Department of Mathematics

The Department of Mathematics seeks to maintain its top ranking in mathematics research and education in the United States. The department is a key part of MIT's educational mission at both the undergraduate and graduate levels and produces the most sought-after young researchers. Key to the department's success is recruitment of the best faculty members, postdoctoral associates, and graduate students in an ever more competitive environment. The department strives to be diverse at all levels in terms of race, gender, and ethnicity. It continues to serve the varied needs of its graduate students, undergraduate students majoring in mathematics, and the broader MIT community.

Awards and Honors

The faculty received numerous distinctions this year. Professor Victor Kac received the Leroy P. Steele Prize for Lifetime Achievement, for "groundbreaking contributions to Lie Theory and its applications to Mathematics and Mathematical Physics." Larry Guth (together with Netz Katz of the California Institute of Technology) won the Clay Mathematics Institute Research Award. Tomasz Mrowka was elected as a member of the National Academy of Sciences and William Minicozzi was elected as a fellow of the American Academy of Arts and Sciences. Alexei Borodin received the 2015 Loève Prize in Probability, given by the University of California, Berkeley, in recognition of outstanding research in mathematical probability by a young researcher. Alan Edelman received the 2015 Babbage Award, given at the IEEE International Parallel and Distributed Processing Symposium, for exceptional contributions to the field of parallel processing. Bonnie Berger was elected vice president of the International Society for Computational Biology. Bjorn Poonen received a 2015 Simons Fellowship in Mathematics. Assistant Professor Vadim Gorin was awarded the Prize of the Moscow Mathematical Society. Ankur Moitra and Jared Speck each received the National Science Foundation's Faculty Early Career Development (CAREER) Award, and Jörn Dunkel and Emmy Murphy received Sloan Research Fellowships.

Approved Faculty Promotions

Assistant Professor Clark Barwick will be promoted to associate professor without tenure.

Associate Professor Laurent Demanet will receive tenure.

Associate Professor Steven Johnson will be promoted to professor.

Internal Honors

Pavel Etingof received the Frank E. Perkins Award for excellence in graduate advising, given by the dean of graduate students.

Jonathan Kelner was selected to be the next holder of the Mark Hyman, Jr., Career Development Professorship.

Bjorn Poonen was awarded the 2014 School of Science Prize in Undergraduate Teaching.

Jared Speck was selected to be the next holder of the Cecil and Ida Green Career Development Professorship.

Jörn Dunkel and Ankur Moitra were selected by the department faculty committee to receive the Edmund F. Kelly research award.

Two of the department's junior faculty members were selected by the MIT research support committee for the following support for FY2015:

Ankur Moitra, NEC Corporation Fund for Research in Computers and Communications
Jörn Dunkel, Solomon Buchsbaum AT&T Research Fund

Distinguished Lectures

Alice Guionnet gave the Takagi Lectures of the Mathematical Society of Japan at the University of Tokyo in November 2014.

Larry Guth gave the 2015 Namboodiri Lectures in Geometry and Topology at the University of Chicago in May 2015.

Haynes Miller gave the Marvin Freedman Memorial Colloquium at Boston University in April 2015.

Bjorn Poonen gave the Earle Raymond Hedrick Lecture Series at the 2014 MathFest of the Mathematical Association of America.

Paul Seidel gave the 2015 Jankowski Memorial Lecture at the University of Gdansk, Poland.

Instructors

Alex Townsend, instructor in applied mathematics, received the 2015 Leslie Fox Prize in Numerical Analysis from by the Institute of Mathematics and its Applications at Oxford University.

Honorary Conferences

The department hosted MikeFest, a day-long symposium honoring the 60th birthday of Michael Sipser, the Barton L. Weller Professor of Mathematics, former dean of the Department of Mathematics, and current dean of science. Several leading theoretical computer scientists gave their perspectives on the past and future of computational complexity, an area shaped by Professor Sipser in his research. During the banquet that followed, a number of Professor Sipser's former students, family members, and colleagues remembered him as a teacher, mentor, researcher, leader, and friend.

New Faculty and Promotions

Semyon Dyatlov joined the pure mathematics faculty as assistant professor in January 2015. He first came to MIT as a Clay Research Fellow in December 2013, following a postdoctoral fellowship at the Mathematical Sciences Research Institute (MSRI). He

received the PhD from the University of California, Berkeley, in spring 2013. Dyatlov is an analyst who uses methods of microlocal analysis and dynamical systems to study problems in scattering theory (specifically scattering resonances), quantum chaos, and general relativity.

