It has been almost six months since I assumed the directorship of the IMA, and this has been a time of rapid change. We are charting new course, and with it, new sources of funding. At the same time, we are continuing to apply the basic principles that have served the IMA so well over its 35-year history. I’m delighted to report that these efforts are succeeding, thanks in large part to the seeds sown by our prior director, Fadil Santosa. But before we look ahead, I want to step back and review a successful and exciting 2016-2017 academic year at the IMA.

Mathematics and Optics

Since its founding in 1982, the IMA structured its programming around a central research theme each year that brought together leaders in the field. The 2016-2017 year was the last such annual thematic program, focusing on Mathematics and Optics and organized by Gang Bao, Shanhui Fan, Graeme Milton, Shari Moskow and Michael Weinstein. It brought together a diverse group of experimentalists, engineers, mathematicians, and physicists interested in emerging technologies arising in optical science, including plasmonics, metamaterials, and advanced optical imaging. The close connection between theoretical scientists and experimentalists created an exciting collaborative atmosphere throughout the year.

We selected six postdoctoral fellows to participate in the annual program. In addition, several long-term visitors spent a semester or the entire year at the IMA, organizing seminars, holding working groups, and running tutorials. Many of the long-term visitors toured the optics labs in the University of Minnesota Department of Electrical and Computer Engineering. The timeliness of the theme was evident from the buzz of activity in Lind Hall, featuring vibrant discussions that carried over to coffee breaks.

This past summer, we ran our second Math-to-Industry Boot Camp which again generated a large number of applications for the 32 spots. This six-week program for Ph.D. students in mathematics provides the technical and interpersonal skills that students need in order to transition into industry, along with experience working in teams on industry-sponsored projects. Our third boot camp will run again this June.

We also held a number of hot topics workshops, including Transdisciplinary Foundations of Data Science in September 2016, which focused on the mathematical underpinnings in this growing field, and Mathematical Modeling of 2D Materials in May 2017.

A more responsive IMA

After the NSF’s decision to ramp down funding of the IMA, we decided to change format to a broader scope of yearly programming that could address the rapidly evolving landscape of applied mathematics and to more directly address the needs of our academic and industrial partners. After a call for proposals to the community, a group of five major activities were formed, and many of these programs will run through the spring and summer of 2018. While only half complete, they’ve already provided valuable insights into effective collaboration models. The major programs are listed on the back cover of this issue.

New initiatives at the IMA

For 2017-18, we are beginning a multiyear collaboration in data science sponsored by Target Corporation and Cargill, Inc. The grants fund six industrial postdocs, who will spend half of their time working on projects directed by industrial scientists and the other half at the IMA under faculty mentorship working on their research program. Augmenting this program are semester-long focus periods that include workshops, long-term visitors, and training programs. Our first thematic program begins this spring 2018 and will focus on Spatial-Temporal Data Science. Plans for the fall 2018 semester are currently underway and will be announced in the near future.

The IMA has had a long history of ties to industry, and we are excited by this novel and diversified funding model for the IMA. These interactions also bring us closer to the mathematical challenges that are bubbling up in the private sector.

In addition to the consortium, we are building further connections with the U.S. Department of Energy, exploring mathematical foundations of problems originating in the national labs. Finally, our Participating Organization program remains vital to the IMA, providing numerous opportunities for support and engagement at the IMA, and we continue to explore new ways to deliver more value to our partners.

On behalf of the mathematical sciences community, I would like to express deep gratitude to Fadil for his vision and positive energy over the last decade. In particular, his cultivation of connections to industry has laid the groundwork for future new directions. He will continue to impact activities as the director of special projects.

Finally, having served as deputy director of the IMA for two years and now as director, it has been striking how many colleagues have expressed their strong affection for the IMA, especially in its ability to nurture the formative stages of many careers. This sense of collective ownership of the IMA remains a powerful force in the community and will help to ensure that the IMA continues as a center of excellence in the mathematical sciences. We look forward to a bright future.
Mathematics and Optics

Optics and photonics are technologies that impact society in a multitude of areas, including information and communications, imaging and sensing, healthcare, energy, manufacturing, and national security.

Building upon impressive progress in fundamental optical science and in nanotechnology in recent years, optics and photonics have become drivers of technological innovation and economic growth.

The growing importance of the field is highlighted in the recent National Research Council report on Optics and Photonics: Essential Technologies for Our Nation, and the 2015 International Year of Light focused on raising global awareness of light-based technologies. Additionally, 2016 marked the 100th anniversary of the Optical Society.

The field of optics and photonics encompasses the fundamental science of light and its applications, and the long history of the field's interactions with mathematics covers topics ranging from ray optics to the classic theory of the electromagnetic spectrum to the quantum nature of light.

The IMA thematic program addressed a wide range of questions that have developed from the study of optical phenomena and connected mathematicians with the interdisciplinary community of scientists working in the field. Workshops participants ranged from pure and applied mathematicians to physicists and computer scientists. Workshop themes introduced participants to related applications, tools, and new techniques.

“The presence of many experts in the physics of optics and electromagnetics gave me an outstanding opportunity to gain an insight into the physical aspect of themes related to my research. This will allow me to pay an increasing attention to the physical properties of the models I analyze in my research,” said a Mathematical and Numerical Modeling in Optics workshop participant.

