

## Department of Mathematics

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

### Faculty

The department had another successful year in faculty hires for AY2014, with three junior faculty hires.

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

Ankur Moitra will also join the applied mathematics faculty as an assistant professor in the area of theoretical computer science. He received his PhD in computer science at MIT under Frank Thomson Leighton and has held a joint postdoctoral appointment at Princeton University and the Institute for Advanced Study. His research concentrates on algorithmic design relevant to several areas, including statistical inference, optimization, and learning theory.

Charles Smart is an analyst who will join the pure mathematics group as an assistant professor. He received his PhD from the University of California, Berkeley, and came to MIT as a CLE Moore Instructor in 2011. His research concentrates primarily on nonlinear partial differential equations arising in probabilistic settings, often as a scaling limit of a discrete stochastic process or game.

Assistant professor Lie Wang (statistics) was promoted to associate professor. Assistant professor Aaron Naber (algebraic geometry) will join the faculty at Northwestern University.

### Chia-Chiao Lin

Institute professor emeritus Chia-Chiao Lin, member of the mathematics faculty for 40 years, died in Beijing at the age of 96. Professor Lin's broad and seminal research, together with his service to the community, were instrumental in the growth of applied mathematics at MIT, in the United States, and in the People's Republic of China.

Lin's initial research concentrated on hydrodynamics stability and turbulence. With Theodore von Kármán he proposed a spectral theory for homogeneous turbulence, which significantly impacted the field. He later contributed to studies in the hydrodynamics of superfluid helium and astrophysics, advancing the density-wave theory of galaxy formation with Frank Shu.

Born in Beijing and educated at Tsinghua University, Lin received his PhD in aeronautics from the California Institute of Technology before joining the MIT faculty in 1947. He served as the department's first faculty chair of the applied mathematics group from 1961–1966 and was president of the Society for Industrial and Applied Mathematics from 1973–1974. He was appointed Institute Professor in 1966 and awarded the James R. Killian Jr. Faculty Achievement Award in 1981. He retired from MIT in 1987. He later returned to China as distinguished professor at Tsinghua University in 2002, serving as honorary director of the newly established Zhou Pei-Yuan Center for Applied Mathematics.

Lin received numerous distinctions, including the Timoshenko Medal of the American Society of Mechanical Engineering, the Award in Applied Mathematics and Numerical Analysis from the National Academy of Sciences, and the first Fluid Dynamic Prize of the American Physical Society. He was a fellow of the American Academy of Arts and Sciences, academician of Academia Sinica, member of the National Academy of Sciences, and foreign member of the Chinese Academy of Sciences. He received honorary doctorates from the Chinese University of Hong Kong, Tsinghua University, and Taiwan's National Tsing Hua University.

### **Administration**

Michael Sipser will continue as department head. Gigliola Staffilani will follow Haynes Miller as associate department head and as the undergraduate officer. Professor Staffilani will step down as graduate co-chair. Tomasz Mrowka will continue as chair of the pure mathematics committee and Michel Goemans as chair of the applied mathematics committee. Paul Seidel will continue as graduate co-chair in pure mathematics in the fall term, followed by Alexei Borodin in the spring term. William Minicozzi will also co-chair the graduate committee in pure mathematics beginning in the fall term. Peter Shor will continue to chair the committee in applied mathematics graduate admissions. Steven Johnson and Ju-Lee Kim will continue to co-chair the committee of undergraduate advisors and Ruben Rosales will continue as chair of the diversity committee. Professor Miller will follow Mark Behrens as the microteaching workshop leader and Lawrence Guth will replace Victor Guillemin as the transfer credit examiner.

### **Faculty Honors and Awards**

Michael Artin received the Wolf Prize in Mathematics for his fundamental contributions to algebraic geometry.

Clark Barwick was selected for the Cecil and Ida Green career development professorship.

Bonnie Berger received the Alumni Achievement Award from Brandeis University. She also joined the board of directors of the International Society for Computational Biology.

Laurent Demanet was selected for the Class of 1954 career development professorship. He also received a National Science Foundation CAREER grant.

Jacob Fox and Sug Woo Shin each received a Sloan Foundation research fellowship.

Professor Goemans was elected a fellow of the Society for Industrial and Applied Mathematics “for contributions to combinatorial optimization, and in particular to the design and analysis of approximation algorithms.” He also received the 2012 Farkas Prize of the Institute for Operations Research and the Management Sciences Optimization Society.