Vadim Gorin came to MIT as a CLE Moore Instructor in 2012 and joined the pure mathematics faculty in January 2015. In 2011, he earned the Candidate of Sciences degree at Moscow State University and received the PhD from Utrecht University. In spring 2012, he was a postdoctoral associate at MSRI. Gorin's research program sits at the intersection of asymptotic representation theory and the study of large stochastic systems, originating in random matrix theory and statistical mechanics.

Emmy Murphy was first appointed at MIT as a CLE Moore Instructor in 2012, before joining the faculty as assistant professor in fall 2014. She received the PhD from Stanford University in 2012. Murphy is a geometric topologist, studying flexibility phenomena and h-principles in symplectic and contact geometry. Her work has led to the resolution of many open questions in symplectic and contact geometry.

Philippe Rigollet joined the faculty as assistant professor in fall 2014. He received the PhD from University Paris 6 in 2006, followed by appointments at the Georgia Institute of Technology and Princeton University. Rigollet works at the intersection of statistics, machine learning, and optimization, focusing primarily on the design and analysis of statistical methods for high-dimensional problems. His recent research focuses on the statistical limitations of learning under computational restraints.

Associate Professor Jonathan Kelner received tenure.

Assistant Professor Jacob Fox received tenure.

In Memoriam

Louis N. Howard

Louis Norberg Howard, emeritus professor of mathematics at MIT and McKenzie emeritus professor at Florida State University, died on Sunday, June 28, at the age of 86. Professor Howard joined the MIT mathematics faculty in 1955 and retired in 1984. He joined the faculty at Florida State University (FSU) in 1981 as professor of mathematics and affiliate professor of mechanical engineering. In 1986, he was appointed the FSU Foundation Professor; he retired from FSU in 1996.

Professor Howard was an applied mathematician working in fluid dynamics. He made fundamental contributions to a broad range of subjects, including hydrodynamic stability and geophysical flows. He produced key advances in the understanding of turbulent convection, flows in Hele-Shaw cells, salt-finger zones, rotating flows, and reaction-diffusion equations. He also had an exceptional command of pure mathematics, as evidenced by his existence proofs concerning the hydrodynamic equations, and his elegant semicircle theorem. He generalized and simplified extensive previous work on the Richardson number criterion for shear flows.

Professor Howard was a generous collaborator and mentor who published widely with colleagues, postdoctoral associates, and students. He supervised the work of nine doctoral students at MIT, one at Princeton University, and two at FSU, and co-mentored several graduate students from other institutions. He continued his research long after retirement; his final paper is soon to appear in the Journal of Fluid Mechanics.

Professor Howard had developed a long-term association with the Woods Hole Oceanographic Institution (WHOI). He was one of the original members of the Geophysical Fluid Dynamics (GFD) Summer Program in 1959, on whose steering committee he served from the early 1960s until 1984. He was the principal lecturer at the GFD program on several occasions, giving a series of advanced courses that helped establish the foundations of geophysical fluid dynamics. He supervised the work of many GFD fellows and remained an active member of the WHOI GFD Summer School long after his retirement.

Louis Howard was born in Chicago, Illinois, on March 12, 1929. He received his BA in physics from Swarthmore College in 1950 and the MA and the PhD in mathematical physics from Princeton University in 1952 and 1953. He was appointed Higgins lecturer at Princeton in 1953, followed by a research associateship at the California Institute of Technology in 1955. He was a fellow of the American Academy of Arts and Sciences and the American Physical Society, and a member of the National Academy of Sciences. In 1997, he was honored with the prestigious Fluid Dynamics Prize of the American Physical Society.

Richard D. Schafer

Richard D. Schafer, emeritus professor and former deputy head of the Department of Mathematics, died on December 28, 2014. He was 96.

Professor Schafer joined the MIT mathematics faculty in 1959 as deputy head under Department Head William Ted Martin. The department had seen a period of rapid growth of faculty and postdoctoral programs in the 1950s, with expanding demands in teaching and graduate supervision. As deputy head, Professor Schafer was instrumental in organizing the application and review processes of the relatively new CLE Moore instructorship program and in making teaching assignments and scheduling classes with the Office of the Registrar systematic. He stepped down as deputy head when Professor Martin ended his tenure as department head in 1968, but he continued at MIT until his retirement in 1988.