The IMA thematic program also served to highlight the importance of topological insulators, a subject that was recognized by the 2016 Nobel Prize in Physics, with talks on the topic arising at many of the workshops.

“Not only did this introduce many mathematicians to the subject, but also the workshop on Novel Optical Materials served to forge links between people working on topological insulators in mechanics and those working on it in optics,” said organizer Graeme Milton (University of Utah). “That workshop also helped forge links between people working on materials and inverse problems with ‘time-interfaces,’ or the material properties switch at given times, and people working in the somewhat closely mathematically-related area of ‘hyperbolic materials’ that received attention due to their capacity for subwavelength resolution.”

Mathematics and Optics was the 35th, and final, annual thematic program held by the IMA, with more than 25 long-term visitors and 10 postdoctoral fellows in residence. As one of the first two math institutes in the country, the IMA is pleased to have set such high standards for how to run programs and workshops of this scope.

More information, including videos of the lectures, is available online at www.ima.umn.edu/2016-2017.
A Home Connection

Originally from Minnesota, long-term visitor Aaron Welters (Florida Institute of Technology) came back home for the mathematics and optics program having long been aware of the IMA as a high-quality mathematical research institute.

Welters remembers his first visit to the IMA quite clearly as a 16-year-old coming to participate in the University of Minnesota Twin Family Study.

“I stood outside the offices of the IMA quite amazed to be standing so close to mathematicians of such high caliber who were hard at work changing the world with theorems,” he said.

Now a mathematician himself, Welters was excited to be in residence at the IMA with experts in his areas of research, namely the mathematical aspects of optics, such as photonics and metamaterials.

“To be able to participate and contribute to such a fine program at the IMA was professionally and personally something I couldn’t pass up,” he added.

Welters dedicated much of his time and effort during his fall semester visit to working with colleagues Graeme Milton (University of Utah) and Maxence Cassier (University of Utah) and with IMA postdoc Robert Viator.

“With collaborators Graeme and Maxence, we continued our study of the Dirichlet-to-Neumann (DtN) map for certain boundary-value problems for linear PDEs, such as Maxwell’s equations in bounded media and stratified media, using the important connection that had been made recently with effective tensors in the theory of composites, for instance. We were especially interested in the applications of this connection to developing bounds and limitations on the DtN map in cloaking and inverse problems.”

“With Robert, we began a study on the dissipative properties of electromagnetic fields in stratified magnetic-dielectric media. Our objective was to develop a deeper understanding of the interplay between magnetism and dissipation in two-component composite systems in which one of the components is highly lossy. One of the specific examples of the model we considered was that of stratified photonic crystals with lossy ferromagnetic layers and lossless dielectric layers. The main motivation for our studies was to understand the mechanisms that allow for simultaneous magnetic Faraday rotation enhancement and absorption suppression when the ferromagnetic layer is highly lossy.”

In addition to research, Welters organized the first half of the annual program seminar series with Peter Monk (University of Delaware) and enjoyed all the social opportunities that come with a long-term visit to the IMA, such as tea time and group outings.

One particular highlight that Welters noted was bringing his 6-year-old son to see the IMA.

“He pretend to do research in my office, followed by pretending to be a student and then a teacher in a classroom, where he lectured to me about mathematics at the University of Minnesota,” he said.

Then recalling his first visit to the IMA, Welters thought about the passage of time.

“Coming back 20 years later to participate in this mathematics and optics program, I now had an office within the offices of the IMA, and I was hard at work trying to change the world with theorems,” he said.

Annual Program Brings Back Former Postdoc

Former IMA industrial postdoc Junshan Lin (Auburn University) came back for a year-long stay when his research interests in wave propagation and optics fit perfectly with the annual program.

Having been an IMA industrial postdoctoral fellow from 2011 to 2013, Lin already knew he would enjoy the atmosphere of the IMA, where visitors and postdocs are free to exchange ideas and explore new research directions.

He especially liked that IMA workshops are interdisciplinary in nature and include participants across disciplines like mathematicians, physicists, and engineers. Lin also felt the exchange of ideas and new developments among the different disciplines injected new vitality to the field.

“For instance, physicists and engineers brought new mathematical problems and insights in several emerging topics in optics, such as the plasmonics and topological insulators, whereas mathematicians provided novel mathematical analysis and computational modeling tools, which have the potential to solve the problems posed by physicists and engineers in the workshops,” Lin explained.

During the second half of the program year, Lin, along with Eric Bonneitier (Université Grenoble-Alpes) organized the annual program seminar series. The subjects of the seminars ranged from inverse and design problems in optics to numerical methods for electromagnetism, and other emerging topics in optics.

“There is also a wonderful tutorial series on surface plasmonics in graphene given by Tony Low (University of Minnesota, Twin Cities),” Lin added. “The talks always generated lively discussions; a group of us usually joined up for lunch together for further discussion after each seminar. The talks also facilitated collaborations among several visitors.”
Developing a New Research Direction

Former IMA industrial postdoc Nilima Nigam (Simon Fraser University) found the annual program workshops to be a near-perfect fit for her increasing interest in the mathematics of optics.

