02 Calculus will be next in line for addition to the open online courses, with the current long-term objective to have all the core courses (18.01–18.06) ultimately in a MITx/edX format.

Graduate Students

There were 125 graduate students in mathematics in 2015–2016, all in the PhD program. A total of 26 students received their doctoral degree.

Following completion of their degrees, most of these graduates advance to postdoctoral positions in mathematics departments or institutes, which this year included positions at Brown University, Columbia University, the Georgia Institute of Technology, Harvard University, the Institute for Advanced Study in Princeton, Princeton University, Washington University in St. Louis, the Universities of California (at Berkeley and at Santa Barbara), and the University of Minnesota.

Internationally, students earned positions at Hebrew University, Institute des Hautes Études Scientifiques, National Taiwan University, and the University of Ottawa. A smaller number, about one quarter of this year's group, chose non-academic positions, including positions with the bioinformatics company Curoverse, the machine vision company Cognex, and financial companies Jane Street and Vatic Labs. One student chose to accept a postdoctoral position at Microsoft Research while another graduate student is co-founding a start-up for which he will serve as the chief technology officer.

There will be 27 new first-year students entering the mathematics doctoral program in September 2016, including five women. The department continues the policy of offering all first-year students fellowship support.

Awards

Zachary Abel and Carlos Sauer Ayala received the Charles and Holly Housman Award for Excellence in Teaching for their exceptional skill and dedication to undergraduate teaching.
Yi Sun and Yun William Yu shared the Charles W. and Jennifer C. Johnson Prize for outstanding research papers accepted in a major journal.

Majors

The mathematics major is the third largest major at MIT, and the largest within the School of Science. During AY2016, a total of 360 students listed mathematics as their major at the official "fall fifth week," but enrollment increased to more than 400 undergraduates by the spring term. Of these, 155 students graduated with degrees in mathematics: 106 with a first major in mathematics and 49 with a second major in mathematics. Responses to our senior survey were only partial, but of the 56 whose post-graduate plans are known, six will continue onto graduate programs in mathematics, 10 to programs in computer science, five to programs in physics, and another six will be pursuing graduate work in other fields (primarily economics and business). Slightly more than half will be pursuing non-academic opportunities, with eight entering into software engineering, eight into consulting services, seven into the financial sector, and others into education, sales, and other domains.

Awards

The Jon A. Bucsela Prize in Mathematics, given in recognition of distinguished scholastic achievement, professional promise, and enthusiasm for mathematics, was awarded to seniors Yongyi Chen and Mitchell Lee.

Other noteworthy awards included a Hertz Foundation Fellowship for senior Felipe Hernandez, and the 2016 AMS-MAA-SIAM Frank and Brennie Morgan Prize for outstanding research in mathematics by an undergraduate, awarded to Amol Aggarwal '15.

Putnam Triumphs

For the third consecutive year, the 2015 MIT team placed first in the William Lowell Putnam Mathematical Competition, with two MIT students placing among the top six individual scorers, earning places as Putnam Fellows (the usual top five was extended to six due to a tie). This year's Putnam team consisted of juniors David Yang and Bobby Shen and sophomore Mark Sellke; Putnam Fellows were David Yang and freshman Yunkun Zhou. MIT students accounted for nine of the top 26 individual scorers, and a total of 33 out of the 89 who received Honorable Mention or above (37% of all such recipients). In addition, this year freshman Danielle Wang was awarded the Elizabeth Lowell Putnam Prize, given for outstanding performance by a female participant. Students benefited from excellent coaching by Professor Peter Shor.

Undergraduate and High School Summer Research Programs

Summer Program in Undergraduate Research

In summer 2015, the department hosted its 19th Summer Program in Undergraduate Research(SPUR), a six-week intensive mathematical research experience for MIT undergraduates in which each undergraduate pursues an individual project with a graduate student mentor. Twelve MIT undergraduates participated in the 2015 six-week SPUR program, mentored by six graduate students. Two student-mentor teams shared the Hartley Rogers Jr. Prize for best paper: Yuchen Fu and his mentor Seth Shelley-Abrahamson, and Ofer Grossman and his mentor Dongkwan Kim.