Professor Schafer was an algebraist, an expert in nonassociative algebras. He did collaborative work with Claude Chevalley on Lie algebras and completed extensive work on Jordan algebras. In 1966, he published Introduction to Nonassociative Algebras (Academic Press), a book that served as a standard reference for many years.

Richard Schafer was born in Buffalo, New York, in 1918. He received both a BA and an MA from the University of Buffalo, and a PhD from the University of Chicago in 1942. Between 1942 and 1945 he served in the U.S. Naval Reserve, followed by faculty appointments at the University of Pennsylvania and the University of Connecticut, the

latter as department head from 1953 to 1959. He also served as associate secretary of the eastern region of the American Mathematical Society.

In 2013, Professor Schafer was elected to the inaugural class of fellows of the American Mathematical Society. He was married to the late Alice T. Schafer—a fellow mathematician and long-time professor at Wellesley College, and a co-founder of the Association for Women in Mathematics.

Administration

Professor Tomasz Mrowka served as interim department head until December 2, 2014, when he became department head. He continued as chair of the pure mathematics committee until June 30, 2015.

In July 2015, John Bush will follow Gigliola Staffilani as associate department head. Paul Seidel will be the next chair of the pure mathematics committee, and Peter Shor will replace Michel Goemans as chair of the applied mathematics committee. Alexei Borodin and William Minicozzi will continue as co-chairs of the graduate committee in pure mathematics; Jonathan Kelner will follow Peter Shor as chair of the committee in applied mathematics. Steven Johnson and Ju-Lee Kim will continue as co-chairs of the committee of undergraduate advisors.

Development

The Department of Mathematics had another successful year in reaching out and engaging alumni and friends of the department. The department 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, professorship chairs, the renovation of Building 2, the Research Science Institute and Summer Program in Undergraduate Research programs, and the Program for Research in Mathematics, Engineering, and Science (PRIMES). It is now looking to raise funds for MathROOTS, the newest addition to the PRIMES outreach program. The department will publish the 10th edition of its annual newsletter, Integral.

Building 2 Renovations

Excitement is building within the department about the impending move back to Building 2, scheduled for December 2015, after the building's extensive renovation. The renovations are moving ahead roughly according to schedule. The move will be just in time for MIT's centenary celebration of the Main Group in 2016. Ann Beha Architects did a wonderful job in modernizing the historic building while staying true to the spirit of the original design. This renovation project is the vanguard for the renovation of the entire original Bosworth building. In addition to the new fourth floor over the south and east wings (with a corner seminar room), there will be an expanded common room and a vast first-year graduate student office suite situated beneath the corner "ziggurat." Classroom 2-190 will boast an impressive array of the technology that is required in the

modern classroom. The support of the department's many colleagues and friends has made Building 2 a beautiful center for mathematics.

Simons Lecture Series

The 2015 Simons Lecture Series featured two world-renowned mathematicians: Leslie Greengard, professor at the Courant Institute, New York University, and Laure Saint-Raymond, professor at the Pierre and Marie Curie University and assistant director of the Mathematics and its Applications Program at the Ecole Normale Supérieure. Professor Greengard is known for co-development of the fast multipole numerical method, considered one of the top 10 algorithms of the 20th century. He is also the founding director of the Simons Center for Data Analysis, recipient of the Leroy P. Steele Prize for seminal research (given by the American Mathematical Society), and a member of the National Academies of Science and Engineering. Professor Greengard spoke on new mathematical approaches to acoustics and electromagnetics. Professor Laure Saint-Raymond is a specialist in hydrodynamics, statistical physics, and fluid mechanics. She lectured on particle systems to kinetic equations. In 2008, she received the Prize of the European Mathematical Society for her work on the hydrodynamic limit of the Boltzmann equation (related to Hilbert's sixth problem), and in 2013 she was the youngest member elected to the French Academy of Sciences' section on mathematical and computer sciences.

Diversity

Women in Mathematics

The department currently has five women who are faculty members (four of whom have tenure), eight women who are postdoctoral associates or instructors, and 20 women who are graduate students. The department sponsors a number of activities to foster a sense of community among women mathematicians. Often these activities include women mathematicians in the greater Boston area. Every fall, for example, Professor Gigliola Staffilani hosts a dinner for women graduate students, postdoctoral associates, and faculty members in the greater Boston area. The department hosts a webpage to showcase current and former women mathematicians at MIT. This has proved to be a useful recruitment tool for women graduate students. The department has been supporting the Women in Math Luncheon about once a month, in which a senior woman mathematician is invited to talk about her career and her research. The undergraduate women have a club called the Undergraduate Society for Women in Mathematics, which helps to welcome new women mathematics majors and brings in speakers to describe their mathematics work in relation to both academics and industry.