“I have been interested in the analysis and discretization of acoustic and electromagnetic scattering problems for several years,” she said. “More recently, my research interests have increasingly included eigenvalue problems, and I wanted to learn more about novel application areas where these arose.”

Nigam knew about advances in optical materials and engineering, but was not sure about the mathematical and computational research questions. She decided to take her sabbatical at the IMA when it became clear that she would not find another venue with such concentrated expertise.

“Nor (would I find) a forum for more casual mathematical interaction, which is my preferred way to develop collaborations,” Nigam added.

Nigam’s long-term visit during the spring semester proved fruitful in terms of collecting new ideas for projects and starting collaborations, which she anticipates will keep her busy for the next few years. Two projects have her particularly excited. One is a collaboration with Jiguang Sun (Michigan Technological University) about eigenvalue problems.

“I met Jiguang Sun, who was visiting the IMA at the same time, and heard him give a wonderful talk about a fast method for locating eigenvalues for unusual problems,” Nigam said. “We chatted at the IMA coffee break, and his work motivated me to revisit a very old eigenvalue problem in elasticity. I’d thought about this problem off and on for almost twenty years, but never had the time to work out the details.”

Nigam and Sun made rapid progress, with access to the University of Minnesota libraries and computing services, and now have a couple manuscripts in preparation.

The other project that excites her stems from her interest in learning about optimization problems arising in spectral geometry.

“One of the world’s experts in the area, Braxton Osting (University of Utah), was another long-term visitor,” Nigam said. “We had many fruitful conversations, and he suggested many interesting open problems. I anticipate these will form an important component of my research program over the next few years.”

When asked about highlights of her visit, Nigam noted the remarkable collection of people and activities that provide a unique forum for mathematical exploration and growth.

“The scientific vibrancy at the IMA is incredible and intellectually inspiring,” she said. “Where else could I have attended public lectures, workshops, postdoctoral seminars, learned for hours from experts in a new field, started several new collaborations, and found a quiet office to hammer out details in?”

“I’ve met people whose work I know and so many whose work I learned about for the first time,” Nigam continued. “I’ve come away with so many new mathematical ideas. Without exaggeration, this visit to the IMA has changed my professional life—again!”

Lin had his own share of collaborations during his stay:

• With Hai Zhang (Hong Kong University of Science and Technology), he worked on mathematical studies of extraordinary field enhancement in nanostructures. “We started by looking at two-dimensional nano-slits structures and were able to present quantitative analysis of electromagnetic field enhancement for the single nano slit and an array of nano slits. The study is a first step toward the understanding of the enormous enhancement that occurs in a rich collection of nanostructures, which we plan to explore next.”

• With David Nicholls (University of Illinois at Chicago) and Xiaobing Feng (University of Tennessee), he worked on fast numerical methods for wave propagation in random media. “We proposed an efficient Monte Carlo–Transformed Field Expansion (MC–TFE) method for the simulation of electromagnetic wave scattering by random rough surfaces.”

Additionally, Lin collaborated with former IMA director Fadil Santosa (University of Minnesota, Twin Cities) on scattering resonances in photonic crystals. The development of photonic structures with high quality factors, or low energy leakage, has significant applications in physics and engineering, such as manufacture of photonic chips, quantum information processing, and electron-photon interactions. Lin and Santosa’s collaboration actually began several years ago when they aimed to analyze, and eventually predict or design, the energy leakage of such structures.

“In the beginning, we investigated a photonic structure that consists of a defect sandwiched between two finite periodic layers,” Lin said. “It is known that waves ‘trapped’ within the defect will eventually leak out of the structure. We studied the scattering resonances for the photonic structure and obtained an estimate which says that the energy leakage rate is exponentially small in the number of layers in the periodic sections.”

“It was a fortuitous chance that we continued to chat on this project when I was back at the IMA as a long-term visitor and started working on scattering resonances for the high-dimensional photonic structures with defects.” Lin added.
How Quantum Physics Democratized Music: A Meditation on Physics and Technology

In May, Sir Michael Berry, a professor emeritus of physics at the University of Bristol, discussed how the connections between physics, technological invention, and aspects of human life that seem far removed from science are both unexpected and unexpectedly common.

Rather than flowing one way—from physics to gadgets—the connections form an intricate web, linking all aspects of human culture.

Berry’s first example of the connections between physics and technology related back to the title of his lecture—music. He contended that the arrival of the compact disc (CD) player should not be perceived as a discrete invention, but one that stretched back to 1917 and Albert Einstein’s ideas about quantum physics and the processes by which atoms absorb and emit light. It was the concept of stimulated emission that led to the invention of the laser, a component critical for the CD player.

“It was unimaginable in 1917 by Einstein that in 1958—40 years later—his quantum physics ideas would lead to the creation of this pure, bright light,” Berry said. “And it was unimaginable in 1958 by the physicists who invented the laser that in 1982, engineers would use it to reproduce music.”

While acknowledging that the CD player needed the connections between physics, engineering, mathematics, business, finance, advertising, and music itself to be successful, Berry stated that the device is still simply a quantum physics machine. And since the CD player made music digital, portable, and convenient, “it’s not an exaggeration to say that quantum physics has democratized music,” he said.