Research Science Institute

Summer 2015 was the 23rd year of the department's participation in the Research Science Institute program for gifted high school students. In summer 2015, nine graduate students and postdocs mentored 13 high school students, selected under the six-week Research Science Institute program. The students came from 10 different states in the US as well as from Bulgaria and Spain. For their research projects, students won six semifinalist awards at Siemens 2015 and one semifinalist award at Intel Student Talent Search 2016. Sarvasva Raghuvanshi became a regional finalist at Siemens 2015 and won an Outstanding Presentation Award at the Mathematical Association of America Undergraduate Poster Session of the 2016 Joint Mathematics Meetings in Seattle, WA.

Undergraduate Research Opportunities Program

In summer 2015, for the second year, the department offered math majors an enhanced type of Undergraduate Research Opportunities Program projects: Supervised UROP, or UROP+. Under this program, UROP+ students work on research projects full time for three summer months, meeting with their mentors individually twice a week. Eight students participated, mentored by seven graduate students, producing research and expository papers posted on the UROP+ website.

Program for Research in Mathematics, Engineering, and Science

In calendar year 2016, the department is participating in the sixth year of the Program for Research in Mathematics, Engineering, and Science. Locally, 19 gifted high school students from Greater Boston are working with 12 graduate student mentors on research projects or participating in reading groups in the mathematical section of PRIMES. Additionally, in the expanded PRIMES-USA math section, 17 exceptional out-of-state students selected from a national pool are conducting research projects under the supervision of 15 graduate students, postdocs, and outside faculty via telecommunication channels.

Another section of PRIMES, PRIMES Circle, teaches mathematical enrichment curriculum to 14 promising students from Boston's urban high schools. (See the Diversity section for a more complete description.)

On May 21 and 22, PRIMES held its sixth annual conference at MIT, where all research projects were successfully presented. The well-attended event demonstrates the solid

success of the program. Several projects will likely lead to publication 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 2016 and will likely continue their research under the Undergraduate Research Opportunities Program.

In fall 2015, PRIMES and PRIMES-USA math students successfully completed 24 individual and group math research projects that they had worked on during calendar year 2015. Three students received Outstanding Presentation awards at the MAA (Mathematics Association of America) Undergraduate Student Poster Session of the 2016 Joint Mathematics Meetings in Seattle. Several students received awards for their projects in the 2016 Intel Science Talent Search (two national finalist and nine national semifinalist awards), and in the 2015 Siemens Competition in Math, Science and Technology (six regional finalist and six semifinalist awards). Meena Jagadeesan, mentored by Miriam Farber, won the second place Medal of Distinction for Basic Research at the 2016 Intel Science Talent Search.

Professor George Lusztig donated a significant portion of his 2014 Shaw Prize in Mathematical Sciences to establish the George Lusztig PRIMES mentorships. These are awarded each year to continuing PRIMES mathematics mentors for exceptional mentoring service in past years. The 2016 Lusztig PRIMES mentors were graduate students Chiheon Kim, Seth Shelley-Abrahamson, and Isabel Vogt (PRIMES Circle coordinator).

Research Highlights

Below are some of the research highlights achieved by mathematics faculty and researchers in AY2016.

Bonnie Berger

Bonnie Berger and her group are currently focused on big biological data, a research area in which group members continue to mathematically formalize the paradigm of compressive genomics—capturing theoretically when compressively accelerated methods can be applied. In particular, the group capitalizes on the unique topological structure of high-dimensional biological data, due to evolutionary constraints, to be able to operate directly on compressed data in sublinear time and space. This work was featured as the cover article, commentary, and perspective in *Cell Systems* (August 2015), as well as in two recent *Nature Biotechnology* papers; moreover, Berger provided invited viewpoints for the 20th Anniversary Issue of *Nature Biotechnology*'s "Voices of biotech" article (April 2016) and delivered multiple keynote addresses on this work. Her group is also investigating how to preserve privacy while at the same time releasing big bio data for analysis. (Also of note, the group has had a large impact on developing novel algorithms for integrating large heterogeneous datasets for predicting RNA-protein interactions and for population genetics, a field with a plethora of top-notch statisticians whose algorithms the group improved upon to be able to infer population evolutionary history.)