Professor Guth gave the Marston Morse Lectures at the Institute for Advanced Study; his talk was titled “The Codimension Barrier in Incidence Geometry.”

David Jerison, with collaborator Jack Lee, received the 2012 Stefan Bergman Prize of the American Mathematical Society (AMS) “for their pioneering works on the CR Yamabe problem, which led to finding canonical metrics in a given conformal class, for strictly pseudo-convex manifolds.”

Victor Kac gave the Hadmard Lecture Series at the Institut des Hautes Études Scientifiques, a series of eight lectures titled Algebraic Structures Arising in Physics and Application. Professor Kac and David Vogan were elected members of the National Academy of Sciences.

Jonathan Kelner received the 2012 School of Science Teaching Prize for Undergraduate Education.

Professor Staffilani was elected to the Massachusetts Academy of Sciences.

Gilbert Strang received a Doctor Honoris Causa from Aalborg University in Denmark.

Chelsea Walton, CLE Moore Instructor, received the School of Science Infinite Kilometer Award.

The American Mathematics Society selected 29 faculty and faculty emeriti (E) as AMS Fellows. They include Michael Artin (E), Herman Chernoff (E), Richard Dudley, Pavel Etingof, Michel Goemans, Victor Guillemin, Sigurdur Helgason, Louis Howard (E), David Jerison, Victor Kac, Steven Kleiman, Bertram Kostant (E), Tom Leighton, George Lusztig, Arthur Mattuck (E), Haynes Miller, William Minicozzi, Bjorn Poonen, Ruben Rosales, Richard Schafer (E), Paul Seidel, Isadore Singer (E), Gigliola Staffilani, Richard Stanley, Gilbert Strang, Harold Stark (E), Daniel Stroock (E), David Vogan, and Katrin Wehrheim.

Two junior faculty members were selected by the MIT Research Support Committee for support in AY2014: Abhinav Kumar, NEC Corporation Fund for Research in Computers and Communications; and Professor Wang, Solomon Buchsbaum AT&T Research Fund.

## Resource Development

The Department of Mathematics had another successful year in reaching out and engaging alumni and friends of the department. We hosted department events and faculty talks for alumni, parents, and friends, as well as stewardship events for donors. During the year, Professor Sipser gave a talk for alumni and friends in London.

The department has been successful in its fundraising efforts for student fellowships, professorship chairs, and the renovation of Building 2. Next year will see the eighth edition of the department's annual newsletter, *Integral*.

## Building 2 Renovations

The department worked closely with Ann Beha Architects and MIT Facilities over the year to design program space for Building 2. This scheme leveraged the department's location along the Charles River with added common spaces, meeting rooms, offices, and updates to Building 2 classrooms. Construction is expected to begin in fall 2013. In the meantime, the Department of Mathematics has temporarily relocated to the third and fourth floors of Buildings E17/E18.

## Simons Lecture Series

The 2013 Simons Lecture Series featured two world-renowned mathematicians: Emmanuel Candés, the Barnum-Simons Chair in Mathematics and Statistics at Stanford University, and Raphaël Rouquier, professor of pure mathematics at the University of California, Los Angeles. Professor Candés is known for his work on image processing, multiscale analysis, and more recently on compressed sensing. He is a recipient of the Alan T. Waterman Award and the George Pólya Prize (with Terence Tao). He spoke on topics in a series titled Unreasonable Effectiveness of Convex Programming. Professor Rouquier has done fundamental work on representation theory. He received the Whitehead Prize and Adams Prize of the University of Cambridge while serving as the Waynflete Professor at Oxford University. His series was titled Higher Representation Theory.

## Department Retreat

Department of Mathematics graduate students organized the department's first annual retreat, held on September 28–30, 2012. Over 160 faculty, instructors, staff, and graduate students spent a fall weekend at the Purity Spring Resort in New Hampshire. Families were invited. The purpose of the event was to build community and morale among department members, especially considering the major changes concerning the move to temporary space in summer 2013. All participants considered the event a major success. A second retreat has been planned for the weekend of October 5, 2013.