According to Berry, Leon Lederman, winner of a Nobel Prize for Physics in 1988, has claimed that at least a third of the gross national product of industrialized countries is the result of the direct application of quantum mechanics. Without understanding quantum theory, there would not have been, among other things, microelectronics, biotechnology, or diagnostic radiography, as new technologies often don’t appear until long after the physics was first formulated.

But physicists don’t always aim to make their work applicable; they instead strive to explain and theorize about things observed in the world. For example, understanding why gold is the color that it is means understanding the interaction of light with the electrons in the crystal structure of the material—and using mathematics to predict the interaction. It turns out the long, detailed calculation requires quantum relativity.

“Isn’t it remarkable that to understand this color that has so fascinated and beguiled human beings for thousands of years requires understanding the interaction of light with the electrons in the crystal structure of the material—and using mathematics to predict the interaction. It turns out the long, detailed calculation requires quantum relativity.”

Berry talked about examples where new technology leads to new physics, such as with quantum revivals, or the periodic recurrence of the quantum wave function. The equations look complicated, but with the help of computers, the mathematics can be brought to life as an image, such as the one that accompanies this article which shows the first one-twentieth of a revival time.

To complete the web of connections, Berry talked about examples where new technology leads to new physics, such as with quantum revivals, or the periodic recurrence of the quantum wave function. The equations look complicated, but with the help of computers, the mathematics can be brought to life as an image, such as the one that accompanies this article which shows the first one-twentieth of a revival time.

Public Lectures, continued next page
Jianfeng Lu Awarded the 2017 IMA Prize in Mathematics and its Applications

In September 2017, the IMA Prize in Mathematics and its Applications was awarded to Jianfeng Lu, an associate professor in the Department of Mathematics at Duke University, with secondary appointments in the departments of chemistry and physics.

Lu received this recognition for his contributions in applied analysis, computational mathematics, and applied probability, in particular for problems from physics, chemistry, and material sciences. The strength of his research is combining advanced mathematical analysis and algorithmic tools with a deep understanding of problems from science and engineering.

“More specifically, I am interested in understanding essential mathematical tools and ideas behind the approximation and numerical methods developed to deal with complex chemical and materials systems modeled at physical levels ranging from quantum mechanics to atomistic models to continuum mechanics,” Lu explained.

Research on the frontiers of mathematics in other fields has been quite fruitful for him. Some of Lu’s major research achievements include groundbreaking contributions to electronic structure models, multiscale methods, rare events, and quantum molecular dynamics. His most recent contribution on the mathematical understanding of surface hopping algorithms has generated enormous excitement in the quantum chemistry community.

“I have always been curious about the latest scientific breakthroughs in other science and engineering disciplines,” Lu said. “Most of my research is driven by curiosity in trying to understand the models and numerical tools that physicists, chemists, and materials scientists have developed and trying to develop a mathematical understanding that helps improve the existing approaches.”

Lu credits his Ph.D. advisor, Weinan E (Princeton University) for teaching him to always look for challenges outside the existing boundaries of applied mathematics and to never be afraid of learning and working in unfamiliar territories.

“My research and career paths have also been majorly influenced by other mentors and collaborators, including Ingrid Daubechies (Duke University), Shi Jin (University of Wisconsin-Madison), Robert Kohn (New York University), Jonathan Mattingly (Duke University), Felix Otto (Max Planck Institute for Mathematics in the Sciences), Eric Vanden-Eijnden (New York University), Michael Weinstein (Columbia University), and Lexing Ying (Stanford University),” Lu added. “They taught me various aspects of applied and computational mathematics.”

Collaborations with his Duke colleagues outside the math department, including Thomas Barthel (physics), Volker Blum (materials science), David Dunson (statistics), Jungsang Kim (electrical engineering), Henry Pfister (electrical engineering), and Weitao Yang (chemistry), bring him new challenges and opportunities to research.

“It has been my long-term goal to help build stronger and tighter connections between applied mathematics with theoretical chemistry and materials science,” Lu noted. “Oftentimes this leads to fascinating challenges from the mathematical point of view and calls for new development on the math side.”

Since receiving his Ph.D. eight years ago, Lu's list of about 100 peer-reviewed publications demonstrates his broad expertise in terms of models, computational tools, and rigorous techniques. Lu is currently focusing on numerical algorithms for high dimensional problems (either classical or quantum) arising from these areas by drawing and further developing tools from other areas of applied mathematics.

“I hope this research direction will lead to fruitful interactions and cross-fertilization between various disciplines,” he said.

The IMA Prize in Mathematics and its Applications is awarded annually to a mathematical scientist who is within 10 years of having received his or her Ph.D. degree. The award recognizes an individual who has made a transformative impact on the mathematical sciences and their applications. The prize can recognize either a single notable achievement or acknowledge a body of work. The prize consists of a certificate and a cash award of $3,000. Funding for the IMA Prize in Mathematics and its Applications is made possible by generous donations of friends of the IMA.

“Jianfeng Lu Awarded the 2017 IMA Prize in Mathematics and its Applications”

Lu’s list of about 100 peer-reviewed publications demonstrates his broad expertise in terms of models, computational tools, and rigorous techniques. Lu is currently focusing on numerical algorithms for high dimensional problems (either classical or quantum) arising from these areas by drawing and further developing tools from other areas of applied mathematics.