The department hosted its fourth Math Prize for Girls, a national mathematics contest for middle and high school students, on September 27, 2014. This year, 271 young women from the United States and Canada competed for cash prizes. Celine Liang, a high school junior from California, was the first-place winner. The top 42 students were invited to compete in the 2014 Math Prize for Girls Olympiad, run by the Advantage Testing Foundation. The Olympiad took place on November 13, 2014, and awarded five gold, four silver, and 14 bronze medals to participants. Next year, the department will host the Math Prize for Girls on September 20, 2015.

Ethnic Diversity

The department continues to examine efforts to attract more undergraduates who are members of underrepresented minorities (URM) to the mathematics major. Over the year, Professor Ruben Rosales was in contact with a group of URM students in a core course to discuss the major. One student has maintained contact and is very strong mathematically. Professor Rosales also consulted with Erika Camacho, associate professor at Arizona State University and a former MLK Visiting Professor of mathematics, in an effort to build a network of outside faculty who can suggest students who would benefit from MIT's Summer Research Program (MSRP). These efforts have begun to pay off. Through Professor Camacho, Professor Rosales identified at least one potential Hispanic student for MSRP in a future year. The first URM student who participated in MSRP, and was later admitted to the department's graduate program, an Hispanic woman, successfully completed her first year of study. This is a welcome affirmation that this access route or pipeline can work for mathematics, at least in applied mathematics, as it has in other departments. Through a second outside faculty contact, Professor Rosales contacted an African American student, a player for the National Football League, who was considering graduate study in mathematics. He applied to MIT and was accepted into the mathematics graduate program. Through the assistance of Dr. Barbara Peskin, the department's academic administrator, and the Office of the Dean for Graduate Education, the student will enter the program in February 2016.

MathROOTS

On June 20, 2015, the department launched its new MathROOTS program. This is a summer mathematics mentoring program for promising high school URM students, offering a 12-day residential camp, filled with math games, guest lectures, recitations, team contests, and group trips. This summer, 20 selected African American and Latino high school students from across the nation participated, studying topics such as modular arithmetic and Hamilton's quaternions. The goal was to engage enthusiastic, young mathematics students from underrepresented backgrounds in creative problem solving outside the standard curriculum, expose them to beautiful yet accessible mathematics, and immerse them in an academic and cultural community of like-minded peers and mentors.

MathROOTS is run by Professor Pavel Etingof, academic director Slava Gerovitch, head mentor Tanya Khovanova, academic coordinator Yi Sun, and program director Quinton McArthur (of MIT Admissions). It is the latest addition to the department's PRIMES outreach program for promising middle and high school students. Dean Michael Sipser suggested the idea and raised the initial funding.

PRIMES Circle

The PRIMES program, described below, saw further expansion of its new section, PRIMES Circle, which teaches a mathematical enrichment curriculum to students from the Boston area with underprivileged backgrounds. Fourteen students from urban public high schools (three African American, three Latino, and eight female students) participated in the program in 2015. They studied advanced topics in geometry,

probability, combinatorics, and knot theory. They gave presentations at a mini-conference at MIT in May 2015 and also prepared expository papers. Graduate student Isabel Vogt, the PRIMES Circle coordinator, was honored as one of MIT's Graduate Women of Excellence.

These efforts, together with the department's participation in the Cambridge Girls' Angle and the national Research Science Institute, are part of the department's efforts to build a pipeline for future mathematics majors, graduate students, and faculty.

Ongoing Initiatives: Support for MIT Student Organizations

The department continued its funding support for the Black Women's Alliance and Ebony Affair of the MIT Black Graduate Student Association. The department 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 SACNAS conference in fall 2014 with CLE Moore instructor Chelsea Walton, who gave a talk, and mentored and reviewed student exhibits. Dennis will participate in the SACNAS 2015 conference in Baltimore.

Education

Curriculum Updates

During AY2014, the Mathematics Department submitted three proposals to the Alumni Fund, all of which were accepted. This is an update on what has been accomplished with those funds.