## Women in Mathematics

The department continues its support of the Undergraduate Society of Women in Mathematics, which became increasingly active this year. In October, the group hosted the "Math in Industries" forum, inviting company representatives from Oracle, Akamai Technologies, and D.E. Shaw & Co., among others, to talk about the mathematical

opportunities in industry. The society arranged two “Math Mixer” events, one in September for freshmen, and one in November for mathematics majors. During Independent Activities Period (IAP), the society joined for the second time with Girls’ Angle to organize SUMiT, a day-long event for sixth- to tenth-grade girls to solve a series of puzzles and problems for a set of prizes. This year, 32 girls participated, coming from as far away as Virginia and California, since SUMiT has become widely known as a collaborative rather than competitive extracurricular event for girls.

For the third consecutive year, the department expects to host its annual Advantage Testing Foundation Math Prize for Girls in September 2013. This is a national mathematics contest for middle school and high school girls. In this year’s contest, 263 young women from the US and Canada competed for cash prizes. Victoria Xia was the first-place winner for the second time. The top 44 students from the competition were invited to the 2012 Math Prize for Girls Olympiad in November 2012.

In the overall department profile for AY2013, women made up 10% of the faculty and 20% of instructors and lecturers.

## **Diversity Efforts**

### **Dr. Martin Luther King, Jr. Visiting Professors and Scholars Program**

Next year, the Department of Mathematics will host two Hispanic American faculty members from Arizona State University, assistant professor Erika Camacho and associate professor Stephen Wirkus, who plan to assist department members connect with minority-serving institutions and key outside faculty active on diversity issues. Within MIT, professors Camacho and Wirkus hope to expand the network of support to attract and sustain underrepresented minorities (URMs) and female students to the mathematics major, and identify potential candidates for the PhD and postdoctoral programs. Professors Camacho and Wirkus are nationally recognized for their teaching and mentoring, particularly of those in the minority communities pursuing higher education. Among many outreach organizations, they are very active in the Society for Advancement of Chicanos and Native Americans in Science (SACNAS).

Both professors are applied mathematicians working on the modeling of biological phenomena. Professor Johnson will host Erika Camacho, who has arranged to collaborate with professor Christopher Burge and Professor Berger. Professor Strang will host Stephen Wirkus, as they share an interest in writing textbooks (Professor Wirkus is completing a second edition of *A Course in Ordinary Differential Equation*).

Faculty benefitted from the appointment of Terrence Blackman as the Martin Luther King, Jr. visiting assistant professor this year. Professor Blackman was very engaging and informative of the challenges facing the African American community when considering higher education in mathematics. During his year with the department, he was impressed with what he described as the “‘missionary zeal’ around mathematics that pervades the MIT culture.” He accepted a faculty appointment in curriculum studies and teaching at the Morgridge College of Education at the University of Denver, where his responsibilities will include developing course content to prepare prospective

K–12 teachers to meet the standards of the Common Core State Standards of Colorado, and assisting in the development of a doctoral program in mathematics education, emphasizing both research and instruction.

### Recruitment

The Department of Mathematics has had only modest success in recruiting qualified URM students to its graduate program. Last year, one Hispanic female student matriculated into the program. This year, two URM students (Native American and Hispanic) will join the department's graduate student body. The incoming Hispanic student was an MIT mathematics major, and the department hopes to continue to build a pipeline of potential URM candidates from the majors program. This will bring the graduate student URM enrollment to four, out of 117 students, or 3.4%.

Next year the department will continue the appointment of two African American postdoctoral instructors, 6.5% of the total group. For AY2014, the department had not received qualified applicants for faculty openings, but with our focus on developing a pool of young scholars, this should eventually change. Currently there are no URM faculty members.

### Other Diversity Efforts

*MIT Summer Research Program.* In summer 2012, Professors Demanet, Kelner, and Shor, and three of the department's graduate students supervised and mentored three outside underrepresented minority undergraduates in the MIT Summer Research Program (MSRP). Two of the three students will be enrolled in mathematics graduate programs in the fall, one at the University of Maryland and one at the University of Minnesota. The mathematics faculty will supervise two MSRP students in summer 2013.