“I hope this research direction will lead to fruitful interactions and cross-fertilization between various disciplines,” he said.

The IMA Prize in Mathematics and its Applications is awarded annually to a mathematical scientist who is within 10 years of having received his or her Ph.D. degree. The award recognizes an individual who has made a transformative impact on the mathematical sciences and their applications. The prize can recognize either a single notable achievement or acknowledge a body of work. The prize consists of a certificate and a cash award of $3,000. Funding for the IMA Prize in Mathematics and its Applications is made possible by generous donations of friends of the IMA.

Jianfeng Lu

Lu’s list of about 100 peer-reviewed publications demonstrates his broad expertise in terms of models, computational tools, and rigorous techniques. Lu is currently focusing on numerical algorithms for high dimensional problems (either classical or quantum) arising from these areas by drawing and further developing tools from other areas of applied mathematics.

“I hope this research direction will lead to fruitful interactions and cross-fertilization between various disciplines,” he said.

The IMA Prize in Mathematics and its Applications is awarded annually to a mathematical scientist who is within 10 years of having received his or her Ph.D. degree. The award recognizes an individual who has made a transformative impact on the mathematical sciences and their applications. The prize can recognize either a single notable achievement or acknowledge a body of work. The prize consists of a certificate and a cash award of $3,000. Funding for the IMA Prize in Mathematics and its Applications is made possible by generous donations of friends of the IMA.

“Jianfeng Lu Awarded the 2017 IMA Prize in Mathematics and its Applications”

Lu’s list of about 100 peer-reviewed publications demonstrates his broad expertise in terms of models, computational tools, and rigorous techniques. Lu is currently focusing on numerical algorithms for high dimensional problems (either classical or quantum) arising from these areas by drawing and further developing tools from other areas of applied mathematics.

“I hope this research direction will lead to fruitful interactions and cross-fertilization between various disciplines,” he said.

The IMA Prize in Mathematics and its Applications is awarded annually to a mathematical scientist who is within 10 years of having received his or her Ph.D. degree. The award recognizes an individual who has made a transformative impact on the mathematical sciences and their applications. The prize can recognize either a single notable achievement or acknowledge a body of work. The prize consists of a certificate and a cash award of $3,000. Funding for the IMA Prize in Mathematics and its Applications is made possible by generous donations of friends of the IMA.

“Jianfeng Lu Awarded the 2017 IMA Prize in Mathematics and its Applications”

Lu’s list of about 100 peer-reviewed publications demonstrates his broad expertise in terms of models, computational tools, and rigorous techniques. Lu is currently focusing on numerical algorithms for high dimensional problems (either classical or quantum) arising from these areas by drawing and further developing tools from other areas of applied mathematics.

“I hope this research direction will lead to fruitful interactions and cross-fertilization between various disciplines,” he said.

The IMA Prize in Mathematics and its Applications is awarded annually to a mathematical scientist who is within 10 years of having received his or her Ph.D. degree. The award recognizes an individual who has made a transformative impact on the mathematical sciences and their applications. The prize can recognize either a single notable achievement or acknowledge a body of work. The prize consists of a certificate and a cash award of $3,000. Funding for the IMA Prize in Mathematics and its Applications is made possible by generous donations of friends of the IMA.

“Jianfeng Lu Awarded the 2017 IMA Prize in Mathematics and its Applications”

Lu’s list of about 100 peer-reviewed publications demonstrates his broad expertise in terms of models, computational tools, and rigorous techniques. Lu is currently focusing on numerical algorithms for high dimensional problems (either classical or quantum) arising from these areas by drawing and further developing tools from other areas of applied mathematics.

“I hope this research direction will lead to fruitful interactions and cross-fertilization between various disciplines,” he said.

The IMA Prize in Mathematics and its Applications is awarded annually to a mathematical scientist who is within 10 years of having received his or her Ph.D. degree. The award recognizes an individual who has made a transformative impact on the mathematical sciences and their applications. The prize can recognize either a single notable achievement or acknowledge a body of work. The prize consists of a certificate and a cash award of $3,000. Funding for the IMA Prize in Mathematics and its Applications is made possible by generous donations of friends of the IMA.
Exploring Cutting-Edge Research Areas

IMA hot topics workshops continue to investigate emerging mathematical and scientific questions while gathering those with diverse backgrounds to strengthen interdisciplinary connections.

Transdisciplinary Foundations of Data Science

As diverse and high-volume data sets have become more easily generated and stored in many scientific and business applications, interest in research pertaining to data science has risen in both academia and industry.

However, according to workshop organizer Gilad Lerman (University of Minnesota, Twin Cities), the foundations of data science as a field are far from developed, and it is difficult for practitioners to develop reliable models from data and for the public to trust the models derived from big data.

“More specific challenges include universality versus domain expertise, casual inference, limits of predictability, non-stationarity of practical settings, guaranteeing successful heuristics such as deep learning, and building data science as its own domain,” Lerman said.

The hot topics workshop in September brought together researchers from academia and industry in three core areas of expertise: mathematics, statistics, and computer science. The talks surveyed discipline-specific perspectives, results, and knowledge gaps as part of a larger exploration into how these perspectives could be integrated and moved into a transdisciplinary, holistic approach to data science and its foundations.