Proposal to fund development of a module on the Laplace Transform, delivered through the MITx platform: this module was offered in January and it was very well received.

Proposal to support translation of a set of problems and applications: A few undergraduates were hired to work on the write-up of these problems. One of them created a whole line of problems featuring zip lines. These problems will be embedded as a guiding theme for the three units of the 18.01x Calculus subject that is being developed using the MITx platform (more below).

Proposal to support continuing development of the recently created subject, Topics in Mathematics with Applications to Finance: this class is now part of the department's curriculum, with the new number 18.642. It has been a very successful class that has also strengthened the department's connection with the Sloan School of Management.

This year a significant effort was conducted by the department's education committee, led by associate head Gigliola Staffilani, to restructure the department's curriculum. The main outcome of this effort has been a more consistent renumbering of several mathematics subjects to indicate the level of the class and the area of mathematics to which it belongs more clearly. Also, a number of dormant subjects have been removed,

some sporadically offered classes have been consolidated under "special topic" umbrellas, and some subjects' names have been changed.

The effort, begun in AY2013, to develop a new syllabus for the core subject 18.03 Differential Equations is now paying off. This project was originally supported in part by a d'Arbeloff grant. It has been conducted by a team consisting of Professors David Jerison, Haynes Miller, and Gilbert Strang, and Lecturers Jennifer French and Jeremy Orloff. Professor Bjorn Poonen also provided a beautiful set of notes that are in use as the backbone of the new version of 18.03 on the MITx platform. In the past two years, the version of 18.03 on MITx has been in use as the textbook for the regular 18.03 class. The students are enthusiastic about the many problems with instant feedback. With some moderate further effort (adding some videos and a few more problems), the course could soon be ready for release to the public.

This year Gilbert Strang, with the help of Jennifer French and graduate student Andrew Rzeznik, started developing problems delivered through the MITx platform for 18.06 Linear Algebra. Future plans include having Professor Alan Edelman, who frequently teaches 18.06, add a computer language he co-developed and called Julia to the platform to be used by students to solve homework problems.

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 and the Class of 1960 Fund. This class will have three modules; the first, on differentiation, is completed and is being offered this summer as a massive open online course. About 9,000 people are following the course and about 3,000 turn in homework and take exams.

Graduate Students

There were 117 graduate students in mathematics in academic year 2015, all in the PhD program. A total of 21 students received the doctoral degree and one graduated with a master's degree.

Following completion of their degrees, most of these graduates will go to postdoctoral positions in mathematics departments or institutes. This year, graduates will take up positions at Brown University, Princeton University, Stanford University, Oxford University, Cambridge University, the University of California (Berkeley, Irvine, and Los Angeles), the University of North Carolina, the University of Utah, and the University of Copenhagen, as well as at the Institute for Advanced Study and the Simons Foundation. A smaller number, but a full third of this year's group, chose non-academic positions, with almost all going into the financial industry at such companies as Teza Technologies, Tech Square Trading, Tower Research Capital, and Goldman Sachs. One graduate is working as a data scientist in the healthcare industry.

There will be 33 new first-year students entering the mathematics doctoral program in September 2015, including five women, with another student joining the department in spring 2016. The department continues the policy of offering all first-year students fellowship support; several incoming students come with support from external sources.

Awards

Michael Andrews, Daniel Harris, and Dana Mendelson received the Charles and Holly Housman Award for excellence in teaching for their exceptional skill and dedication to undergraduate teaching.

Francesco Lin and Yufei Zhao shared the Charles W. and Jennifer C. Johnson Prize for outstanding research papers accepted in a major journal.

Isabel Vogt received the Graduate Woman of Excellence Award for leadership, research, and mentoring, given biennially by the MIT Office of the Dean for Graduate Education.

Majors

During AY2015, a total of 392 students listed mathematics as their major, which means that it remains the largest undergraduate program in the School of Science and the third largest in the Institute. This is the official "fall fifth week" figure, which increased to more than 430 undergraduates by the spring term. Of these, 142 students graduated with degrees in mathematics—96 with a first major in mathematics and 46 with a second major in mathematics. Responses to the senior survey were only partial (approximately 43% responded), but of those who did respond, 18% will continue in PhD programs in mathematics, with another 15% pursuing PhDs in other fields (e.g., computer science, physics, economics), and 21% will enter master's programs (in mechanical engineering or management, or the Tripos Part III in mathematics at Cambridge University). Many graduates are pursuing non-academic opportunities, with 13% going into software engineering and 11% into the financial sector or consulting services. Other students plan to travel or take some time off before pursuing other options.