*Mentoring Partnerships.* The IAP Directed Reading Program, in which an undergraduate is mentored by a graduate student in the reading of a mathematics text during IAP, attracted only one URM student this year, but did include four female undergraduate students out of a total of 11 students. The Reading Outreach for Undergraduate Talent Exploration is a yearlong program with a similar mentoring arrangement both for text study and a research project. This year, four undergraduate students participated, two URMs and two women. Two students graduated. One student (URM) will continue at MIT on a research project, co-mentored by Professor Behrens. The other graduate (female) is interested in pursuing a PhD in computer science. As described in last year's report, the selection criteria are weighted to favor students with the greatest mathematics improvement, and to promote and accelerate the trajectories of URM and women mathematics majors (though the program is not restricted to these populations).

*Program for Research in Mathematics, Engineering, and Science—PRIMES Circle.* The Program for Research in Mathematics, Engineering, and Science (PRIMES), described below, added a new section, PRIMES Circle, which teaches mathematical enrichment curriculum to students with underprivileged backgrounds from the Boston area. Chelsea Walton is the PRIMES Circle coordinator. She proactively recruited eight promising students (four African Americans and four young women) into the program. They are studying advanced mathematics under the guidance of mentors from MIT and Harvard

University, and are making excellent progress. Dr. Walton closely monitors the day-to-day operations of PRIMES Circle, ensuring that the instruction is top quality and that the students are motivated and enjoy the program.

Dr. Walton is one of the department's African American instructors. Her recruitment success demonstrates the value of having minority scholars reach out to the community. In the short time that she has been at MIT, she has built a network of contacts with Boston-area educators, which allowed her to arrange visits to some 20 classrooms and meet with hundreds of high school students at urban schools. For her outstanding contributions to MIT and outreach to the wider community, Dr. Walton received the Infinite Kilometer Award this year.

*National Conferences.* The department has continued to encourage faculty and staff to attend diversity-related events. Staff member Dennis Porche attended the SACNAS conference in fall 2012 and will do so again in October 2013. He will be joined by Professor Camacho.

## Education

### Curriculum Renovation

In June 2012, the Mathematics Department was awarded a \$231,292 grant from the Davis Educational Foundation to redevelop Course 18.05 Probability and Statistics, under the leadership of associate department head Professor Miller and lecturer Jeremy Orloff. This grant made possible the creation of an entirely new syllabus and pedagogical model for this subject. It used one of the Technology-enhanced Active Learning classrooms, and followed a "flipped classroom" approach, using MITx (MIT's online learning initiative) to deliver text and check homework solutions. Work will continue this year on the development of courseware for this subject.

Supported in part by a d'Arbello Fund for Excellence in Education grant, a team consisting of Professors Jerison, Miller, and Strang, and Instructor Orloff has been rewriting the syllabus for the central subject 18.03 Differential Equations. The new version will mesh better with current engineering offerings. Most of the resources of the MITx mathematics fellow Jennifer French (PhD '10) are currently being devoted to this project.

### Graduate Students

There were 108 graduate students in Mathematics in AY2013, all of them in the PhD program. During AY2013, a total of 22 students received their doctoral degree.

Following completion of their degrees, most of the graduates went on to postdoctoral positions in mathematics departments or institutes, including both national universities (the University of California, Berkeley; Harvard School of Public Health; Princeton University; Stanford University; and the University of Virginia), and international institutions (the University of Bonn, the University of Copenhagen, Eidgenössische Technische Hochschule Zürich, the University of Göttingen, the University of Münster, the University of Paris, the University of Tokyo's Kavli Institute, and Technion Israel

Institute of Technology). A small but increasing number chose non-academic positions, with one graduate joining the edX effort, another taking a position in the financial industry, and several working in research and development positions with organizations such as Oracle, Raytheon, and Yelp.

There will be 27 first-year students entering the department's doctoral program in AY2014, including four women. The department continues the policy of offering all first-year students fellowship support; as usual, several incoming students come with support from external sources. The department will also have two transfer students joining the doctoral program in the fall.

### **Graduate Student Awards**

Ailsa Keating, John Lesieutre, and Nan Li received the Charles and Holly Housman Award for Excellence in Teaching, for their exceptional skill and dedication to undergraduate teaching.

Yin Tat Lee and Eric Marberg shared the Charles W. and Jennifer C. Johnson Prize for outstanding research papers accepted in a major journal.