Foundational considerations included scientific methods (such as reproducibility of results), mathematical (such as performance guarantees, probabilistic estimates, and generalization bounds), statistical (such as causal inference, uncertainty quantification, and post modal selection inference), and computing (such as computational complexity of problems, scalable algorithms, and resource trade-offs). Lerman noted that one such outcome was the agreement that reproducibility and generalizability of results are important to demand.

“There was an inspiring discussion and talk by Daniel Goroff (Alfred P. Sloan Foundation) on the possible use of differential privacy as a way to improve reproducibility,” Lerman added.

The workshop also had several group discussions, which covered the challenges and open problems facing researchers, curriculum development in data sciences, and effective interaction between industry and academia. A particularly important discussion revolved around building effective data science centers, as many of the participants have been involved in helping build a center or program at their home universities. One workshop participant noted that “I finally found a way to start learning about data science and thinking about a research program.”

Lerman, who is also director of the IMA Data Science Lab, said “the University of Minnesota data science activities and curriculum development were strongly affected by the discussions and talks.”

Smart Urban Transportation Forum

The rapid increase in urban populations, the surge of online retailing sales, and the rising concerns of climate change all call for a more safe, efficient, and clean urban transportation system. In May, the IMA hosted a one-day forum for experts to offer
their perspectives on the design, planning, and operation of the next generation urban transportation system.

According to organizers Qie He (University of Minnesota, Twin Cities) and Anton Klegweyt (Georgia Institute of Technology), the increasing popularity of ride-sharing and ride-hailing companies already significantly affects the way people commute, and the arrival of self-driving cars, communicating cars, non-gasoline powered cars, such as electric cars, and connected vehicles is expected to change the landscape of urban transportation systems dramatically over the next 10 years.

“Associated changes in infrastructure are needed to facilitate these new types of vehicles,” Klegweyt explained. “This creates a chicken-and-egg dilemma—the car designers would like to know what the infrastructure of the future will be like, but the infrastructure designers need to know how the cars of the future will work.”

The recent advent of new technologies in computer vision, telecommunication, and auto industries and new transportation business models also provide enormous opportunities.

“One long-standing challenge is the traffic congestion caused by the mismatch between growing travel demand and existing infrastructure capacities,” He said. “Some recent developments to address this challenge include intelligent traffic signals making use of massive data from roadside and vehicular sensors, as well as a multi-modal transit system including bike and car sharing.”

The forum brought together a diverse group of speakers, panelists, and participants from industry, national labs, government agencies, and academia to promote communication and collaboration on interdisciplinary research related to urban transportation. A wide variety of disciplines were also represented, including computer science, operations research, civil engineering, industrial and systems engineering, mechanical engineering, mathematics, and public policy.

Participants were able to learn about emerging issues, new research, and the types of technologies being developed in the transportation field.

“The panel discussion at the end (of the day) demonstrated the potential for rich discussion between practitioners and researchers,” said a forum participant.

Mathematical Modeling of 2D Materials

The hot topics workshop held in May was the first to focus on the mathematical modeling and computing aspects of 2D materials, which are a class of nanomaterials that are only one or two atoms thick and behave as two-dimensional structures. Despite being so miniscule, these materials possess the remarkable properties of being exceptionally strong, lightweight, flexible, and excellent conductors of heat and electricity.

There has been an extraordinary level of research activity on the electronic, optical, and mechanical properties of 2D materials in the materials science community. Interest in the mathematics community has recently emerged with the goal of developing rigorous foundations and efficient and accurate computational methods. The major challenge addressed by this workshop was the modeling and computation of the mechanical and electronic properties of 2D materials.

“One of the main themes explored from the perspective of physics, materials science, and mathematics was the mechanical relaxation of 2D heterostructures into Moire patterns of commensuration and incommensuration, and models for the effect of this relaxation on electronic properties,” said workshop organizer Mitchell Luskin (University of Minnesota, Twin Cities).

Other new challenges have arisen over the years to address the inhomogeneity of real 2D materials, which have ripples, defects, boundaries, and incommensurability. These aspects lead to challenges in parametrizing tight-binding coefficients for physical graphene and in the modeling and computation of electronic properties,” Luskin added. “Thus, modeling the electronic properties of 2D materials depends on accurate modeling of their mechanical properties.

The explosion of scientific and technological interest in 2D materials was sparked by the 2004 isolation of freestanding graphene sheets. However, workshop organizer and speaker Efthimios Kaxiras (Harvard University) noted that “graphene, despite its exciting and unique properties, has its limitations, mostly due to the absence of a band gap which is a necessary feature in most optical and electronic applications.”

However, only one decade after the discovery of graphene, a host of other 2D materials with semiconducting or insulating behavior have since been discovered.

“Even more exciting and promising is the possibility of interleaving these materials to create stable structures with any combination of desired electronic, optical, magnetic, and thermal properties with atomic-scale features,” Luskin said.

Workshops related to this topic will be held in winter/spring 2018 under the “Multiscale Mathematics and Computing in Science and Engineering” program. See www.ima.umn.edu/2017-2018.3 for more details.
Learning Data Science at the IMA

To help meet the burgeoning needs of industry in data analytics, and to create career pathways for young mathematical scientists, the IMA held a Data Science Fellowship this past winter to prepare Ph.D. students near graduation and recent postdoctoral mathematicians to become successful data science professionals.