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 Ka Yu Tam.

Senior Sheela Devadas was awarded the Alice T. Schafer Prize, given by the Association for Women in Mathematics, for excellence in mathematics by an undergraduate woman.

Other noteworthy awards included a Churchill Scholarship for senior Daniel Kang, the Hertz Fellowship for seniors Jordan Cotler, Cole Graham, and Alexander Siegenfeld, and a Barry Goldwater Scholarship for junior Felipe Hernandez.

Putnam Triumphs:

For the second consecutive year, the 2014 MIT team placed first in the William Lowell Putnam Mathematical Competition, with an unprecedented five of six top individual scorers, named Putnam Fellows (the usual top five was extended to six because of a tie). This year's Putnam team consisted of sophomore David Yang, junior Mitchell Lee, and senior Zipei Nie; the Putnam Fellows were senior Zipei Nie, sophomores Bobby Shen, David Yang, and Lingfu Zhang, and freshman Mark Sellke. In addition, MIT students accounted for 16 of the top 27 individual scorers, and for a total of 32 out of the 89 who

received Honorable Mention or above (36% of all such recipients). Students benefited from excellent coaching by Professor Bjorn Poonen.

Undergraduate and High School Summer Research Programs

In summer 2014, the department hosted its 18th 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. Twelve MIT undergraduates participated, supervised by six graduate students. The program culminated in oral presentations and final research papers. A jury of faculty members selected winners for the Hartley Rogers Jr. Family Prize, awarded jointly to a student–mentor team. The 2014 Rogers Prize was awarded to sophomore Saarik Kalia and his mentor Ben Yang.

Summer 2014 was the 22nd year of the Mathematics Department's participation in the Research Science Institute program (RSI) for gifted high school students. Eleven students carried out mathematics projects, supervised by seven graduate students. The program concluded with oral presentations and final research papers. Five RSI students reached the final stage at national and international science competitions (11 awards total). Peter Tian, whose mentor was Jesse Geneson, won the First Prize at Siemens 2014; Noah Golowich, whose mentor was David Rolnick, was awarded the First Place Medal for Basic Research, Shashwat Kishore, whose mentor was Gus Lonergan, received the Third Place Medal, and Yelena Mandelshtam, whose mentor was by Miriam Farber, became a finalist at Intel STS 2015. Petar Gaydarov, whose mentor was Sam Hopkins, won the Second Prize at the Intel International Science Fair 2015.

Program for Research in Mathematics, Engineering, and Science

In calendar year 2015, the department is participating in the fifth year of the Program for Research in Mathematics, Engineering, and Science (PRIMES). This spring, 21 gifted high school students from Greater Boston are working on research projects or participating in reading groups in the mathematical section of PRIMES, with 13 graduate students and postdoctoral associates as mentors. Additionally, in the expanded PRIMES-USA mathematics section, 15 exceptional out-of-state students, selected from across the nation, are doing research projects, supervised by 13 graduate students and postdoctorates via telecommunication channels.

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

On May 16–17, PRIMES held its fifth annual conference at MIT, where all research projects were successfully presented. The well-attended event demonstrated the spectacular 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 2015 and will likely continue their research under the Undergraduate Research Opportunities Program.

In fall 2014, PRIMES and PRIMES-USA students successfully completed 17 individual and group math research projects, on which they had worked during calendar year 2014. Ten students were invited to present at the Mathematical Association of America Undergraduate Student Poster Session of the 2015 Joint Mathematics Meeting in San Antonio, Texas, and two received an Outstanding Presentation award. Several students received awards for their projects in the 2015 Intel Science Talent Search (three national finalist and nine national semifinalist awards), and in the 2014 Siemens Competition in Math, Science and Technology, two regional finalist and nine semifinalist awards).

Brice Huang, whose mentor was Wuttisak Trongsiriwat, was awarded the Second Place Medal for Basic Research at the 2015 Intel Science Talent Search; Joseph Zurier, whose mentor was Ben Yang, was a National Finalist Individual Winner at the Siemens Competition in 2014; and Jessica Li, whose mentor was Laura Schaposnik, won the Third Place at the 2015 National Junior Science & Humanities Symposium. Research Sciences Institute students Peter Tian, Noah Golowich, and Shashwat Kishore, who won top prizes at the Intel Science Talent Search and the Siemens Competition, also participated in the PRIMES program.