### **Majors**

During 2012–2013, a total of 336 students listed mathematics as their major, keeping mathematics as the largest undergraduate program in the School of Science and the third largest at the Institute. This is the official “fall fifth week” figure, but over the course of the year the number grew to over 400 undergraduates by spring term. Of these, 87 students graduated with a first degree in mathematics, and 44 finished with a second degree in the department. While responses to the department's senior survey were incomplete, at least 13 seniors will continue in graduate school in mathematics, 16 in computer science, and seven in other disciplines. Other graduates will begin work in a wide array of related areas, with software engineering and the financial sector being popular choices.

### **Undergraduate Awards**

The MIT team placed second in the William Lowell Putnam Mathematical Competition. The department's team consisted of sophomore Benjamin Gunby, junior Brian Hamrick, and senior Jonathan Schneider. Overall, MIT students once again dominated the competition. Three MIT participants ranked in the top five test-takers, the so-called “Putnam Fellows”: sophomores Benjamin Gunby and Zipei Nie, and freshman Mitchell Lee. In addition, nine MIT students ranked in the next 20, and a record 34 out of 84 received honorable mention or above (thus, a full 40% of all recipients). The MIT students benefited from excellent coaching by professors Richard Stanley, Abhinav Kumar, and Henry Cohn.

The Jon A. Bucsela Prize in Mathematics, given in recognition of distinguished scholastic achievement, professional promise, and enthusiasm for mathematics, was awarded to senior Holden Lee. He also received a Gates Cambridge Scholarship to study at the University of Cambridge.



Senior Yangzhou Hu was an honorable mention awardee of the Alice T. Schafer Prize, given by the Associate for Women in Mathematics for excellence in mathematics by an undergraduate woman.

Senior Noam Angrist, a double mathematics and economics major, was selected to receive a Fulbright research grant, to study educational reform in Botswana.

Alumna Fan Wei '12 received the 2013 AMS–Mathematical Association of America–Society for Industrial and Applied Mathematics Frank and Brennie Morgan Prize for outstanding research in mathematics by an undergraduate student. Senior Jonathan Schneider was an honorable mention awardee.

### **Undergraduate and High School Summer Research Programs**

In summer 2012 the department hosted its 16th 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 eight graduate students. The program culminates in oral presentations and final research papers, posted online. A jury of faculty members selects winners for the Hartley Rogers Jr. Family Prize, which is awarded jointly to a student-mentor team. The 2012 Rogers Prize was awarded to sophomore Amol Aggarwal and graduate student Guozhen Wang.

Summer 2012 was the 20th year of the department's participation in the Research Science Institute program (RSI) for gifted high school students. Twelve students carried out mathematics projects in RSI, supervised by eight graduate students. The program concluded with oral presentations and final research papers, posted online. Several RSI students achieved success with their projects in the 2013 Intel Science Talent Search and the 2012 Siemens Competition in Math, Science, and Technology (Siemens 2012). Ten students reached the semifinal stage (top 300) in one or both competitions, and four were finalists (top 40). Katherine Cordwell, mentored by Teng Fei, won first prize at the Intel International Science and Engineering Fair, receiving a \$3,000 scholarship; Simanta Gautam, mentored by Dmitry Vaintrob, won second prize and a \$1,500 scholarship.

### **The Program for Research in Mathematics, Engineering, and Science**

In the PRIMES Program during spring 2012, 16 gifted high school students from the Greater Boston area were mentored on individual and group projects, resulting in 13 research papers: eight of the students were invited to present at the Undergraduate Student Poster Session of the 2013 Joint Mathematics Meeting. Several students received awards for their projects in the 2013 Intel Science Talent Search (two finalists and five semifinalists) and in Siemens 2012 (eight regional finalists and one semifinalist). Two students, Rohil Prasad and Jonathan Tidor, supervised by mentor Jesse Geneson, won fifth prize (\$20,000 scholarship) at Siemens.

In 2013, the department will participate in the third year of PRIMES. The program has significantly expanded. This year, 19 gifted high school students from the Greater Boston area are working on research projects or participating in reading groups in the mathematical section of PRIMES, mentored by 12 graduate students and postdoctorates.

Additionally, under the pilot PRIMES-USA program, five out-of-state students are doing research projects, supervised by five graduate students via telecommunication channels.

PRIMES held its third annual conference at MIT in May, during which student research projects were 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 2013 and will likely continue their research under the Undergraduate Research Opportunities Program.