The seven-week program trained participants in the basic techniques and tools in data science and provided the opportunity to work in teams on real-world industrial projects proposed by partner companies.

The six selected fellows arrived with varied backgrounds—from low-dimensional topology and partial differential equations to scientific computing to combinatorics, probability, and numerical analysis—and while many of them had computing experience, there was limited exposure to data science. The fellowship served as a way to bridge the gap in knowledge between graduate school and working in industry while providing a demonstrable skill set in data science for employers.

“I’m looking to start a career in data science, but I come from a background in theoretical math with only occasional experience working with real-world data,” said Gavin King, a fifth-year graduate student at the University of Wyoming.

“During my graduate training, my interest in data science and machine learning grew ‘by the second,’ but I had lots of questions about the field and the best approach to handle some machine learning problems,” added Olabanji Shonibare, a recent graduate from Michigan Technological University.

The program began with two weeks of instruction on basic skills by Daniel Kaplan, a professor of mathematics, statistics, and computer science at Macalester College. The small size of the program let participants interact closely with Kaplan and former IMA Director Fadil Santosa for help, advice, and feedback.

The remaining weeks of the fellowship were devoted to working on real-world projects provided by Ford, New Frontier Data, Corning, 3M, and Alternative Strategies Advisors on topics related to data wrangling, machine learning, predictive analytics, natural language processing, and sentiment analysis. This included analyzing glass data and building models to predict properties of glass; examining the results of an owner survey to study capacity loss of the Tesla Model S battery; evaluating municipal bond trading activities and building a model to predict higher trading prices in the future; and analyzing Comcast consumer reviews to determine patterns that would improve customer service strategies.

Over the course of seven weeks, the fellows received several valuable lessons: learning to speak the language of their clients, using visualization tools effectively, developing “storytelling” using quantitative findings, and recognizing that some data are nonsense and contain little information.

“We were given the opportunity to learn not only how to analyze data, but how to present it in an easily consumable fashion,” said Melissa Davidson, a graduate from the University of Notre Dame.

“I learned the pipeline of a data science project if given a raw data set—how to start from it, how to clean data, perform basic data analysis, and tell stories from data, how to apply machine learning algorithms, and how to deal with clients,” added Xiao Wang, a fifth-year graduate student from University of Illinois at Urbana-Champaign.

The fellowship also assisted participants with building their career paths by helping them seek employment in industry and inviting professionals working in data science to talk about their jobs. All six fellows left the program with promising job leads, with three now having found employment with DST Systems, Starkey Hearing Technologies, and Anheuser-Busch InBev.

“This fellowship gave me the opportunity to create a demonstrable skill set to show employers that I have the knowledge to be successful in a data career.”

– MELISSA DAVIDSON
Math-to-Industry Boot Camp

This summer program returned for its second year to give 32 graduate students from across the country the training and skills needed to work in industry.

As in the first year, the six-week boot camp was divided into two parts: technical training and team-based, hands-on projects. Instructors from the University of Minnesota School of Mathematics and Department of Industrial and Systems Engineering and from the local colleges of Macalester College and the University of St. Thomas taught students about probabilistic and stochastic modeling, optimization theory, and programming.

Updates to the training portion of the 2017 boot camp included adding in the section on optimization theory and spending more time teaching statistics. These technical changes were incorporated to match the skills needed for the projects and after consulting industrial scientists about the kinds of skills they look for in job candidates and employees. The soft skills training was refined to focus on teamwork, effectiveness, and communication. Students also learned essential skills for giving presentations geared toward a non-technical audience.

"It's not something that you're trained for in mathematics because in school you're trying to give seminars, but if you're working in a company, you have a different audience than an academic audience," said IMA Director Daniel Spirn.

The project work that followed in the second half of the boot camp allowed students to utilize their new skills and acclimate to teamwork. The first project allotted students one week to work on a small-scale, open-ended problem posed by IMA directors. One project involved generating a product or an app based on specific cell-phone data. The assigned team devised an app that measures certain fitness activities using machine learning and signal processing in a novel way. An unexpected result of this project is that the team is working to bring their product to market.

The entrepreneurial aspect is "not something that many of them thought was possible with a math degree," Spirn noted.

Students were also able to make an immediate impact through their second projects, which were real-world problems posed by industry scientists. Industry mentor Thomas Grandine (Boeing), with the help of another senior technical fellow at Boeing, posed a problem related to machine tool and robot calibration through kinematic analysis.

"The graduate students discovered a bug in his software that had been in place for over 15 years," Grandine explained. "The fact that his software still worked in spite of this error meant that there was something deep going on with the mathematics in the application, and the graduate students were able to figure it out after a few days."

After the boot camp, Grandine's colleague fixed the bug in his software, and, equipped with the insight provided by the graduate students, was able to put a software enhancement plan in place.

"We are currently working through this plan and hope to have the upgraded capability in place in 2018," Grandine said. "This new capability will improve the rapidity with which Boeing can calibrate machine tools and robots."

There are two key ways the IMA directorship is gauging the success of students in the boot camp: (1) being able to find good technical results in a short period of time that may not be optimal but are effective and (2) being able to convey that information in a useful and concise way.