Professor George Lusztig donated a significant portion of his 2014 Shaw Prize in Mathematical Sciences to establish the George Lusztig PRIMES mentorships. These are to be awarded each year to continuing PRIMES mathematics mentors for exceptional mentoring service in past years. The first selected Lusztig PRIMES mentors in 2015 were graduate students Jesse Geneson, Darij Grinberg, and Yufei Zhao.

Research Highlights

Below is a sampling of highlights of the research recently done by the department's faculty, divided into some of the major areas of study across pure and applied mathematics.

Symmetry vs. randomness in the distribution of prime numbers: These studies address deep questions in representation theory, number theory, and algebraic geometry, covering a good cross section of the pure mathematics faculty. They include many well-known, unsolved questions, such as the Riemann hypothesis, the twin prime conjecture, and those of the Langlands program.

Roman Bezrukavnikov does research at the interface between algebraic geometry and representation theory. With I. Mirkovic, he recently completed a long-term project devoted to the proof of the so-called Lusztig's Hope, considered a central conjecture in modular representation theory. In another program following up on Professor George Lusztig's more recent work, Bezrukavnikov (with D. Kazhdan and others) worked on algebro-geometric aspects of Langland's colorfully named theory of endoscopy. The goal here is to come to a comprehensive algebro-geometric theory to generalize on Lusztig's theory of character sheaves and encompass a celebrated result in algebraic geometry of Fields medalist Ngô Bảo Châu.

Pavel Etingof works on quantum groups and noncommutative algebra. His program has focused on the use of the representation theory of affine Lie algebras to develop

a representation theory of Cherednik algebras and symplectic reflection algebras, proposing a number of relevant conjectures. Some of these conjectures were recently proved by Gordon-Losev and Shan-Vasserot, and later the main conjecture was generalized and proved in the fundamental work of Bezrukavnikov and Losev. He has also recently written a paper with Gorsky and Losev on the relationship between Cherednik algebras and knot invariants, a paper with CLE Moore Instructor Chelsea Walton on Hopf algebras action on rings, and a paper on the Deligne categories.

The statistical features that appear in random structures: Random processes often lead to surprising and beautiful structures—for example, attempting to model the growth of crystals mathematically, as molecules randomly attach to an existing crystal.

Vadim Gorin works in probability and representation theory. He developed (with Greta Panova) a new method for studying the asymptotics of symmetric polynomials as the number of variables tends to infinity. This has already found numerous important applications; for instance, it was used to prove random matrix asymptotics for random lozenge tilings, and the six-vertex (the so-called square-ice) model of statistical mechanics. It was also used in the study of tensor products of irreducible representations, leading to a quantization of the free convolution notion from the free probability theory.

Scott Sheffield studies probability and mathematical physics. He recently completed a 211-page research paper, "Liouville Quantum Gravity as a Mating of Trees," jointly with MIT postdoctoral associate Jason Miller and physicist Bertrand Duplantier of the Institute of Theoretical Physics in Paris. Among other developments, this paper completes the solution of one version of the problem of showing that discrete random planar maps converge to Liouville quantum gravity in the scaling limit. It establishes surprising connections between several different familiar and canonical random objects: canonical random trees, canonical random surfaces, and canonical random paths. These are significant milestones for the theory.

It is also part of a general program for proving the equivalence of the foremost two continuum random surface models: Liouville quantum gravity and the Brownian map. Sheffield and Miller hope to complete this program in a series of papers this calendar year, building on about 1,000 pages of work that they had already completed on this subject during the past five years.

The modeling of large systems such as weather and climate: Alan Edelman is a specialist in parallel computing, numerical linear algebra, and random matrices. He is a co-developer of Julia, a high-level, high-performance dynamic programming language for technical computing on parallel platforms. Julia's features include distributed parallel execution and an extensive mathematical function library. It has spawned its own developer community, which has contributed a number of external packages. Julia's impact is changing the way people compute and is widely used in classes at MIT. Edelman also works on advances of random matrix theory and reports on recent developments that show the continuum of random matrix theories are breaking down the former classical division of algebras (real, complex, and quaternion).

What makes certain problems computationally difficult to solve while others are computationally easy? This includes work on attempting to understand why algorithms with randomness appear to be effective, or whether quantum mechanics can be used to make faster computers.