## Faculty Research

Bonnie Berger's recent advances in automated data collection are producing large data sets and her program works at the interface of algorithms and biology in such diverse areas as protein folding, network inference, genomics, and disease classification. One major recent advance was her group's introduction of "compressive genomics," a general algorithmic paradigm that harnesses redundancy within data sets to speed up analyses, compressing data in such a way as to allow direct computation. Previous approaches used compression alone, which requires decompression before computational analysis. The relative advantage of compressive genomics over existing algorithms is anticipated to grow with the accumulation of genomic data. Professor Berger's group implemented proof-of-concept compressive versions of both the indispensable Basic Local Alignment Search Tool (BLAST) and the BLAST-like Alignment Tool. These algorithms scale linearly with the amount of non-redundant data and perform as accurately as the original methods. A resulting paper was featured as In This Issue of *Nature Biotechnology*, and listed as the top most-downloaded article in its first month of release.

Roman Bezrukavnikov's research lies at the borderline of algebraic geometry and representation theory. One completed long-term project, joint with Ivan Mirkovic, was devoted to the proof of the so-called "Lusztig's Hope," which is considered a central conjecture in modular representation theory. Bezrukavnikov and Mirkovic also produced a proof based on Bezrukavnikov's earlier work in geometric Langlands duality. In other directions, joint with Professor Etingof, Andrei Okounkov, et al., Bezrukavnikov has sought to apply ideas of representation theory to quantum cohomology and other objects of today's algebraic geometry. He also collaborated with David Kazhdan and others on algebra-geometric aspects of endoscopy. The goal of this project is to get a comprehensive algebra-geometric theory, generalizing on Lusztig's theory of character sheaves, and encompassing, among other things, the celebrated result of B.-C. Ngo.

John Bush's research program is concerned with fluid dynamics and is currently focused on hydrodynamic quantum analogs. Yves Couder demonstrated that droplets bouncing on a vibrating fluid bath can exhibit dynamical features previously thought to be peculiar to the microscopic quantum realm, including single-particle diffraction, tunneling, and quantized orbits. Professor Bush's group recently examined walkers in a confined circular geometry and found that, as in quantum mechanics, the statistics of the walking drops may be readily deduced from a linear wave equation. Whatever the

case may be in quantum mechanics, in the droplet system, it is clear that the coherent statistical behavior of the bouncing drops is underlain by a complex nonlinear dynamics. Professor Bush and his group have made tremendous progress in the mathematical modeling of the bouncing droplets; their work now allows them to rationalize all reported bouncing and walking behaviors.

The bouncing-droplet system represents a macroscopic realization of the pilot-wave dynamics proposed by Louis de Broglie in 1926 as a model of microscopic quantum particles. Professor Bush's group has derived a trajectory equation that makes clear that, in their system, quantization emerges naturally from the pilot-wave dynamics, and wave-like statistics from chaotic pilot-wave dynamics. The goal of their research is to understand the potential and limitations of this hydrodynamic system as a quantum analog. In so doing, it will raise the possibility that quantum statistics is underlain by a chaotic pilot-wave mechanics, thereby challenging and informing the foundations of modern physics.

Laurent Demanet's research program covers a broad subset of computational mathematics related to wave-based imaging and inversion. His group's research either directly addresses imaging, such as seismic and radar, or studies fundamental algorithmic questions that have a bearing on imaging. This includes fast algorithms for oscillatory problems, convex recovery principles, and methods of nonsmooth optimization. Recently completed projects over the last five years include:

- Design of a variety of novel  $O(N \log N)$  algorithms for oscillatory integrals and high-frequency wave computation, with applications to synthetic aperture radar imaging
- Introduction of "matrix probing," a method of fitting matrices from random projections with provable recovery guarantees, with applications to seismic imaging and computational wave propagation
- "Super-resolution" in sparse imaging—new algorithms and theoretical guarantees extend the Shannon sampling theorem to sparse coherent recovery with band-limited information
- Phase retrieval from quadratic measurements proof that the first recovery result for a semidefinite relaxation formulation does not involve a trace regularization

Alan Edelman works on both random matrix theory and numerical methods. In random matrix theory, he works on the theoretical side and on developing applications for scientists. His interactions with chemists led to applications of free probability to interacting systems. His group also applied ideas from free probability to a physics application named Isotropic Entanglement. On the applied numerical methods side, Professor Edelman and his colleagues introduced the Julia programming language in 2009 and continue with its upgrade. Julia is a high-level, high-performance dynamic language for technical computing, offering productivity, performance, and programming abilities for numerical methods previously considered unobtainable.