"I think, on both of these points, there is just a remarkable transformation that happens in the six weeks," Spirn said.

"There is no doubt that these students can quickly learn the skills and gain the technical acumen to do well on the technical side for these projects," Spirn continued. "It's more the comfort level of getting used to working and thinking in a different way. They have to get used to not finding the most optimal result, as we're taught in math, but finding the result quickly enough and that's effective enough for the industry mentor to be satisfied."

The results and positive experiences seen with the boot camp have led the IMA to create a BIG, or business, industry, and government, Internship Network to support the development of similar graduate training programs. The IMA will serve as a hub to share resources, information, and connections to industry among the network, which aims to serve a geographically distributed audience.
The IMA Remembers Hans Weinberger

The IMA expresses its sadness at the passing of its founding Director Hans Weinberger, a professor emeritus in the School of Mathematics at the University of Minnesota, on Friday, September 15, 2017 in Durham, North Carolina.

Weinberger was an integral part of the IMA proposal created in response to the National Science Foundation's request for proposals to establish a Mathematical Sciences Research Institute in 1979. Along with George Sell and Willard Miller, both math professors from the University of Minnesota, they envisioned a mathematics institute that would be bold and look outward from the core of mathematics toward applications. Its goal was to bring mathematicians and scientists together to focus on interdisciplinary problems from academia and industry, creating new research that would have an impact on the science and enrich mathematics.

Weinberger served as the IMA’s first director from 1982 to 1987. Under his leadership, the IMA quickly became known for cutting-edge scientific programs, a collaborative atmosphere, and as a training ground for postdoctoral researchers. During his tenure, Weinberger was very engaged in scientific life at the IMA, attending lectures and collaborating with visitors and postdocs. His presence at these lectures usually meant that the toughest and most penetrating questions were asked.

While well known for his contributions to the analysis of partial differential equations, especially eigenvalue problems, Weinberger turned his attention to mathematical biology later in his career. He remained active in research throughout his life and authored several papers after his retirement in 1998. Weinberger was elected a member of the American Academy of Arts and Sciences in 1986 and was in the inaugural class of the American Mathematical Society Fellows in 2012.

“In spite of his impressive accomplishments, Hans was the most modest and accessible person one could ever meet,” said former IMA Director Fadil Santosa. “He was generous with his time and his ideas. He will be sorely missed.”

In 2009, the IMA established the Hans Weinberger IMA Fund in his honor. The fund continues to support programs and activities that strengthen the IMA’s mission.
The IMA is a partnership of the National Science Foundation, the University of Minnesota, and a broad consortium of affiliated universities, government laboratories, and corporations. Affiliation brings many benefits to members, including access to research, influence over the IMA’s agenda, collaboration within the IMA’s network, and opportunities to participate in workshops, short courses, and tutorials.

Istitutions

- Arizona State University
- Colorado State University
- Georgia Institute of Technology
- Indiana University
- Iowa State University
- Korea Advanced Institute of Science and Technology (KAIST)
- Michigan State University
- Michigan Technological University
- Mississippi State University
- National Institute for Mathematical Sciences (NIMS)
- Ohio State University
- Pennsylvania State University
- Pohang University of Science and Technology (POSTECH)
- Portland State University
- Purdue University
- Seoul National University
- Texas A&M University
- University of Central Florida
- University of Chicago
- University of Delaware
- University of Houston
- University of Illinois at Urbana-Champaign
- University of Iowa
- University of Kansas
- University of Kentucky
- University of Maryland
- University of Michigan
- University of Minnesota – Twin Cities
- University of North Carolina Greensboro
- University of Notre Dame
- University of Pittsburgh
- University of Tennessee
- University of Wisconsin – Madison
- University of Wyoming
- Wayne State University
- Worcester Polytechnic Institute
- Zhejiang University

Corporations

- Corning Incorporated
- ExxonMobil
- Ford Motor Company
- Honeywell
- IBM
- Los Alamos National Laboratory
- Medtronic
- Microsoft Research
- Mitsubishi Electric Research Laboratories
- National Institute of Standards and Technology
- Sandia National Laboratories
- Schlumberger-Doll
- Siemens

2016–2017 Postdoctoral Fellows

- Shelvean Kapita, 2016 Ph.D., University of Delaware
- Wei Li, 2016 Ph.D., University of Michigan
- Shixu Meng, 2016 Ph.D., University of Delaware
- Natalie Sheils, 2015 Ph.D., University of Washington
- Robert Vator, 2016 Ph.D., Louisiana State University
- Haitao Xu, 2016 Ph.D., University of Massachusetts Amherst

Industrial Postdoctoral Fellows

- Mark Hubenthal, 2012 Ph.D., University of Washington

Credits

Writer/editor: Rebecca Malkovich
Designer: Dawn Mathers
Photography: iStock; Rebecca Malkovich

© 2017 Regents of the University of Minnesota. All rights reserved.
July 2017–August 2018

Major Programs for 2017-18

PROGRAMS

Industrial Mathematics: Collaboratively Tackling Emerging Problems in Industry

Innovative Statistics and Machine Learning in Precision Medicine

Modeling, Stochastic Control, Optimization, and Related Applications

Multiscale Mathematics and Computing in Science and Engineering

SageMath Coding Sprints