John Bush

A decade ago, Professor Yves Couder (University of Paris) discovered that a millimetric droplet can "walk" across the surface of a vibrating fluid bath, propelled or "piloted"

by its own monochromatic wave field. Remarkably, these walking droplets exhibit many features previously thought to be peculiar to the microscopic, quantum realm. For the past five years, this hydrodynamic pilot-wave system has been the focus of John Bush's research in the Applied Math Laboratory. His group's work demonstrates that quantization is a natural consequence of pilot-wave dynamics, specifically, the constraint imposed on the droplet by its monochromatic pilot wave. Quantum-like statistics are a feature of chaotic pilot-wave dynamics, wherein the droplet drifts between dynamically unstable states. The group's theoretical developments also point to a more general framework for pilot-wave dynamics, of which the fluid system is one, and quantum mechanics is quite possibly another. Most importantly, this pilot-wave system provides a framework for understanding many mysteries of quantum mechanics, including the single- and double-slit experiments, quantized orbits, spin states, quantum-like statistics, and entanglement.

The bouncing drop system is reminiscent of French physicist Louis de Broglie's early rational model of relativistic quantum mechanics, according to which quantum particles are oscillators moving in resonance with a monochromatic pilot-wave field with the de Broglie wavelength. When considered in light of de Broglie's pilot-wave mechanics, the group's work suggests the possibility that, in quantum mechanics, there is an unresolved dynamic on a very fast (and presently unmeasurable) timescale, that of the Compton frequency, the resolution of which would yield a rational quantum dynamics. It would thus suggest that quantum mechanics may be at a stage analogous to fluid mechanics prior to the resolution of the viscous boundary layer (circa 1900), at which time the field of fluid mechanics was similarly awash with paradoxes.

Semyon Dyatlov

Semyon Dyatlov has studied the behavior of chaotic dynamical systems and their quantum counterparts, focusing on systems with hyperbolic behavior. For open hyperbolic systems, he obtained the first proof (with Colin Guillarmou—to appear in *Annales Henri Poincaré: A Journal of Theoretical and Mathematical Physics,* November 2016) of meromorphic continuation of the power spectrum of classical correlations as well as of the Ruelle zeta function, essentially settling the 1967 conjecture of Stephen Smale. Also, with Maciej Zworski, he proved (submitted to *Annals of Mathematics,* 2016) that the order of vanishing at zero of the Ruelle zeta function of a negatively curved surface is equal to the Euler characteristic, which is the first result linking dynamical zeta functions and topology without symmetry assumptions. For open quantum systems, he established with Joshua Zahl (to appear in *Geometric and Functional Analysis,* July 2016) a connection between the spectral gap question, a fractal version of the uncertainty principle, and additive combinatorics. He later used it to establish improved Weyl laws (submitted to *Journal of the European Mathematical Society*, 2015), and with Long Jin obtain rather precise results on spectral gaps as well as Weyl bounds for open quantum baker's maps (submitted to *Inventiones mathematicae* 2016).

William Minicozzi and Tobias Colding

A major theme in partial differential equations (PDE's) over the past 50 years has been understanding singularities and the set where singularities occur. Recently, William Minicozzi and Tobias Colding solved a number of long-standing questions about the

singularities of mean curvature flow. This work will be featured in the *Notices of the American Mathematical Society*'s November 2016 cover article.

Modeling of a wide class of physical phenomena, such as crystal growth and flame propagation, leads to tracking fronts moving with curvature-dependent speed. When the speed is the curvature, this leads to one of the classical degenerate nonlinear second order differential equations. A priori solutions are only defined in a weak sense and one naturally wonders, "What is the regularity of solutions?"

Minicozzi and Colding completely settled this question in a series of papers, the final of which was submitted to *Communications on Pure and Applied Mathematics* in June 2016. It turns out that the solutions are always twice differentiable. Moreover, this result is optimal; their second derivative is continuous only in very rigid situations that have a simple geometric interpretation. This solved a problem that had been open since the 1990s. One of the major ingredients was a paper by Colding and Minicozzi in the *Annals of Mathematics* (January 2015) that settled the long-standing uniqueness of blow-ups conjecture for monotone fronts.