Peter Shor and his collaborators (mostly MIT graduate students) have been looking at quantum money. Quantum money is a quantum cryptographic protocol that consists of creating a quantum state that is verifiable but not duplicable. That is, there is some verification procedure (a quantum algorithm) that, when a valid quantum money state is input, will output a "yes." However, an adversary who knows the verification procedure and has access to one valid quantum money state cannot create a second state that passes the verification procedure. Shor came up with a quantum money protocol several years ago. He is now writing a paper that shows that if an oracle version of this protocol can be broken, then one could solve a graph isomorphism with a quantum computer.

Geometries and large-scale features of mathematical models of space-time: Jared Speck recently completed a 441-page monograph that provides a detailed description of the formation of shock wave singularities in solutions to a large class of nonlinear wave equations of mathematical, physical, and geometric interest (the monograph is being considered for publication in the AMS Mathematical Surveys and Monographs series). He proved that the set of initial conditions that lead to singularity formation is open and contains small perturbations of the 0 solution. In particular, without making any symmetry assumptions, he proved that the shock-formation processes are stable. The main results apply whenever the nonlinear terms fail to satisfy Sergiu Klainerman's null condition. Consequently, the monograph provides a sharp converse to a well-known result of Klainerman, which shows that no singularities can form when the null condition is satisfied and the initial conditions are small.

The monograph significantly unifies, extends, and simplifies the proofs of the handful of previously known shock-formation results in three spatial dimensions, which were developed by Demetrios Christodoulou, Serge Alinhac, and Fritz John. In particular, it provides a new class of wave equations whose singularity-forming solutions can be completely understood in the small initial condition regime. There are very few such results known in three spatial dimensions.

Understanding the mathematics of quantum mechanics and high energy physics: Richard Melrose has recently concentrated on problems related to index theory and K-theory, asymptotic behavior of solutions to wave equations, scattering and inverse scattering theory, smooth group actions, and the geometry of moduli spaces and loop spaces. Melrose, with his former graduate student Chris Kottke, has characterized generalized blow-down maps, an important step in the structure theory of manifolds with corners, and recovered the homology of a manifold in terms of a new topology on its loop space. With his student Xuwen Zhu, he has answered the long-standing question of the asymptotic behavior of the Weil-Petersson metric on Riemann moduli spaces.

Combinatorics of mathematical structures: Alexander Postnikov works on several topics in algebraic combinatorics, such as the combinatorics of the positive Grassmannian,

generalized permutohedra and associahedra, and power ideals. He is interested in applications of combinatorics to other areas of mathematics and physics, including the study of scattering amplitudes and cluster algebras. In the recent paper, "Arrangements of Equal Minors in the Positive Grassmannian" (written jointly with Miriam Farber), accepted to Advances in Mathematics, Postnikov investigates the structure of equalities between matrix minors and links the equalities to alcoved polytopes and cluster algebras. Postnikov collaborated with a group of physicists and a mathematician (Nima Arkani-Hamed, Jacob Bourjaily, Freddy Cachazo, Alexander Goncharov, and Jaroslav Trnka). They wrote the book Grassmanian Geometry of Scattering Amplitudes, to be published by Cambridge University Press, which establishes a direct connection between scattering amplitudes in four-dimensional Super Yang Mills theory and the positive Grassmannian.

Understanding mathematical models of biological processes Over the past five years, Jörn Dunkel has contributed mathematical modeling to studies in active biological fluids and soft matter theory. Specifically, he and his co-authors reported on the first direct measurement of a bacterial flow field and identified the first quantitative mathematical model of self-sustained bacterial turbulence in two dimensions and three dimensions. These papers have already become widely cited standard references in the field of biological fluid dynamics, as they provide the foundation for a quantitative understanding of individual and collective bacterial motion. In collaboration with experimental biophysicist Vasily Kantsler, Dunkel performed the first large-scale quantitative analysis demonstrating the importance of direct contact interactions for the surface-scattering of eukaryotic swimming cells, and the relevance of rheotaxis (flow-gradient sensing) for long-distance navigation of mammalian sperm cells. In collaboration with Associate Professor Pedro Reis's lab and with Norbert Stoop, instructor in applied mathematics, Dunkel's most recent work developed and confirmed a new mathematical theory to predict the symmetry-breaking transitions in wrinkling patterns on curved elastic bilayer surfaces.

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