Jonathan Kelner's research seeks to apply techniques from pure mathematics to the solution of problems in algorithms and complexity theory. He has applied this approach to a range of topics in computer science and mathematics. Below are some recent examples.

Fast graph algorithms: With collaborators and students, Professor Kelner introduced a new approach to obtaining fast algorithms for graph problems, based on applying techniques from computational linear algebra and numerical scientific computing. Previous approaches to most of these problems were largely discrete/combinatorial; Professor Kelner, et al., have worked to augment these with a new collection of continuous algebraic primitives for algorithmic graph theory. Using these, they have obtained better algorithms for a wide range of the basic problems in the field, many of which had not seen asymptotic improvements in several decades.

Computational linear algebra/numerical scientific computing: Professor Kelner and his group obtained a new approach to Laplacian linear systems, which are among the most important systems in numerical scientific computing, form a key component of many of the graph algorithms described above, and are pervasive in machine learning, operations research, computing vision, and network analysis. Using this approach, they can solve these systems in nearly linear time while using very little of the machinery that previously appeared necessary for such an algorithm, replacing complicated algebraic techniques with simple graph decompositions and data structures. The result is much simpler than existing nearly linear algorithms and is the fastest known algorithm in the standard unit-cost RAM model.

Approximation algorithms for NP-hard problems: Professor Kelner, et al., provided a connection between proof complexity in a certain restricted proof system, approximation algorithms, and the mathematical properties of quantum entanglement. Using this, they gave efficient approximation algorithms for problems where this was not previously thought to be possible and provided a new approach to resolving one of the main open questions in the complexity theory, the Unique Games Conjecture.

Jared Speck is an analyst of nonlinear partial differential equations arising in mathematical physics. His research is connected to problems in general relativity, relativistic fluid mechanics, relativistic kinetic theory, and nonlinear electrodynamics. With Igor Rodnianski, Professor Speck and his group recently proved that some of the well-known Friedmann-Lemaitre-Robertson-Walker Big Bang spacetimes appearing in the standard model of cosmology are nonlinearly stable solutions to Einstein's equations. Einstein's equations are the fundamental equations of general relativity. While the group's previous work had addressed the global behavior of related solutions in the expanding direction (that is, towards the future), its recent work addresses the behavior of solutions in the collapsing direction. Specifically, their work reveals the stable character of the Big Bang singularity itself when certain kinds of matter are present, and is based on a newly discovered form of approximate monotonicity that holds for a class of solutions to the Einstein equation.

Lie Wang's program broadly focuses on functional data and high dimensional inference, in three distinct areas: nonparametric function estimation, high-dimensional sparse regression and high-dimensional covariance matrix, and precision matrix estimation. Recent results are listed below.

- Proposal of a new procedure for estimating high-dimensional Gaussian graphical models called Tuning-insensitive Graph Estimation and Regression. This procedure is significantly faster than existing methods due to its tuning-insensitive property. It simultaneously obtains minimax optimal for precision matrix estimation under different norms.
- Introduction of a new approach for estimating high-dimensional positive-definite covariance matrices. Professor Wang's estimated covariance matrix simultaneously achieves sparsity and positive definiteness. The estimator is rate optimal in the minimax sense, and he developed an efficient iterative softthresholding and projection algorithm.
- Development of an algorithm for the application of the parametric simplex algorithm for solving large-scale compressed sensing problems. Professor Wang's algorithm is significantly faster than existing ones and it illustrates a tradeoff between computational complexity and informational complexity.
- Proposal of a new method named calibrated multivariate regression (CMR) for fitting high-dimensional multivariate regression models. Compared to existing methods, CMR calibrates the regularization for each regression task with respect to its noise level so that it is simultaneously tuning-insensitive and achieves an improved finite sample performance. An efficient smoothed proximal gradient algorithm is developed. Professor Wang also applied CMR on a brain activity prediction problem and found that CMR outperforms the handcrafted models created by human experts.

**Michael Sipser**  
**Department Head**  
**Professor of Applied Mathematics**