Gigliola Staffilani

Dispersive partial differential equations model certain wave propagation phenomena in nature. Their solutions are waves that spread out in space as time evolves while conserving their energy. Probably the most well-known equation within the class of dispersive PDE is the nonlinear Schrödinger equation, a fundamental equation in physics. In the last 20 years, enormous progress has been made in settling fundamental questions on existence of solutions, as well as their long-time behavior, singularity formation, and interactions. This body of work has focused primarily on deterministic aspects of wave phenomena that have been studied with sophisticated tools from harmonic analysis, nonlinear Fourier analysis, analytic number theory, and geometry.

Gigliola Staffilani has conducted research on these aspects of mathematics for many years. More recently, though, a growing interest has been shown by the community in incorporating a non-deterministic point of view in the field of dispersive PDEs. In fact, as a more detailed picture of these kinds of waves emerges and as the questions asked become yet more challenging, it also becomes clear that even if a certain property is not true for *all* solutions of a certain equation, one can still prove it for *many* of them. This leads us to the realm of probability. Introducing a relatively *soft* probabilistic approach into her research has become one of Staffilani's favorite new tools in the past few years. In particular, during fall 2015 Staffilani was the lead organizer of a large (about 90 mathematicians, counting postdocs, professors, and members) research program at the Mathematical Sciences Research Institute, in which experts from the PDE community and the probability community came together to more exactly formulate the kind of deterministic/random interaction mentioned above. The program was a great success and several papers have been submitted for publication.

Professor Staffilani recently began to explore mathematically a phenomenon that experimentally has also brought a Nobel Prize to MIT: The Bose-Einstein Condensate. In general terms, she has been studying the process to pass from a complex system of

particles interacting among each other to a macroscopic wave function that is able to describe the most important features of the system as a whole. More precisely, she is interested in effective evolution equations arising as an appropriate limit of many-body quantum dynamics. In recent months, with her student Dana Mendelson and two senior collaborators (Andrea Nahmod and Natasa Pavlovic), she has proved that one of these (infinite-dimensional) limit systems actually enjoys an infinite family of conservation laws. This is a remarkable feature that was expected, but it had been an elusive property to show. The paper is still in its manuscript stage, but once published it will be the first paper written by four women mathematicians!

Gilbert Strang

A central idea in understanding large matrices (data matrices or discrete operators for differential equations) is to approximate by a matrix of Low Rank. One of Strang's papers reviews this theory: "The Fundamental Theorem of Linear Algebra: Three Ways." That theorem produces orthogonal bases for the row and column spaces of the matrix A. Those bases are the columns of U and V in the Singular Value Decomposition $A = U S V^T$. The key for applications (in data analysis, statistics, and much more) is that the first k columns of U and V give the *best* low rank (rank k) approximation to A. The paper includes a new proof of this fundamental theorem. A second paper is in preparation with Alex Townsend. The key question is to identify large matrices that allow good low-rank approximations. For example, we analyze a 0-1 matrix with a large disk of ones surrounded by all zeros. This is the discrete form of a 0-1 function that is one inside a circle and zero outside. We find the rank of A, and the exact range of its singular values—for this and a wide class of other examples. The essential problem, not fully solved, is to identify those matrices for which the singular values decay quickly—which makes them well approximated by a matrix of low rank.

Andrew Sutherland

On May 10, 2016, an international group of researchers at MIT and other institutions launched a new online resource, the L-functions and Modular Forms Database, or LMFDB. The database is an atlas of mathematical objects that explicitly maps connections predicted by the Langlands program that are encoded as L-functions. The most well-known L-function is the Riemann zeta function, which is intimately related to the distribution of prime numbers. The Riemann hypothesis is concerned with the zeros of this L-function, 100 billion of which are cataloged in the database. In total, the database contains information on nearly 20 million L-functions, each with its own "Riemann hypothesis" that conjecturally governs the behavior of an associated mathematical object. These include L-functions of elliptic curves, which are the subject of the Birch and Swinnerton-Dyer conjecture, and many more exotic L-functions.

Tomasz S. Mrowka
Department Head
Singer Professor of Mathematics